AN AUSTRALIAN

BIOLOGY

PERSPECTIVE

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Contents

To the teacher

This book was written on the basis of several premises:

- Each school community is unique. The students enter Years 11 and 12 with different cultural and social backgrounds, knowledge of biological phenomena, academic abilities, and aspirations for the future. Each school, therefore, needs to tailor the course content and the ways in which investigative and problem-solving skills are developed for its own population.
- The study of biological science is also unique. A complete understanding of the functioning of an organism cannot be achieved by studying individual aspects and attempting to link them together, without relating the whole organism to its environment and its evolutionary history. In a similar way, any attempt to understand the living world by studying isolated units is fraught with misrepresentations. The role of the teacher is to attempt to bring information together in such a way that students can see patterns emerging and thus gain greater insights into biological phenomena.
- Students can be taught the skills of problem solving, but will not be able to solve problems unless they possess a readily accessible and usable understanding of key concepts.

This book aims to provide a holistic view of biological science. Interwoven themes link the units: the requirements of organisms and their need to maintain homeostasis; interactions between organisms and their environment; and adaptations of organisms to their environment through evolution.

The units have been written in such a way that they can be taught in any order. The introduction to each of the nine units in this book contains an overview statement and appropriate key concepts and key ideas from the Queensland Biology syllabus. The material in each unit can be covered at a variety of academic levels. In desining a work program, a school can use a unit or sample aspects of several units to develop themes, contexts or problem-based modules of work appropriate to their student population. A large number of case studies have been provided, which can be used either as student stimulus material or as part of the course content. Questions have been included with each chapter to aid the student in attaining and self-testing understanding, and to develop process skills. The extension items range from relatively straightforward to difficult, in order to provide the students with opportunities to reach a high standard of critical thinking skills. These questions have been identified according to the general objectives of the Queensland Biology syllabus. A full glossary can be found at the end of the book to ensure ready accessibility to information.

The materials included in this book have been successfully trialled over a number of years on students from a variety of cultural and socioeconomic backgrounds and broad academic abilities. Thus the book provides schools with a wide selection of material from which to develop their specific program and to challenge the more able students in mixed-ability groups to reach their potential.

DEDICATION

This book is dedicated to:

- our families who encouraged and supported us in this venture. Their understanding of the massive time commitment involved in such an undertaking ensured its completion
- the senior students of Brigidine College and Somerville House who continue to offer invaluable feedback
- all who inspire in us a continuing passion to understand the tapestry of life
- the wonder of the unfolding intricacies of biology which challenge us to maintain lifetime learning.

Margaret Walter **Lorraine Huxley**

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UNIT 1

Introduction to biology

Biology is a science which seeks to make sense of the diversity of life forms found on planet Earth—the types of organisms that exist, where they come from, and how they interact with others and their non-living environment. Living things have special characteristics which distinguish them from the inanimate matter around them. Like non-living matter, however, organisms are governed by physical and chemical laws, so biologists draw from other sciences to better understand the living systems they study. Explanations of observations of biological processes are validated in controlled experiments. This process is called the scientific method.

Key concepts

- Cells are the functioning units of all living things.
- Multicellular organisms are functioning sets of interrelated systems.
- Organisms live an interdependent existence in environments to which they are adapted.
- A variety of mechanisms result in continual change at all levels of the natural world.
- There are processes in place which maintain dynamic equilibrium at all organisational levels.
- There are mechanisms by which characteristics in individuals in one generation are passed on to the next generation.

Key ideas

- Cells have a chemical composition that must be maintained for the continued life of the cell.
- Organelles contribute to the structure and functioning of eukaryotic cells.
- Energy required by all living things is obtained in different ways.
- Cell division is an integral part of growth and reproduction.
- Systems of the body work together to maintain a constant internal environment.
- Different types of multicellular organisms have different roles in the environment.
- Different organisms perform different interdependent roles in an ecosystem.
- An organism has adaptations specific to its environment.
- Living things employ a variety of reproductive strategies.
- Theories of evolution by natural selection can be used to explain speciation and changes in organisms through time.
- In most organisms coded instructions within the DNA molecule account for their inherited characteristics.
- During reproduction, DNA is passed from parent(s) to offspring.
- Humans group organisms in a variety of ways to make sense of diversity and to aid communication.

1 The nature of biology

1.1 Biology and its branches of study

Biology is the study of living organisms. Biologists are concerned with the types of organisms that occur on earth and how they operate individually, in interactions with other organisms and with their non-living environment. Biology is such a vast field of study (see Figure 1.1) that individual researchers tend to specialise in only a small aspect.

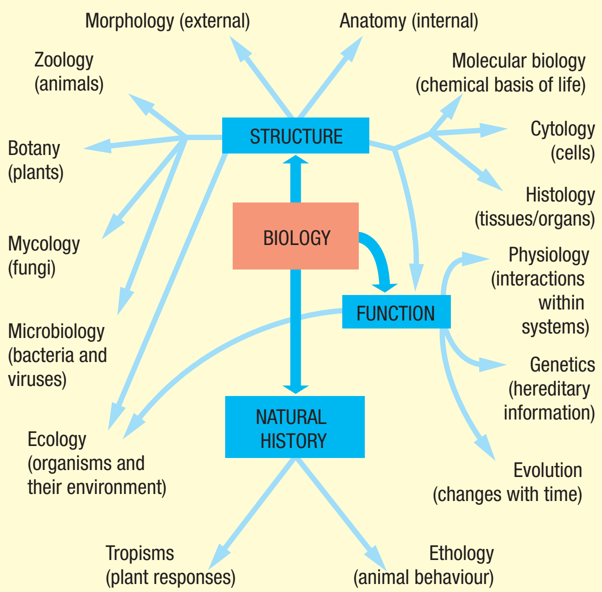


Figure 1.1 Branches in the study of biology

Studying any one of these aspects of biology gives some knowledge of living organisms. However, a true understanding of our living world cannot be gained by simply adding up all of the known bits. For example, a biologist can cut open a body and find out the position of all of the organs and the way they are physically connected to each other, but cannot tell how they actually operate in the living organism. All parts of an organism are in dynamic relationship with each other. Each organism reacts with others around it (of both the same and different kinds), and with the non-living environment. A slight change in any one of these factors may have dramatic effects on the organism as a whole.

Perhaps the one overriding concept of biology is survival—both of the individual and of the species. For this reason, organisms are adapted to their environment. Their structure, physiology and/or behaviour allow them to live successfully in a particular place. The structure of an organism is closely related to the functions it performs. Adaptation is not something that an organism consciously brings about. As much as we might think we need another pair of hands to complete chores, wishing them into existence simply does not happen! Adaptation, and thus survival, is linked with evolution. **Evolution** is the process whereby, through changes in genetic make-up over time, alterations to structure and function within groups of a particular organism come about, ultimately leading to new types of organisms.

The following case study illustrates how various specialist studies can lead to a better understanding of an organism.

Case study 1.1: An Australian species—the feathertail glider

The feathertail glider, *Acrobates pygmaeus* (from *acro* = dancer, *bates* = of the summits and *pygmaeus* = pygmy), is the tiniest of the Australian marsupial gliders. A **marsupial** is a **mammal** (an animal covered with fur or hair) which gives birth to very undeveloped young, which usually complete their development in a pouch situated on the mother's abdomen.

Structure

Gliders have a membrane which extends from the elbow to the ankle of each forelimb. The membranes are designed to catch an airstream, but can function only when there is an adequate air speed or when gravity causes the glider to parachute down in an almost vertical path. The animal climbs a tree to gain height and then jumps. It falls steeply down until its air speed is great enough for it to sail off in a curved path. The glider's long tail stretches out behind it and serves as a rudder to direct its flight. The greater the height of take-off, the further it travels horizontally. This type of locomotion allows gliders to move quickly from location to location to escape from predators, as well as increasing their foraging (food-seeking) area. Since their forelimbs are not greatly specialised they are still useful for climbing and manipulating food, unlike the wings of true flyers such as bats and birds.

As its scientific name suggests, the feathertail glider is very small, measuring about 15 cm from its nose to the tip of its tail. The tail fur is arranged in two flat fringes along either side like a feather. These hairs are stiff, but the rest of its fur is soft and silky, silvery brown on the upper surface and paler underneath. It has long whiskers which are thought to help in finding its way through tiny cracks and crevices in the bark of trees in search of insects. The tail can be used to hang from branches. The toes have large, finely serrated pads which allow the animal to cling to smooth surfaces. The first toe of all four feet is large and grasping, like a thumb, so the glider can run with great agility along thin twigs to reach flowers.

Distribution

The feathertail glider is found in forests of tall, well-watered eucalypts along the east coast of Australia and across the south-east to the border of South Australia (where it extends into the drier regions of woodland). Although it is tree-dwelling (**arboreal**), it also forages through thick shrub layers such as lantana. The feathertail glider feeds on nectar, small insects found on the trunks, foliage and blossoms of trees, and manna (a sugary plant sap exuded from breaks in the bark made by larger marsupials as they climb or pull away at it to feed on insects hidden beneath).

Evolutionary relationships

Researchers believe that the feathertail glider is a specialised form of pygmy possum, a very agile species found in treetops. In Papua New Guinea, there is at least one species of feathertailed pygmy possum which, apart from lacking the gliding membrane, is almost an exact copy of the feathertail glider. It is thought that this species could represent an intermediate form in the evolution of the gliding form. Pygmy possums are believed to resemble the ancestors from which all the possum family evolved. The early tree-climbing marsupials were known to be insectivorous (insect-eating), and the feathertail glider retains their characteristic arrangement of small, sharp teeth.

Behaviour and physiology

The feathertail glider is normally active at night throughout the year, moving swiftly along branches and leaping through the uppermost foliage. It has a wide range of predators and therefore takes alarm at the slightest disturbance, often leaping so hurriedly that it may glide to the ground. There, it may 'freeze' for several minutes (inactivity is a good way of not being seen) or take off in a leaping scamper for the nearest tree. During very cold weather these animals may become **torpid** (noun = *torpor*) for up to 48 hours. In this state they lower their body temperature by slowing down all body actions (blood flow and chemical reactions). This reduces their food requirements over that short period. Since feathertail gliders cannot store food, which is necessary for true hibernation, they must wake up at intervals to feed. It takes about an hour for them to come out of their torpid state.

Feathertail gliders build round, communal nests which contain up to sixteen individuals. Nests may be found in hollow trees, old nests of other animals or in the plastic bags used to cover bunches of bananas. The whole nest is about the size of an orange. Breeding occurs throughout most of the year in the northern part of the range but only in late winter, spring and summer in the southern areas. The female has four teats but

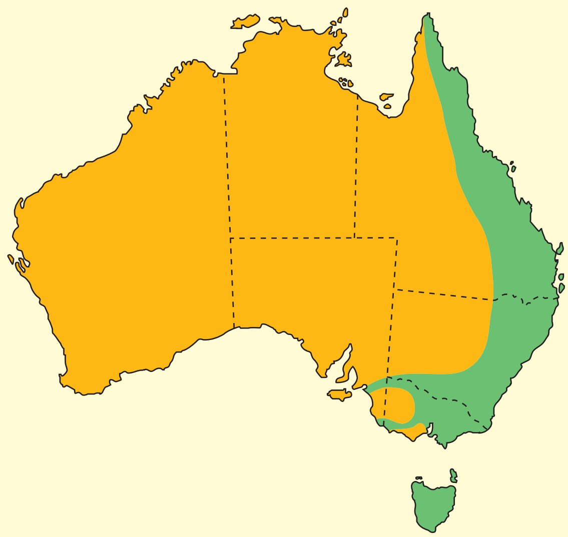


Figure 1.2 Feathertail glider and its distribution (right)

seldom carries more than three young, which are exceptionally minute (only a few millimetres long) when born. The young then complete their development in the pouch where they obtain nourishment from milk secreted by the teats. The female can become pregnant while carrying pouched young, so litters may be reared in quick succession.

Overview

The preceding account is derived from several aspects in the study of biology. As an animal, the feathertail glider comes under the study of **zoology**. Zoologists have given it a special name, its species name, to distinguish this type of animal from all others; the naming, or classifying, of living organisms is a specialised field of study called **taxonomy**. The study of the feathertail glider's distribution and feeding relationships is part of **ecology**. Description of its external features is **morphology**. Patterns of its movement, relationships with other members of its species and reactions to predators belong to the study of **ethology** (behaviour); studies of its reproduction and reaction to temperature are part of **physiology**. The relationships between this glider and other possums, such as the pygmy possum, are investigated in **evolution**.

SUMMARY

Biology is the study of living things. It involves the study of the types of organisms that exist, how they perform their functions and how they interact with each other and their environment. Since this involves a vast field of knowledge, researchers tend to specialise in a particular area. It is vital to remember that organisms are not merely the sum of their parts but are beings that exist in complex, dynamic, ever-changing interactions with their living and non-living environment.

Review questions

1.1 'Koalas are adapted to their environment.' This statement means that:

A. due to features that they possess, koalas are able to survive in most environments

B. due to features that they possess, koalas are well suited to the environment in which they are naturally found

C. koalas developed special features which they needed in order to survive in their environment

D. koalas are able to develop features which make them better suited to the environment should the need arise.

1.2 Read the following account carefully. The paragraphs are lettered to help you answer the questions at the end.

A. The red kangaroo is the largest living marsupial. It is widely distributed across inland Australia, being found in most open habitats with an annual rainfall of less than 375 mm.

B. A fully grown male red kangaroo is nearly 2 metres high when sitting fully upright on its large, powerful hind legs and thick, muscular tail. The thick, woolly body fur is generally a rich reddish brown with paler fur on the chest, belly and tip of the tail. Mature males weigh about 80 kg. There are conspicuous white marks on either side of the muzzle, slashed through with a black line. Females are usually blue in colour and seldom weigh more than 30 kg.

C. Red kangaroos are mainly nocturnal, spending their days under shady trees (when available) and moving out in the open at night to find food (grass) and water.

D. When moving slowly or feeding, the red kangaroo proceeds in a kind of crawl on all fours, using its tail as a prop. When moving at speed, the animal adopts the characteristic springy bound. A kangaroo uses less oxygen, weight for weight, than a running animal with orthodox gait. This is in part due to the storage of energy on each bound by tensioning of the great hamstring tendons on the hind legs.

E. Red kangaroos show adaptations which are linked to the fall of rain. In good seasons the red kangaroo reaches sexual maturity at between 18 and 24 months old. At any one time the female can have a large joey at heel still suckling, a smaller pouch joey and a dormant very early embryo in reserve. The composition of the mother's milk changes with the age of the joey. When she is feeding young of two different ages, the composition of milk secreted by each nipple is different, to accommodate each joey's requirements. In drought, within the first 6–10 weeks many of the pouch young die, and after 5 months most females stop breeding totally. With the onset of rain the females immediately resume reproduction.

F. Red kangaroos can maintain body temperature at a tolerable level of 37.5°C for several hours in an air temperature of up to 44°C and average humidity, if water is available. By panting rapidly, like a dog, the red kangaroo gets rid of excess heat by evaporation of water from the lungs. Evaporative heat loss is also achieved by licking the forelimbs. (Evaporative heat loss is the removal of heat from the body by the conversion of water to vapour.) Water in the fresh green grass (their feeding preference) replaces that lost by evaporative cooling. Body water loss can be reduced by the production of very concentrated urine.

G. Groups of red kangaroos from half a dozen up to a thousand can be found. Such groups are in a constant state of flux, with kangaroos almost continually joining and leaving the group. The only true social behaviour is the continued association of the offspring with the mother for a period after weaning.

(a) Define the term 'marsupial'.

(b) Using paragraph letters, identify the following areas of biology in the account above:

(i) anatomy

(ii) ecology

(iii) ethology

(iv) morphology

(v) physiology.

(c) List three adaptations of the red kangaroo to arid and semi-arid conditions.

1.2 The living condition

1.2.1 Organisation of living matter

Living things range in size from microscopic single-celled organisms through to massive **multicellular** entities such as the whale. They, like the components of the earth around them, are composed of matter. Matter is anything that has mass and takes up space. Organisms sit about midway in the organisation of living systems:

Biosphere the part of the earth that supports life

Ecosystem a community of organisms and their environment

Community all of the species that coexist and occupy a particular space at any particular time

Population a number of an individual species living in a particular space at a particular time

Species individuals with similar characteristics, which can interbreed under natural conditions to produce fertile offspring

Organism a living thing

Organ system a group of organs working together to perform a particular function

Organ a group of tissues bound together to perform a particular function

Tissue a group of similar cells with specialisation for a particular function

Cell basic unit of living things

Organelle membrane-bound subdivision of a cell, specialised for a specific function

Molecule two or more atoms bound together in a definite arrangement; may consist of a single element or several elements linked together by chemical bonds to form a compound

Atoms the building blocks of matter

In living things the main elements are carbon, hydrogen, oxygen and nitrogen, although others such as phosphorus and sulfur are also found. The elements are arranged into large, complex chemical molecules. All of these contain carbon and are called **organic compounds**. All other chemical compounds are said to be **inorganic**. The four main types of organic compounds in living things are carbohydrates, proteins, lipids and nucleic acids. Water, phosphates, carbon dioxide and nitrates are examples of inorganic compounds which are important to living things. Although chemicals can be changed from one form to another, they cannot normally be created or destroyed in chemical reactions.

A property of all matter at temperatures greater than absolute zero (i.e. –273.15°C) is motion. At a base level this takes the form of vibration of the atoms making up matter. The energy possessed by matter as a result of its motion is called **kinetic energy**. This can be converted to different types of energy such as light, sound and heat. In the formation of molecules and compounds, energy is stored in the bonds that hold the atoms together. This **chemical bond energy** is a source of **potential** (resting) **energy** since it can be released and converted to other forms of energy.

1.2.2 Characteristics of living things

Living things are made up of constantly changing organic molecules which take up, store or release chemical energy. The wood on a table top is made up of organic molecules which store energy, but it is no longer alive. When it died, a permanent and irreversible change occurred, preventing the tree, which produces wood, from carrying out specific processes. Being alive is therefore characterised by a set of processes that the organism can perform. A distinction must be made between those things which are dead but were once alive (e.g. wood) and those which were never living (e.g. a rock). Although some non-living objects can carry out some of the processes that living organisms perform (e.g. a non-living crystal can grow in a predetermined shape, as do living things), they are limited in the scope of these activities.

Some of the properties of living things are obvious from the description of the feathertail glider given in the case study. Feathertail gliders need to feed, move, respond to stimuli (e.g. 'freezing' on hearing or seeing something unusual; going into torpor in cold conditions) and reproduce. What are not so obvious are the activities that take place inside its body.

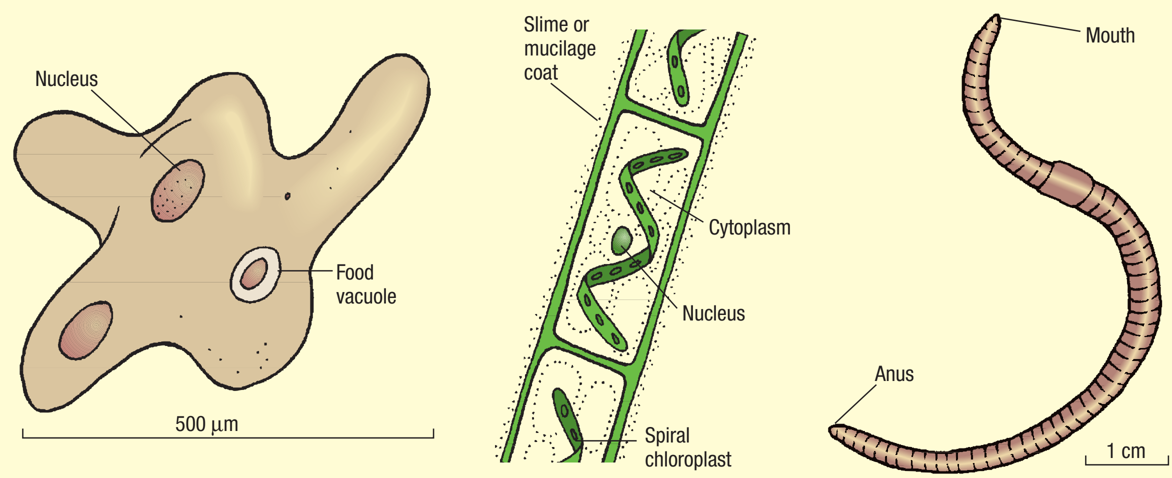
The processes that characterise living things are described on pages 6–12.

Living things are composed of cells and their products

The basic unit of living things is the cell. As in the cell of a battery, it has an outer barrier which contains specific matter. If the barrier is broken the contents spill out and the living cell, like the battery, no longer operates. A function of a battery is to convert chemical energy into electrical energy through chemical reactions which take place within its cell(s). If its chemicals are not recharged or replenished, the battery's life is limited. Similarly, the living cell must be constantly recharged with an outside source of energy in order to maintain its structure and correct functioning. The maintenance of the correct internal state of the cell, and thus of the organism, is termed **homeostasis**.

Some organisms (e.g. bacteria and some protists) consist of a single cell. The cells of bacteria are very simple. They essentially consist of a membrane enclosing a large number of molecules, many of which are in solution, the **cytoplasm**. Some of these molecules are very large and play a specific role in the overall function of the organism. This type of cell is called **prokaryotic** (noun = *prokaryote*). The cells of protists and all other organisms are more complex and are called **eukaryotic** (noun = *eukaryote*). The cytoplasm in these cells is subdivided into smaller units called **organelles**, each of which has a specific function in the cell. Each organelle is surrounded by its own membrane, similar to that which surrounds the entire cell.

Other organisms are made up of many cells. The larger the organism, the more cells it contains. As the number of cells in an organism increases, cells become specialised. Specialisation allows different cells and groups of cells to perform specific functions. This organisation is more efficient than one in which all the cells in a large, multicellular



(a) *Amoeba* – a single-celled organism

(b) *Spirogyra* – a filamentous green alga composed of many similar cells loosely linked together in a single strand (total length 120–300 µm)

(c) Earthworm – composed of many cells specialised into coordinated tissues and organs

Figure 1.3 Examples of the cellular basis of organisms organism carry out exactly the same processes. Since different specialised cells in these multicellular organisms will have their own specific requirements, their activities need to be coordinated to achieve homostasis of the whole organism.

Not all parts of multicellular organisms are living. Bone, for example, is made up of cells surrounded by hard minerals. The hard central heartwood of a tree, which acts as its 'skeleton', consists of cells which are no longer living.

A cell can only be formed from another cell. The existing cell undergoes a special process, dividing to form two identical cells.

The **Cell Theory** states that:

- All living matter is composed of cells and its products, and
- All cells arise from pre-existing ones.

Living things metabolise

Metabolism is the term used to describe the chemical reactions of the body which build up or break down large, complex molecules. The first step of this process is to trap energy, in the form of solar or chemical potential energy, from the surroundings. This requires the intake of specific substances to sustain life—**nutrition**.

Plants and some micro-organisms take in simple inorganic molecules (carbon dioxide, water and minerals), which they build up into complex organic molecules. This is called **autotrophic nutrition** '(self-feeding'). Plants and some bacteria convert the radiant energy of sunlight into chemical bond energy in a series of complex chemical reactions called **photosynthesis**. An essential chemical in trapping solar energy is the green pigment chlorophyll. Thus all photosynthetic organisms must contain chlorophyll. Other bacteria use the chemical bond energy of inorganic molecules to produce their organic nutritional requirements in a process called **chemosynthesis**. Autotrophic organisms make the organic compounds on which all other organisms depend for survival —they are **producers**. Life on earth would not exist without them.

Animals generally feed on ready-made organic matter or 'food'. They use **heterotrophic nutrition** ('other feeding'). Chemical reactions convert their food into the forms they require to maintain their life processes. Because they take in organic matter which has been produced by another organism, they are known as **consumers**.

Different types of heterotrophs feed on different things. **Carnivores** are animals which kill and eat other animals (e.g. the dingo). Because they have to catch and kill their prey, they are also termed **predators. Parasites** also feed on other organisms, but unlike carnivores, it is to their advantage to keep their host alive, since it provides them with a constant source of food. They are usually small organisms which live either in or on their host. A tapeworm living in the human intestine and the fungus *Tinea* living on human skin are examples of parasites.

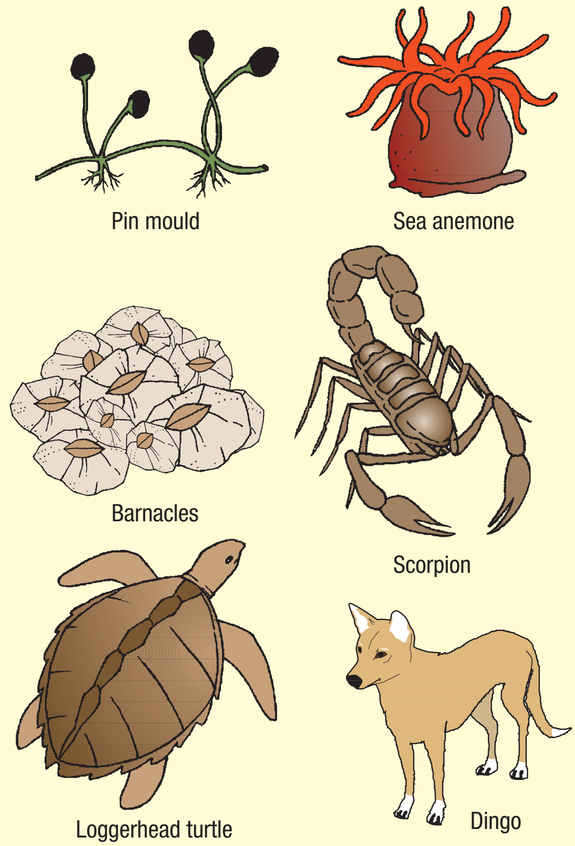


Figure 1.4 Different types of heterotrophs (not to scale)

Herbivores eat plant matter. Examples include the kangaroo, which feeds on grass, the koala, which eats leaves, and honeyeaters, which take in nectar from flowers. The feathertail glider is an **omnivore** because its diet includes both plant matter (nectar and manna) and insects. **Scavengers** eat the remains of dead organisms (carrion) or their products. Crows are often seen feeding on road kills of other animals or looking for food in school rubbish bins. **Detritivores** eat the remains of organic matter in soil or water. For example, the earthworm ingests soil as it tunnels through the ground, extracting any organic matter such as leaf or animal remains and eliminating the unwanted dirt in small pellets. Prawns perform a similar function in the ocean.

Decomposers (e.g. fungi and some bacteria) feed on dead organisms and their excretory products, breaking them down into simple inorganic molecules which are released back into the environment and can then be reused by autotrophs.

The array of feeding relationships between the producers, consumers and decomposers within any group of organisms living in a particular area—a community of organisms—is called a **food web** (see Figure 1.5).

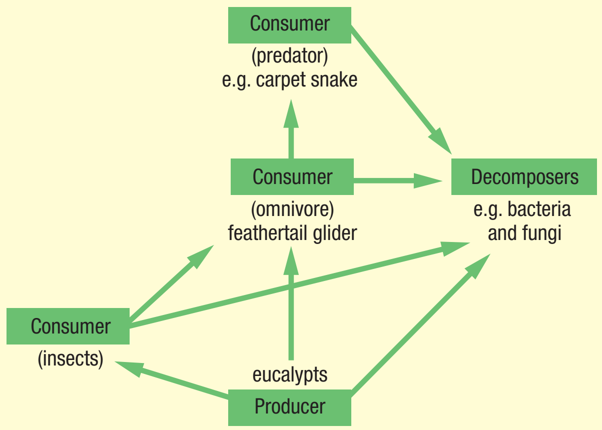


Figure 1.5 Simple food web involving the feathertail glider. Note that the direction of the arrow indicates the direction of the flow of matter and energy in the community.

Living things respire

'Food' supplies an organism with both matter and energy. Energy from chemicals is released during a series of chemical reactions called **respiration** within the cell(s) of the organism. All organisms respire.

When sugar, exposed to air containing oxygen, is burnt in a saucepan, all of the chemical energy stored in it is converted to heat and light energy in a rapid reaction, leaving the products carbon dioxide and water. These are small molecules which do not have a high level of chemical potential energy. If this reaction occurred within cells, the amount of energy released would raise the temperature to such an extent that vital chemicals such as proteins would be destroyed and the cells would die.

During respiration the energy is released in small steps. Each step is controlled by special chemicals called **enzymes**. The energy is transferred to another molecule which can then make it available for reactions that require energy. More energy is released from the food when oxygen is present (**aerobic respiration**) than when it is absent (**anaerobic respiration**). Carbon dioxide is produced during respiration. Most organisms have gas-exchange structures (e.g. lungs) that absorb oxygen from the environment and release the carbon dioxide formed in the body.

The rate at which respiration occurs depends upon the type of organism, its age and level of activity, and the temperature of the surrounding environment. Plants do not have the same energy requirements as animals because they do not move from place to place. Most animals do not maintain a constant body temperature but allow it to fluctuate with that of the environment. This does not mean that they can withstand extremes of heat and cold. They use behavioural means to control their body temperature. For example, snakes hibernate during winter months and avoid very hot weather by being inactive during the heat of the day. These animals are often referred to as cold-blooded, but this is an inaccurate term since their body temperature can in fact be quite high. They are better named **ectotherms**.

Birds and mammals have the special ability to maintain their body temperatures within a very narrow range by physiological means. These animals are **endotherms**. Their temperature control requires a high rate of respiration (and thus a regular supply of 'fuel'), and allows them to remain active over a wide range of environmental temperatures.

Energy requirements of young animals are far greater than those of adults since they are actively growing and thus forming new cells and cell components. Similarly, an active animal will have a higher rate of cellular respiration than will a resting one.

Living things can grow, develop, repair and maintain their 'body'

Parts of an organism may become damaged in the course of its life. A fall while running can result in severely grazed knees, but after a period of time a scab forms which eventually comes off to reveal undamaged skin. Individual cells age and are replaced. These are examples of the **maintenance** process.

Growth is an increase in the amount of living material of an organism. At first this is achieved by an increase in the size of the cells. However, the cell's efficiency at performing its functions decreases beyond a certain size, and further growth comes about by the production of new cells. Existing cells divide and produce new ones by a process called **mitosis**. Initial growth of an organism is usually rapid but slows down as sexual maturity is reached. Not all organisms continue to grow throughout their life. Most have a definite size limit which is influenced by environmental factors.

Development is the series of changes an organism goes through in achieving its final form. Thus a young child not only increases in size with

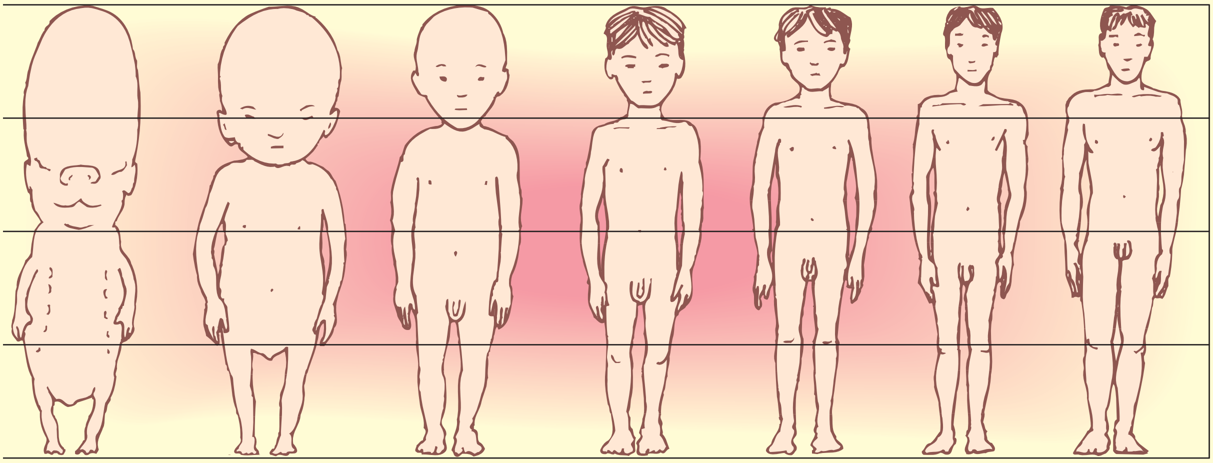


Figure 1.6 As young organisms mature into adults they may both grow and develop.

age but also undergoes a series of developmental changes to become a sexually mature adult. In some cases, development is more dramatic, such as the change of a caterpillar into the adult butterfly.

Living things excrete metabolic wastes

Excretion is the removal from the organism of waste products, produced during chemical reactions within the body. These wastes include carbon dioxide, water, salts and nitrogen-containing products. If the wastes are allowed to accumulate they alter the chemical balance within the cells. This can change the types of reactions that occur and can lead to the death of the cell.

The process of excretion is distinct from **egestion**, which is the expulsion of undigested food.

In simple organisms excretion takes place directly from the cells to the outside environment. In more complex animals, where the inner cells are too far from the outside for this to be effective, wastes are carried from individual cells in a transport medium such as blood to special organs (e.g. the skin, lungs and kidneys) for removal.

Living things can detect and respond to stimuli

Irritability is the detection of, and response to, stimuli (e.g. noise, light, touch, gravity etc.) from both inside and outside the body. At its simplest level all cells have the ability to monitor the types and concentrations of particular chemicals present and to take action to maintain the correct levels. This is a chemical response. At the whole organism level many responses take place. For example, when an athlete runs a marathon, the heart rate adjusts in

(a) Growth hormones cause the roots of a strangler fig to clasp around the host tree.

(b) The soccer player's eyes and brain detect the ball approaching, and there is a rapid response involving muscles.

Figure 1.7 Irritability

response to high levels of carbon dioxide in the blood; a hand placed on a hot object is rapidly withdrawn; or the tendrils of the sweet pea plant twine around a trellis when they touch it.

In complex organisms some cells are specialised for the detection of stimuli and bringing about the appropriate response. In the flowering plants, growth responses to stimuli are brought about by special chemicals called hormones; and most animals use both hormones and nerves in the process of irritability.

Living things can move

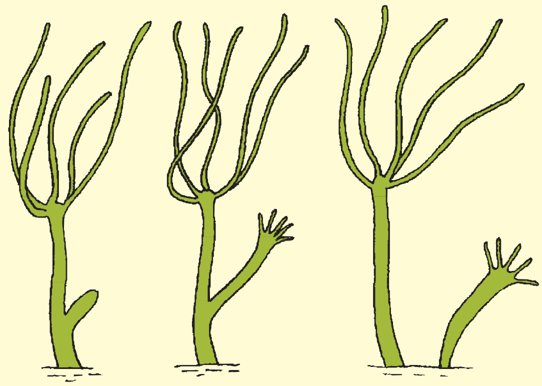
Movement can involve the change in position of the whole organism from place to place (**locomotion**), as seen in animals, or movement of only parts of the organism. For example, a plant bends towards light, or cytoplasm streams within a cell. The degree of movement that can be performed by an organism depends upon its structure and the types of tissues and organs which are specialised for that function. Thus the fine hand movements required to tie a shoelace cannot be performed by a horse or a whale, since their forelimbs are adapted for a different type of action.

Living things reproduce

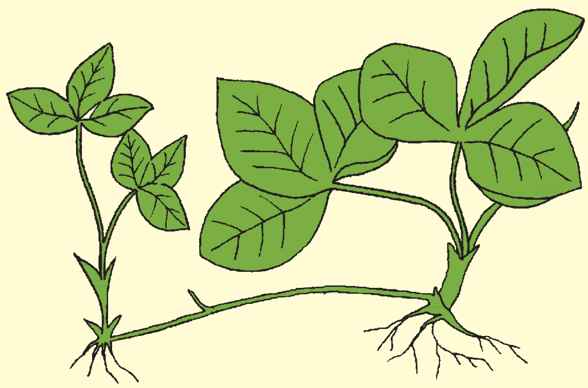
Reproduction, which may be either asexual or sexual, is the formation of new organisms through coded instructions from the parent organism(s). These coded instructions are contained within the nucleic acid molecules (usually deoxyribonucleic acid—**DNA**) contained within the cell. The codes, or **genes**, are specific for each type of organism (species). Nucleic acid molecules form one or more **chromosomes** within the cell, and different chromosomes carry different genes. Each member of a particular species, therefore, has the same number and types of chromosomes.

In **asexual reproduction** only one individual is involved in the production of offspring. This type of reproduction occurs mainly in simple organisms and plants. It involves a cell or group of cells dividing to produce identical daughter cells which will grow into a new individual. When the single-celled *Amoeba* reproduces, its cell divides into two identical cells, each of which will operate as a separate organism. This type of reproduction is called **binary fission**. Other organisms (e.g. *Hydra*) may grow a new individual from certain of its cells in a process called **budding**. The bud, when developed, breaks away from the parent to take up an independent life.

Asexual reproduction ensures that all members of a species are genetically identical. This is an advantage in those environments which are not subject to change, since they will be well adapted to the conditions of these particular environments. The only differences which can occur in species which only reproduce asexually are from chance **mutations**—random changes in a gene or chromosome which usually occur during the process of cell division.



(a) Budding in *Hydra*



(b) Production of a new plant from a strawberry runner

Figure 1.8 Asexual reproduction

In **sexual reproduction** two different individuals of the species, usually a male and a female, are involved in the formation of offspring. In multicellular organisms, sexual reproduction usually involves the formation of special cells **(gametes)** in organs called **gonads**. The male gametes (**spermatozoa** or sperm) are released by the organism and fuse with female gametes (**ova** or eggs) in a process called **fertilisation** to form a **zygote** which will grow into a new individual.

Sexual reproduction is an advantage to a species because it increases the amount of variability of characteristics within that group of organisms. Although each species will have exactly the same types of genes, the expression of those genes may differ. For example, a gene may determine the type

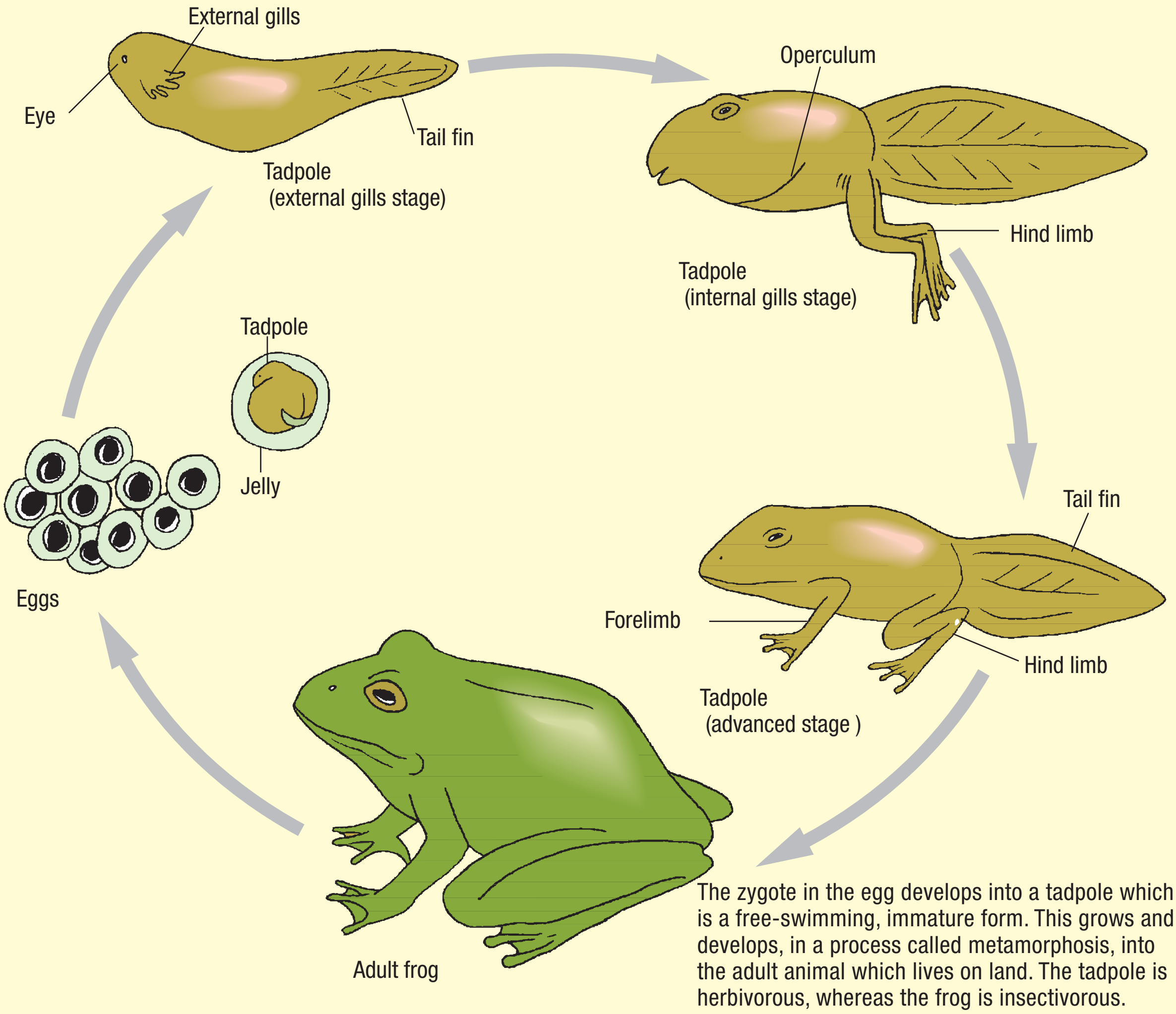


Figure 1.9 Reproduction in the frog

of fur in the feathertail glider but the expression of that gene may be for thick fur (an advantage in colder parts of its range) or finer fur (an advantage in hotter parts of its range). Since most genes have at least two possible expressions, the variability which can be produced within a single individual can be great.

As sexual reproduction involves passing on information from two parents, each of which will have some genes with different expressions, the offspring will differ from the parents in some ways. This is particularly important where the environment is subject to change. Some individuals of the species may have characteristics that enable them to survive in different environmental conditions, and thus the species as a whole will survive.

Plants and many algae undergo both sexual and asexual reproduction in a process called **alternation of generations**. Two different forms (which may or may not look alike) exist. One of these (the **gametophyte generation**) undergoes sexual reproduction, producing a generation (the **sporophyte**) which undergoes asexual reproduction. Each generation has different numbers but the same types of chromosomes. The gametophyte generation only has one of each type of chromosome (the **haploid** condition). The sporophyte generation has two of each type of chromosome (the **diploid** condition). This type of reproduction ensures that those variations produced during sexual reproduction which allow some individuals to survive and reproduce more successfully will be passed on to a large proportion of the next generation.

Living things die

Death occurs as organisms eventually lose their capacity to regenerate new cells and life processes cease. Parts of living organisms may, however, be dead and still perform important functions. The outer layer of the human skin, for example, is composed of dead cells which protect the underlying tissues from environmental hazards such as bacterial attack, dehydration and moderate radiation damage. Death of the whole organism occurs when general body cells, or cells of a vital organ, stop functioning.

Case study 1.2: Is a virus a living organism?

The biological status of viruses is uncertain. Viruses do not have a cellular structure and cannot carry out life processes. They are 'crystalline' when not invading a host cell. These inactive particles are transmitted to cells from the air, in water and in food, as well as by direct contact with an infected host organism. Many are transmitted by other (vector) organisms such as mosquitoes and ticks. Inside the host cell they can 'switch off' the host's DNA and, using their own nucleic acid, instruct the cell to make new copies of themselves. Viruses have been found to parasitise all known living organisms.

About twenty times smaller than a bacterium, they have a very simple structure consisting of a length of genetic material (either DNA or RNA), forming a core, surrounded and protected by a coat of protein. The composition of the protein coat determines the type of cells that the virus can invade. A few viruses, such as herpes and influenza viruses, have an additional lipoprotein envelope which is derived from its host's cell membrane.

Most viruses are one of two basic shapes: rod-shaped or with twenty triangular sides. The most complex viruses are those which attack bacteria. They are called bacteriophages and are composed of a 'head' and a 'tail'. The head contains the DNA and the tail acts like a hypodermic syringe, penetrating the host's cell membrane and injecting the DNA into it.

As the host cells invaded by viruses are destroyed, the virus will invariably have a detrimental effect upon its host. This may result in a **disease** or malfunction in the host.

Because their structure is so simple, it was once thought that viruses were the first life forms on earth. Since they cannot reproduce by themselves and can multiply only by parasitising a host cell, however, this theory is no longer considered possible. Two views are:

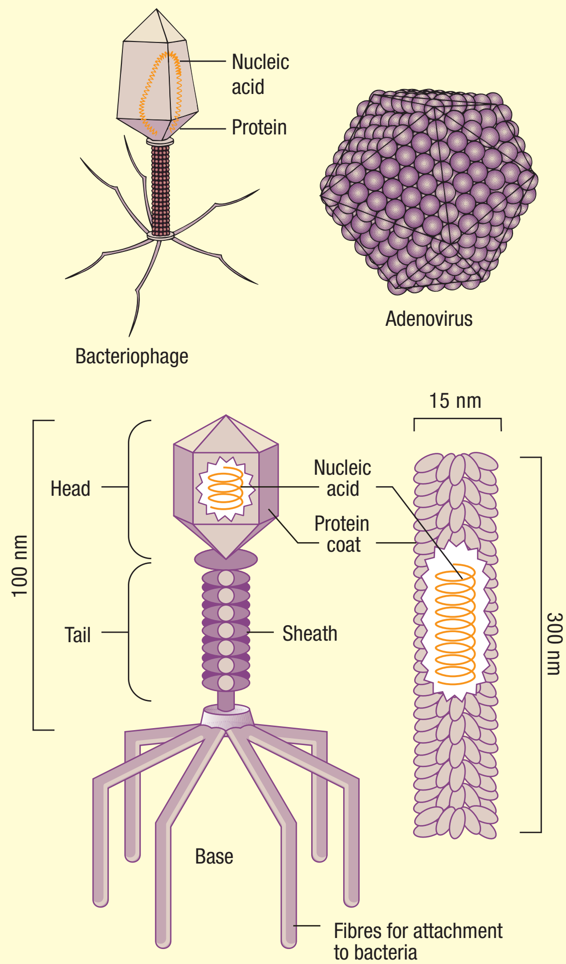


Figure 1.10 Structure and size of some viruses

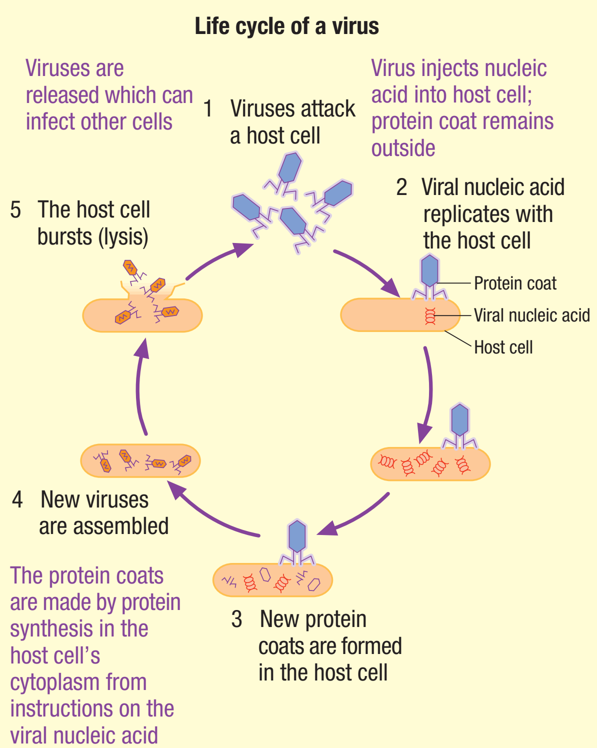


Figure 1.11 Replication phases of a bacteriophage

- Viruses are a result of degenerative evolution. They were once more complex organisms, capable of existing alone. Through evolution they have acquired a parasitic mode, and have become specialised to a reproductive unit only. Degeneration of certain systems is a common phenomenon in parasites.
- Viruses were never living organisms but originated in the primordial seas as small segments of nucleic acid protected by protein coats which made their transmission from host to host easier.

SUMMARY

The basic unit of living things is the cell, which is made up of a complex array of organic compounds. An organism consists of one or more cells and their products. It is alive when it can trap, store and release energy to perform specific functions—metabolism, respiration, maintenance, growth, development, excretion, irritability, movement and reproduction—and maintain its cell(s) at the correct internal state (homeostasis). Death occurs when the organism no longer has these capabilities. Non-living objects have never performed life functions.

Review questions

1.3 Distinguish between the following terms:

(a) 'autotroph' and 'heterotroph'
(b) 'anaerobic respiration' and 'aerobic respiration'
(c) 'locomotion' and 'movement'
(d) 'excretion' and 'egestion'
(e) 'growth' and 'development'
(f) 'asexual reproduction' and 'sexual reproduction'
(g) 'alive' and 'dead'
(h) 'organic chemicals' and 'inorganic chemicals'
(i) 'matter' and 'energy'.

1.4 Explain why it is necessary for organisms to constantly replenish their energy supplies.

1.5 Different heterotrophic organisms obtain their energy and nutrient requirements from different sources and in different ways. Giving specific examples, describe three different types of heterotrophic nutrition.

1.6 An automobile requires food (nutrition) and oxygen to release energy (respiration), which is used in locomotion. When the driver puts his/her foot on the accelerator, the car goes faster; when he/she uses the brake, it slows down (i.e. it responds to stimuli—irritability). Waste products from the burning of the fuel are removed from the vehicle (excretion). With time its parts wear out and cannot be replaced, and its processes cease to function (death). Why, then, is an automobile not considered to be living?

1.3 Ethics and the definition of death

Not so long ago if someone stopped breathing, or the heart stopped beating, the person was considered to be dead. Medical technology has advanced to the point where it is no longer possible to use such a simple definition. Life-support systems which can take over the function of many of the body's systems have saved lives. The brain still functions and the artificial aid gives the body time to recover.

Certain organs which are diseased or malfunctioning can now be replaced with a transplanted healthy organ from another person. In the case of a kidney transplant, the suitable donor individual has one of their functioning kidneys removed and carries on life with a single kidney. Bone marrow transplants involve the transfer of some marrow from a suitable donor into the bloodstream of the recipient. The healthy cells then become embedded in the recipient's bone marrow. Heart, liver or lung transplants are far more complex.

The success of any transplant hinges on:

- Compatibility of the recipient and donor with respect to their tissue type. The cells of each individual can recognise, by way of chemical markers, matter which is 'self' and that which is 'non-self'. Any cells introduced into the body which do not display the 'self' identification bring about reactions which lead to their rejection. This has been overcome to some extent by the use of drugs which must be used throughout the life of the recipient.
- The rapid transfer of the organ from the donor to the recipient. In the case of organs that can be transplanted only from someone who has died, this means as soon as possible after the death of the donor. The decision of exactly when the donor dies, therefore, is critical. Is brain death (cessation of all recordable brain activity) a suitable criterion for death?

The definition of death now raises some ethical and legal questions with which society has yet to come to terms. Other questions associated with modern medical technology include the following:

- When is a person dead?
- Who 'owns' the body of the newly decreased—the next of kin or the state?
- To what extent should religious beliefs determine the extent of treatment?
- At what point should artificial life support systems be turned off for coma victims?
- Should critically ill people be allowed to die with dignity rather than be kept alive by artificial means?
- If it were possible to transplant a brain, would the recipient still be the same person, or take on the characteristics of the donor?
- Is 'dying with dignity' now a possible option for the critically ill in our society?

SUMMARY

With the advent of organ transplants from a newly deceased person to a compatible donor, the correct diagnosis of death has become crucial. Many biological and ethical questions have been raised by such procedures.

Review questions

1.7 Distinguish between a donor and recipient in transplant operations.

1.8 Why are some transplants rejected by a recipient?

1.4 How is biology studied?

Biology is classified as a natural science. The meaning of the word **science**, derived from Latin, is *to know*. Thus the study of biology is an attempt to understand the natural world, of which we are a part. All investigations begin in observations:

The sky is blue.

which lead to questions:

Why is the sky blue?

and seeking answers. Unlike other disciplines, such as philosophy and art, science follows a particular method to verify the answer. This is called the **scientific method**.

The basis of science is accurate observations which are recorded as **data**. For example:

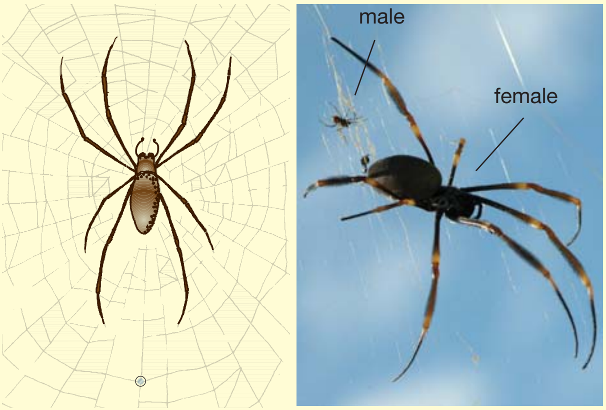


Figure 1.12 The golden orb spider and dewdrop spider (circled) share the same web in the illustration at left. The male and female golden orb spider are shown in the photograph at right.

Dewdrop spiders are found in the webs of golden orb spiders. Orb spiders kill and ingest the body contents of living things trapped in their webs. The silk of golden orb spiders is particularly thick and strong. Golden orb spiders are large. Dewdrop spiders are very small.

Data may be **qualitative** (descriptive) or **quantitative** (measured and represented by a numerical unit). After repeated observations have been verified, preferably by different people, an observation becomes accepted as **fact**. Observations usually need to be interpreted (logical reasoning), and this leads to question-asking.

Asking the right question is a key step in the scientific method. For example:

Are dewdrop spiders too small for the golden orb to detect? If spiders larger than dewdrop spiders are placed in the webs of golden orb spiders, will they be captured?

The essential requirement about the right question is that it is testable. *Why* and *how* questions cannot be tested; *what if* questions can. Questions lead to hypotheses.

The **hypothesis** is a statement that attempts to answer the question(s) raised from observation(s). This explanation is then tested by experimentation. For example:

'The introduction of spiders slightly larger than the dewdrop spider to golden orb webs in the Brisbane Forest Park, during the spring–summer season of 2004, will not result in their being captured and eaten by the golden orb spider.'

This detailed hypothesis:

- sets limits on the problem to be solved by specifying

— the particular species under study
— the area involved
— the effects to be studied
— the time period over which the question is to be investigated

- points the way to the solution of the question
- leads to the prediction of new information.

Note that the hypothesis given was written in the negative—the introduced spiders will not be eaten by the golden orb spiders. A hypothesis written in this form is termed a **null hypothesis**. Scientists use this form because it is more difficult to show that a particular factor has a specific effect than it is to show that it does not.

The scientific method is unique in that it alone tests hypotheses by experimentation. If the experimental evidence for the proposed hypothesis is negative or inconclusive, further hypotheses are suggested until the correct explanation is found by experimentation. The most successful hypothesis for a particular investigation is termed the **ruling hypothesis**.

The experiment compares the results of two parallel tests which are identical in all but one respect. One test, called the **control**, provides a standard of comparison—a basis for assessing the outcome of the **experimental test**. In the experimental test the variation, or **variable factor**, is altered in ways known by the experimenter. Only one variable is changed at a time. Thus a different experimental group is set up for each variable to be tested. The assumption is made that the changes in the variable are the cause of any new effects observed in the experimental test.

Sometimes, however, changes may be due to outside influences not originally considered by the experimenter (**extraneous variables**). For instance, in testing the effects of nutrients on plant growth, the investigator may attempt to grow all of the plants at the incorrect temperature for the best growth of that species. If the experimenter has not taken this into account, an incorrect conclusion could be drawn. Care must therefore be taken to work out all possible extraneous variables.

The experiment must be repeated many times to ensure that the results are not due to chance. This is particularly important when using living organisms in experiments, since some individuals may respond to the experimental variable on the basis of their individual characteristics rather than those of the species. A good experiment is one designed to produce useful information which is clearly related to the hypothesis and is typical of the species under investigation.

Repetition of the sequence (observation—hypothesis—experiment), in a number of situations, gradually allows broad generalisations or **theories** about many facts to be drawn. It is important, therefore, that scientists report the details of their experiments fully, so that others may repeat them and so validate their findings. Theories in science are never considered absolute since further discoveries can lead to more accurate ways of observing, testing or interpreting information.

On the basis of accumulated generalisations, **predictions** about an *unknown* can be made. A prediction is the forecast of what will happen in a given situation using the current scientific ruling hypothesis.

This account of the steps in the scientific method should not be taken as a rigid formula. Other factors do enter into scientific discoveries. Accident, the inference leap, prejudice and emotions all play a part in science and should not be overlooked. The fact remains, however, that science is a logical method of considering problems and that it follows a pattern of inductive and deductive reasoning characterised by observation, questions, formation of hypotheses, controlled experiments and prediction.

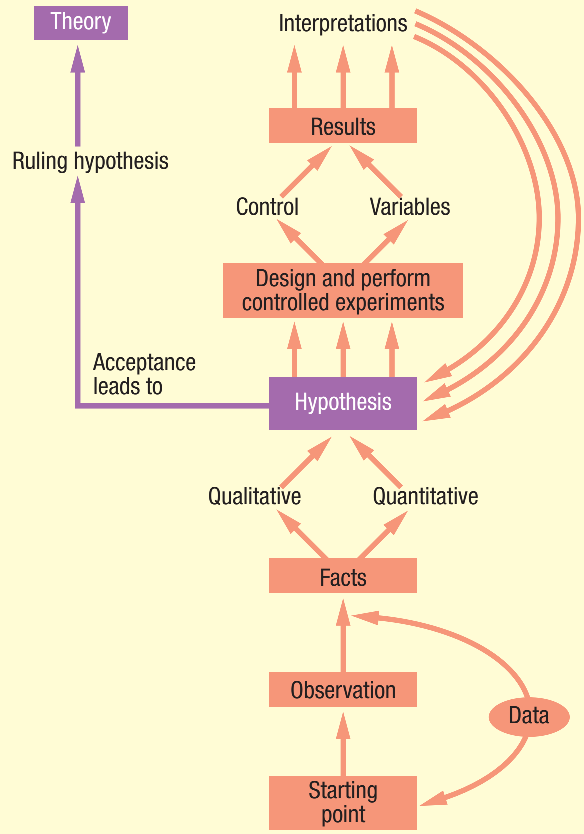


Figure 1.13 Steps of the scientific method

SUMMARY

Biology, like all sciences, utilises the scientific method in investigations. This method involves the following cycle of activities:

- **Observation** This may be qualitative (descriptive) or quantitative (measured) data. Repeated verified observations become facts. Observations usually need to be interpreted (logical reasoning) and this leads to the asking of questions.
- **Questioning** Asking the right question is a key step in the scientific method. The essential requirement is that it is testable. Questions lead to hypotheses.
- **Hypothesis** The hypothesis is a statement that attempts to answer the question(s) raised by the observation(s). This explanation is tested by experimentation. It should:
  - set limits on the problem to be solved by specifying:
    - the particular species under study
    - the area involved
    - the effects to be studied
    - the time period over which the question is to be investigated
  - point the way to a solution of the question
  - lead to the prediction of new information.

  It is more difficult to show that a particular experimental variable has a specific effect than to disprove it. Thus scientists tend to express the hypothesis in the negative form—the null hypothesis.
- **Controlled experiment** The scientific method employs a duplicate set of experiments, one in which all the conditions are set (the control), and the other in which one of the conditions only (the experimental variable) is different. The experiment must be repeated with the same results to ensure that they are not due to chance and thus that the hypothesis is valid.
- **Interpretation** A theory is a broad generalisation based on verified hypotheses.

Review questions

1.9 Distinguish between quantitative and qualitative data.

1.10 In what ways does the scientific method differ from other methods of explaining observations?

1.11 Draw a simple concept map of the scientific method.

1.12 Why do scientists prefer not to use the word 'proof'?

1.13 What is an extraneous variable? How can it influence the outcome of an experiment?

1.14 How do scientists use the terms 'hypothesis', 'ruling hypothesis' and 'theory'?

1.15 How would you conduct an experiment to test a new dog food for 'dog appeal'?

EXTENDING YOUR IDEAS

1. IB A student noticed that there seemed to be a direct relationship (correlation) between length of leg (measured in centimetres from the hip joint to the base of the ankle) and length of the person's stride. To check the accuracy of this observation, the student measured leg length and stride of several people. A sand area with a base board was set up. The subjects aligned the tips of their toes with this board and stepped into the sand. Length of stride was measured as the distance from the base board to the back of the heel-marking in the sand. The results were plotted as shown in Figure 1.14.
   (a) What hypothesis was the student testing?
   (b) What were the variables in the experiment?
   (c) Was this a controlled experiment? Explain your answer.
   (d) What do scientists call the measurements shown on the graph?
   (e) Why were the results presented graphically?
   (f) What range of lengths of stride was recorded for people with legs 90 cm long?
   (g) Divide the graph into four equal boxes to give four categories: short leg, short stride; short leg, long stride; long leg, short stride; long leg, long stride. Count the number of people in each category. In which boxes do most people fit?

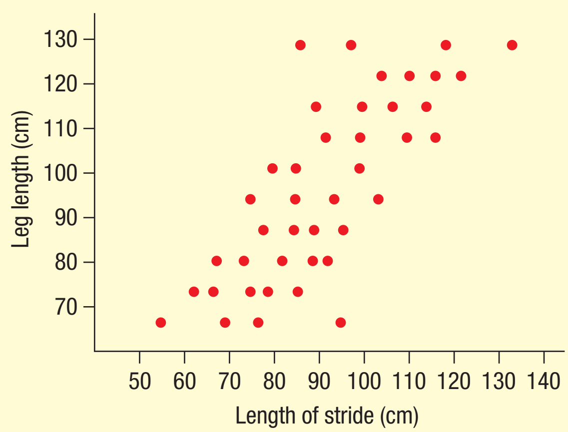


Figure 1.14 Relationship between leg length and length of stride

(h) Was the hypothesis correct? Explain.

(i) What possible extraneous variables were present in this experiment?

(j) How could this experiment be improved to give a more accurate interpretation?

2. You have been selected for a committee to examine the ethics of organ transplants requiring the death of the donor (e.g. heart transplants).

EBI

Write a report which:

- outlines the advantages to society of organ transplants
- responds to possible opposition to transplants
- makes recommendations to ensure an adequate supply of donor organs.

3. Carefully read Case study 1.2. Construct a table that compares and contrasts those features of a virus that would indicate that it is a living organism with those suggesting it is non-living matter. Use this to determine whether or not a virus can be classified as a living organism. Justify your answer.

UB

4. In April 1984 six-year-old Lorenzo Odone was diagnosed as suffering from a rare genetic disorder called ALD (adrenoleukodystrophy) for which there was no known cure. This disease affects boys between the ages of five and twelve and results in the loss of sight, hearing, speech and ability to walk. Lorenzo's parents, Michaela and Augusto, refused to accept the medical verdict and began a remarkable journey of discovery even though neither had any scientific background. They first searched through all of the available literature on ALD, finding that it was caused by a build-up of very long-chain fatty acids (VLCFA) in blood and body tissues due to the lack of an enzyme which normally breaks these down. These VLCFA destroy the myelin sheath which insulates and protects the nerves, resulting in the loss of voluntary motion and early death.

IB

Special diet

In May, Lorenzo was put on a special diet (devised by Dr Hugo Moser) in an attempt to reduce fatty acid levels. Although adhering strictly to the diet, Lorenzo's symptoms became worse. Next came an experimental immunosuppressant course—again unsuccessful. Augusto compiled lists of everyone who had ever written about ALD and doggedly contacted them all—checking and double-checking all of the information. He wanted to know why the Moser diet did not work. After obtaining the raw data from Moser's original work, Augusto meticulously recalculated it and discovered that Moser had made an incorrect assumption. Two toxic substances ($C_{26}O$ and $C_{24}O$) occur in ALD. Moser thought that food with a lot of $C_{26}O$ also contained a lot of $C_{24}O$ and thus that by screening for one, the other was automatically screened. Augusto found some foods had acceptable levels of $C_{26}O$ but unacceptable levels of $C_{24}O$. At that time Michaela found a Polish article which showed that rats deprived of certain fatty acids, including VLCFA, increased their fat production. They concluded that if humans responded in the same manner, diet alone could never be an effective treatment. The Polish experiment reported, however, that the fatty acid levels of the blood could be reduced by feeding the rats with other types of fat.

New discovery

Michaela and Augusto then discovered that Dr William Rizzo at the Medical College at Virginia had found that, in the test-tube situation, a mono-unsaturated fat (oleic acid) halved production of VLCFA in cells taken from ALD sufferers. Unfortunately Dr Rizzo pointed out that oleic acid was not available anywhere in an edible form. Michaela made a list of every company in the US that manufactured medical oils and contacted them. Finally she located one company which produced a substance, glycerol trioleate (GT) which was drinkable, 95 per cent oleic oil. They were able to let the Odones have one pint. Lorenzo by this time was fading fast, no longer able to even sit up.

Augusto set about cooking delicious Italian meals spiced with the GT. Michaela and her two sisters had previously been found to be carriers for ALD, so one of the sisters offered to be the 'family rat'—eating the meals and having her VLCFA monitored. By Christmas, Lorenzo was unable to speak and could hardly eat. At the beginning of January he had to be fitted with a nasogastric tube. At this time his parents started feeding him controlled amounts of GT in his food. Within weeks his VLCFA level had dropped but was still double the normal rate. Although there was a slight improvement in his condition, it soon became obvious that GT alone was not enough.

Search continues

The Odones continued their search for a solution. Augusto kept questioning the reason that oleic acid would work. One night he had a sudden insight. He deduced that the production of VLCFA and harmless unsaturated fatty acids depended on the same mechanism—a single enzyme—and the more that the one type of fatty acid was forced onto the enzyme's pathway, the less the other type was produced. Oleic acid worked by monopolising the enzyme. He thought that the reason that oleic acid was only partially successful in reducing the VLCFA was because it had only 18 carbons in its chain rather than the 24 or 26 of the toxic types.

The only fatty acid available in nature with a long enough carbon chain was erucic acid, derived from rape-seed, but which also contained $C_{24}O$ and $C_{26}O$, and was thought to cause heart disease. Further research by Augusto dispelled the fear of heart disease—erucic acid forms a part of the staple diet in the form of mustard oil in the Madras region of India. As with all of his previous findings, he sent reports to the medical fraternity but again, they were met with scepticism.

The Odones obtained a bottle of erucic acid and tested its effects on Michaela's other sister. It had no effect on lowering her VLCFA. It was obvious that the $C_{26}O$ and $C_{24}O$ needed to be removed from the erucic acid. Michaela finally found a British firm which was prepared to attempt this task. Don Suddaby, soon to retire, was assigned the project. After 6 months of intensive research he succeeded in producing a small amount of pure erucic acid.

Twelve months after the first trial with GT (Lorenzo still alive against all odds), they mixed their next brew (erucic acid and oleic acid in the ratio of 1:3—as occurs in mustard oil) with food, called in the 'family rat' and monitored the results of VLCFA in the blood as well as giving her regular cardiogram checks. After 11 days the blood levels were normal—the first time in medical history that VLCFA levels had been normalised in an ALD patient. Over the next 2 years Lorenzo, on this treatment, improved considerably, although further progress was hampered by his body's inability to regenerate the myelin in his brain that was destroyed by the disease. The Odones' next project—worldwide research into remyelination!

(Adapted from 'Lorenzo's oil', *Australian Magazine*, 1990)

(a) In what ways did the Odones follow the scientific method?

(b) Which steps were inductive and which were deductive?

(c) What hypotheses did the Odones test?

(d) Were their experiments controlled?

(e) Cite evidence from the article of:

  (i) scientific prejudice

  (ii) scientific misinterpretation.

(f) 'Lorenzo's oil' is still not generally available for ALD sufferers and will not be until further clinical trials are undertaken. Suggest possible reasons for this.

(g) In 2002 Dr Hugo Moser released the results of a ten-year study into the oil's effects on a group of boys with the same genetic defect as Lorenzo. All 104 boys were given the oil before any of the symptoms had developed. Some boys were given regular doses of the oil and others had irregular doses. After 10 years, 76 per cent of the boys regularly taking the oil were still healthy with normal brains. Only about one-third of the boys given irregular doses, however, were still healthy.

  (i) Does this evidence prove that Lorenzo's oil prevents the development of ADL? Justify your answer.

  (ii) There was no control group of boys given only a placebo. Moser felt that this would have been unethical.
  Do you agree with Moser's view? Give reasons for your answer.

UNIT
2

The diversity of life

Most scientists believe that the solar system originated by condensation of cosmic dust about 4.6 billion years ago. According to this hypothesis, organic chemicals formed under special anaerobic conditions in the earth's primitive oceans and clumped together to become the first life forms. This development of living from non-living matter has not been shown to recur in the history of the planet.

Organisms have changed their environment, creating opportunities for the development of new life forms. As environments change, the conditions for some organisms may no longer be suitable for their survival. If they cannot move away, individuals die, and this can lead to the extinction of particular types of organisms. Despite the great diversity of living forms existing on earth, which are thought to have evolved from the first life forms of 4 billion years ago, these represent only some of the living things which have inhabited the earth during that time.

Biologists use knowledge of these life forms to classify them according to the way they are believed to have evolved. Changes occur both within classificatory systems and in approaches to classification as research is carried out and knowledge increases.

Key concepts

- Multicellular organisms are functioning sets of interrelated systems.
- Organisms live an interdependent existence in environments to which they are adapted.
- A variety of mechanisms result in continual change at all levels of the natural world.
- There are mechanisms by which characteristics in individuals in one generation are passed on to the next generation.

Key ideas

- The set of systems comprising an organism enable it to function in its environment.
- Different types of multicellular organisms have different roles in the environment.
- An organism has adaptations specific to its environment.
- Living things employ a variety of reproductive strategies.
- Evidence shows that organisms change through time.
- Theories of evolution by natural selection can be used to explain speciation and changes in organisms through time.
- Evolutionary processes acting on gene pools of populations have given rise to diversity of organisms.
- The activity of organisms changes the environment.
- In most organisms coded instructions within the DNA molecule account for their inherited characteristics.
- Humans group organisms in a variety of ways to make sense of diversity and to aid communication.
- Malfunctioning in one system or part of a system may affect the whole organism.

2 CLASSIFYING ORGANISMS

2.1 LIVING THINGS

Organisms exist in a variety of shapes and sizes. They can be found in the water, in or on other organisms, in the soil, at ground level and in the air. Each type of organism has special structures that allow it to survive in its environment. These structures are called **adaptation**. Thus particular adaptations are required for particular environments.

The term **biodiversity** refers to all forms of life, from the smallest microbe to the largest animals and plants, the genes that give them their specific characteristics and the ecosystems of which they are a part. In order to maintain a balanced, healthy environment it is important that we know the types of organisms that exist, their needs for survival and how they interact with both the living and non-living world.

Evidence suggests that the first life forms arose in the sea as simple organisms similar to bacteria about 4 billion years ago. **Mutations** in these organisms have resulted, over time, in the multitude of life forms that exist today.

2.1.1 LIVING IN WATER

In Chapter 1, the processes for maintaining life were explored. It was seen that all living things are composed of one or more cells, the contents of which contain chemicals either suspended or dissolved in water. The concentration of the cell solution is approximately the same as that of sea water. If the concentration of cell chemicals becomes too high or too low, the cells cannot operate properly and the organism dies.

In freshwater habitats, the cell contents are at a higher concentration than that of the surroundings; on land the organism is no longer bathed in any water. In both situations water will be lost from the body unless there are mechanisms to prevent this.

Water is an ideal environment for organisms to live in. It is a very stable living place, with little variation in temperature and salinity with the different seasons. Since it is very buoyant, organisms can grow to a large size without needing any support structure such as a skeleton. Materials need to be in solution to pass in and out of cells, and in an aquatic environment the organisms are surrounded by their requirements already dissolved. For sexual reproduction to take place, sperm cells (the male gametes) must move to the female gametes, and water is an ideal medium for this transfer. Organisms do not need any special protective structures for their developing young since they can grow and develop in the water, obtaining their needs from the environment.

Representatives of all groups of organisms live in water and many (most prokaryotes, the protists, and simple animals) are found only in this habitat. Some parasites have solved their water requirement problems by living within the cells and tissue fluids of another organism.

Living in water can, however, impose some limitations on organisms. For instance, oxygen does not dissolve well in water. The upper, more turbulent surfaces, where wave action can mix the gases from the air, are therefore the most suitable for life. Water absorbs light, so again photosynthetic organisms are limited to the surface regions. The turbulence which is important for dissolving gases, however, further disrupts light penetration. Thus competition for resources exists between photosynthetic organisms in this limited zone of the aquatic environment. Any species with adaptations that enabled them to live in a terrestrial environment, therefore, had an advantage.

2.1.2 LIVING ON LAND

On land, light is abundant and is not blocked by turbulent water. Carbon dioxide, essential for photosynthesis, is readily available in air where it circulates more freely than in water. At the time of their evolution some 400 million years ago, the emerging land plants did not have to compete with any other life forms. Once a food supply was available, however, evolution of terrestrial animals soon followed.

The terrestrial environment is hostile in many ways, and many adaptations were needed for terrestrial organisms to survive. Among the many problems they faced were:

- obtaining enough water when fluid no longer bathes the entire surface
- preventing excessive loss of water by evaporation

- maintaining a sufficiently extensive moist surface for gas exchange when the surrounding medium is air instead of water; materials can only pass across cell membranes in solution
- transporting water and dissolved substances from the restricted areas of uptake to other parts of the body
- supporting the body against the pull of gravity when the buoyancy of water is no longer available
- carrying out reproduction when there is little water through which the sperm may swim to the egg, and where the zygote and young embryo are in severe danger of desiccation
- withstanding the severe fluctuations of temperature, humidity, wind, light and other environmental conditions to which terrestrial organisms are often subjected.

Fungi, plants, insects and vertebrates have been the most successful organisms in colonising the terrestrial environment. The methods they have evolved to cope with environmental stress will be discussed in the following chapters.

SUMMARY

Biodiversity refers to the organisms that inhabit earth, their genetic composition and the ecosystems in which they live. The first living organisms are believed to have evolved in the sea. Mutations in those early life forms have resulted in millions of different types of organisms. Many adaptations were required for organisms to make the transition from sea water to fresh water and then to land.

? Review questions

2.1 What environmental conditions are conducive to living in water?

2.2 What factors limit life in an aquatic environment?

2.3 Describe some of the problems associated with a transition from living in water to living on land.

2.2 Making sense of the diversity of life forms

It is characteristic of humans that they name and group objects together to make sense of the world and communicate effectively with others. The more specific the object, the greater is the detail in which it is described. For example, a brother and sister both go to Billabong High School. They are in Year 11 and study Biology. Specifically they are Mirabelle and Joshua Marconi, each with distinctive features which show that they are closely related but individual. Note that the grouping has gone from the general to the specific. This method of grouping is termed **hierarchical**, with groups within groups. Grouping things together is known as **classification**.

The knowledge that most people have of the organisms around them is generally restricted to those plants and animals that have a direct bearing on their lives. Thus we are familiar with mosquitoes, which transmit several types of disease (e.g. malaria, dengue fever and Ross River fever), flies which are an annoyance, moulds which spoil clothing and food, and plants and animals that supply food.

There are at least 5 million types of species currently existing on earth. Of all the animals that have ever lived, it is estimated that 99 per cent are now extinct. Biologists face the task of identifying, studying and exchanging information about this vast diversity of life forms. They therefore need an orderly and logical system for naming and grouping organisms which shows their past and present relationships.

The kind of classification of organisms used depends on the needs of the organiser of the system. According to Aboriginal beliefs, all plants and animals are related to them through the spirit world of the Dreamtime and so their naming is associated with religion, various taboos and food usage.

In 300 BC Aristotle developed the first biological system of classification. He distinguished two major groups—plants and animals. Since that time there has been a massive expansion in knowledge of the different types of organisms and the means by which biologists can study them. This has led to the development of different groupings. Any system of classification is only an aid to understanding and communication and will continue to change as new information comes to hand.

SUMMARY

Biological classification is a hierarchical, evolutionary system of grouping organisms in an orderly and logical manner which will aid understanding of the living world.

Review questions

2.4 Define the term 'classification'.

2.5 Classification systems tend to be hierarchical. What does the term 'hierarchical' mean?

2.6 Classify, from the general to a specific example, one of the following:
   (a) music
   (b) food in a supermarket
   (c) computers
   (d) motor vehicles.

2.3 THE BASIS OF BIOLOGICAL CLASSIFICATION

The science of naming and classifying living things is called **taxonomy**. In grouping organisms together, biologists are concerned not only with similarities and differences between groups but also with the relationships between them. Related organisms are believed to have a common ancestor. Taxonomists, therefore, are concerned with the evolution of species, and classification systems are attempts to reflect this accurately. Accurate classification of organisms can also lead to prediction. Thus if certain organisms are known to have a great number of similarities, it is very likely that they will also have other things in common although these may not have been studied in detail.

2.3.1 THE SPECIES

The basic unit of biological classification is the **species**. This word means 'kind' in Latin. It is written in the same way in both singular and plural. A species is generally defined as a group of similar organisms whose members can interbreed with each other in natural environments to reproduce fertile offspring. This implies that a species is reproductively isolated from all other species. **Reproductive isolation** may result from: different types of behaviour; different requirements from the same environment; or different make-up of the genetic material (nucleic acid) within the cells. Closely related organisms are known to interbreed in artificial situations (e.g. lions and tigers in zoos), but the offspring are usually sterile.

Although the species concept works well with sexually reproducing animals, it presents some problems in classifying asexually reproducing organisms, such as bacteria and the unicellular eukaryotes, and fossils. Many plants can reproduce asexually, and others can form fertile hybrids with different species. The term 'species' applied to these organisms is therefore one of convenience.

Scientific nomenclature

Different species are given scientific names. During the eighteenth century Carolus Linnaeus developed the taxonomic system which forms the basis of that used by biologists today. In this system every type of organism was given a two-word scientific name. This is called **binomial nomenclature** (*bi* = two; *nomen* = name; *calator* = caller). The scientific name was written in Latin because that was the common language of scientists of the time.

The tradition of using Latin or Ancient Greek for naming organisms has been maintained because these are 'dead' languages and the meanings of their words do not change with dialect or fashion as they do in modern languages. Better known organisms also have common names. Although these may be easier to learn, they can be confusing since different common names can be used for the same species in different localities. The scientific name always refers to one specific type of organism and is used worldwide to describe it.

Genus and species

The scientific name consists of the **genus** name and a **specific name**. A group of closely related species, most probably arising from a common ancestor, belong to the same genus (plural *genera*). The specific name (an adjective or modifier) indicates the particular species within that genus. The domestic cat, the lion, the tiger, the leopard and the wild cat bear such close resemblance to each other that they are usually placed in the same genus. The specific names distinguish the different types of cats.

domestic cat	*Felis domestica*
tiger	*Felis tigris*
lion	*Felis leo*
leopard	*Felis pardus*
wild cat	*Felis catus*

Note that the scientific name is typeset in *italics*, but is underlined when handwritten. The genus name begins with a capital letter and the specific name is in lower case. The genus is always placed first in the scientific name.

When referring to a particular group of organisms, it is common to use the genus name. The word *Felis* automatically refers to common features of the cat group. A specific name, on the other hand, is meaningless when written alone since it can be used as a descriptor for many unrelated genera. For example, two organisms are given the specific name *alba*—*Egretta alba* and *Eucalyptus alba*. *Egretta alba* is the large white bird found feeding in shallow waters and swamps in tropical and temperate regions of the world. *Eucalyptus alba* is the poplar or white gum tree found in the tropical regions of northern Australia; it has a smooth, white bark.

In a context where there is no possible confusion the genus name may be abbreviated to its initial letter. An author discussing a particular group of fruit fly, for example, might write *Drosophila melanogaster* as *D. melanogaster* after the generic name has already been mentioned in full.

Naming organisms

The person who first describes a species has the right to name it. There are various sources of scientific names. The scientist may name it after a person (but never oneself), or the locality from which it was first observed. Many Australian biologists have utilised indigenous Aboriginal names; for example, the burramys, a pygmy possum found in the high country on the New South Wales–Victorian border, belongs to the genus *Burramys* from the Aboriginal word '*burra-burra*' (place of many stones) and the Greek '*mys*' (mouse). Some biologists have a great sense of humour and have used this in naming new species. Thus members of mosquito genera have been given the specific names of *tormentor* and *horrida*. One beetle (presumably treacherous) has been named *Ytu brutus*. It is more common for the name to be descriptive. The scientific name for the red kangaroo is *Macropus rufus*, which gives a physical description: *Macropus* means 'large-footed' (*macros* = large; *pus* = foot) and *rufus* means 'red'.

An understanding of Latin and Ancient Greek roots is a valuable aid for serious students of Biology.

2.3.2 Grouping species

In the hierarchical system of biological classification, related species are grouped together into genera, related genera into **families**, related families into **orders**, related orders into **classes**, related classes into **phyla** (singular *phylum*) or **divisions** and related phyla or divisions into **kingdoms**. The term 'phylum' is used in the description of animals and the single-celled Protozoa, whereas 'division' is used in describing all other types of organisms (bacteria, plants etc.).

Within each of these groups there may be subdivisions. Thus a phylum may include several subphyla. Members of a species may differ, but not enough to be considered separate species. They are placed into categories called **varieties**—the poodle is a variety of dog (*Canis familiaris*). In other situations, members of a particular species may be reproductively isolated because they live in different places with limited overlap between their ranges; those members at the far ends of the range are geographically isolated. These groups have adaptations (e.g. different colour patterns) which better suit them to their particular habitats, but they still belong to the same species because they are still *potentially* capable of interbreeding. Biologists term these groups **subspecies** or **races**. They are distinguished from varieties in that they have a greater possibility of forming new species in the future.

Diagnostic features are those characteristics which distinguish one group from all others and are most general at the kingdom level. They become more specific as classification progresses down to the species. In the examples given in Table 2.1 all four species share common diagnostic features down to the class level. At the order level, the human diverges from the other three. The diagnostic

Table 2.1 Full classification of four mammals

Taxonomic group	Dingo	Australian fur seal	New Zealand fur seal	Human
Kingdom	Animalia	Animalia	Animalia	Animalia
Phylum	Chordata	Chordata	Chordata	Chordata
Subphylum	Vertebrata	Vertebrata	Vertebrata	Vertebrata
Class	Mammalia	Mammalia	Mammalia	Mammalia
Order	Carnivora	Carnivora	Carnivora	Primata
Family	Canidae	Phocidae	Phocidae	Primata
Genus	*Canis*	*Arctocephalus*	*Arctocephalus*	*Homo*
Species	*C. familiaris*	*A. doriferus*	*A. forsteri*	*H. sapiens*

features for primates differ from those for carnivores and, from this point on, the human becomes more and more dissimilar to the others. The dingo has different diagnostic features from the seals and so is placed in a separate family. The two seals are very similar and so are placed in the same genus, but they are reproductively isolated and therefore different species. This classification shows that the seals are closely related and have a reasonable evolutionary relationship to the dingo. Both types are only distantly related to the human.

The use of diagnostic features is shown in Figure 2.1.

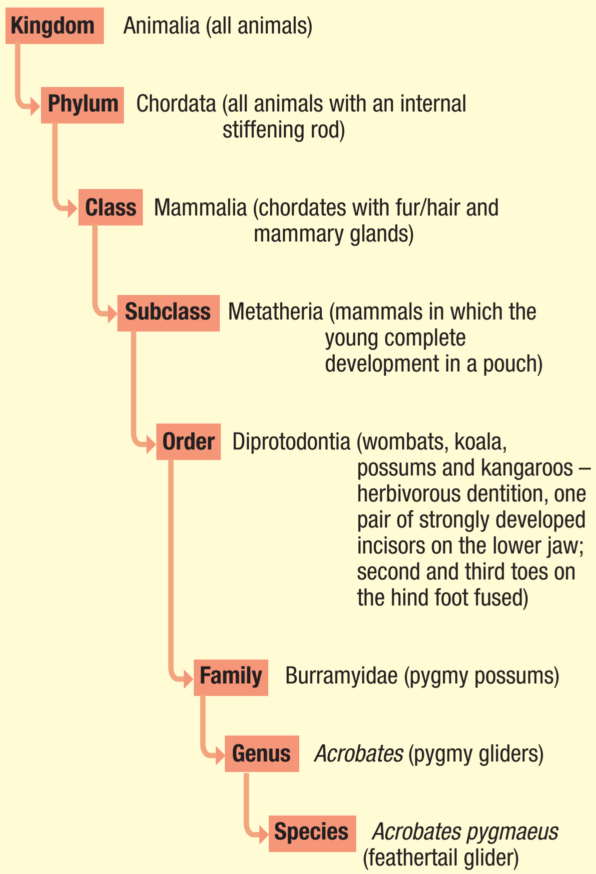


Figure 2.1 Classification of the feathertail glider described in Chapter 1

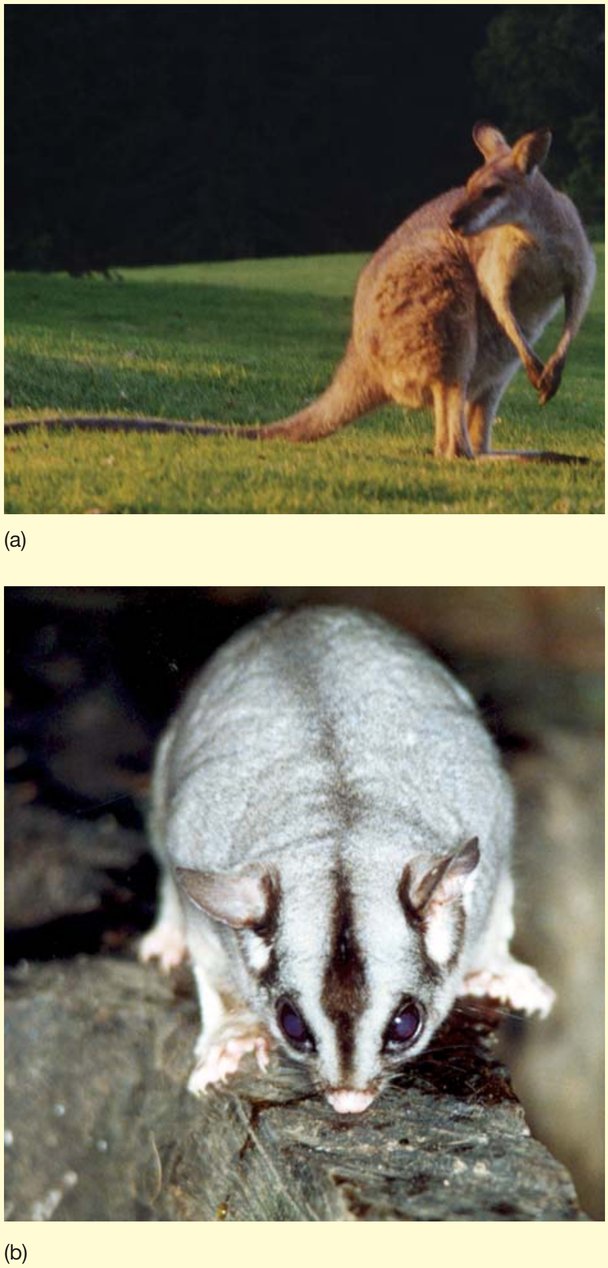


Figure 2.2 Two members of the order Diprotodonta: (a) whiptail wallaby, *Macropus parryi* (b) sugar glider, *Pteraurus breviceps*

2.3.3 Features used in classification

Biologists group species in such a way as to reflect the relationships between them, both in the present and in the past. The groups are, in effect, hypotheses about evolutionary history. As such they can be tested, by detailed study of the fossil record and comparison with features of other living organisms, and revised as new information becomes available.

The general appearance of organisms gives important clues to their classification. Structure alone, however, can be very misleading. Insects, birds and bats could be grouped together on the basis of the presence of wings; fish and dolphins could be grouped on the basis of their streamlined bodies, tail and 'fins'. Biologists therefore ask two important questions when looking at structure:

- Does a similarity reflect inheritance from a common ancestor, or does it reflect adaptation to similar environments by organisms that do not share a common ancestor (**convergent evolution**)?

- Does a difference reflect separate evolutionary histories, or does it reflect adaptations of closely related organisms to very different environments (**divergent evolution**)?

Taxonomists must therefore view internal as well as external structure.

The wing of a bird, the flipper of a whale, the forelimb of a horse and the human arm all serve different functions and look unalike. A detailed study of the bone structure of each, however, reveals that they have the same basic structure. This suggests that they all had a common ancestor. Structures with a common origin are termed **homologous structures**. The greater the number of homologous organs different species have, the closer is the relationship between them.

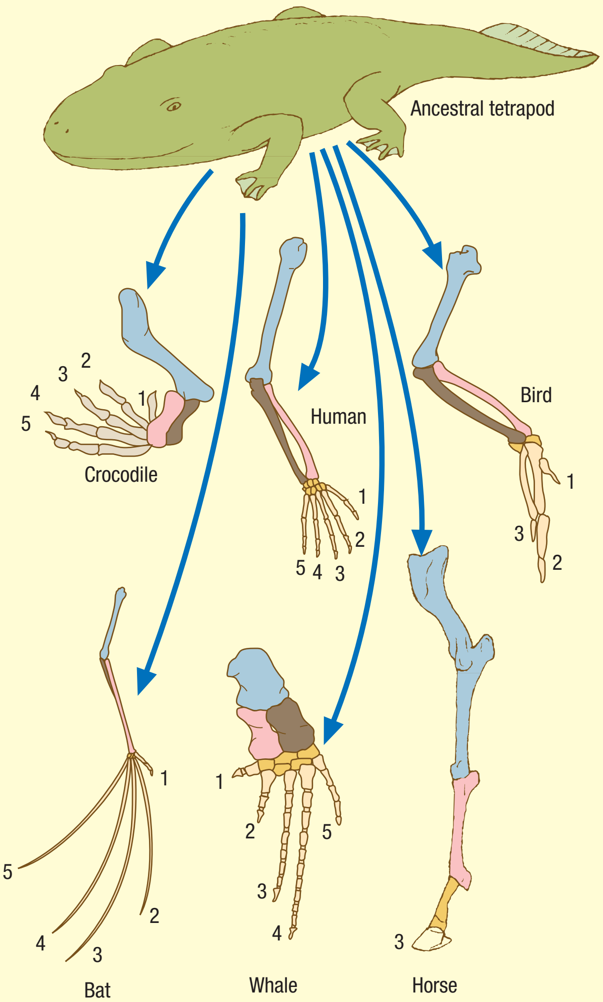


Figure 2.3 Homologous structures: the forelimb of terrestrial vertebrates. (Colour shows matching bones; numbers show matching fingers.)

The wings of birds and insects, on the other hand, are 'built' on different plans. The bird's wing develops as part of a bony skeleton; insects do not have bones. Although they serve the same function and have a similar superficial appearance, they show no evidence of relatedness. They are said to be **analogous structures**.

Figure 2.4 Evolutionary convergence between marsupial mammals of Australia and placental mammals of other continents

It is sometimes very difficult to determine whether a structure is homologous or analogous, and other characteristics are needed to classify organisms.

Analysis of blood and other proteins provides another clue for relatedness. The greater the similarity of body chemicals, the more closely related are organisms. The nucleic acid in the cell's nucleus determines which proteins are produced, so if two organisms have very similar proteins, they will have similar nucleic acid and thus may have a common origin. Using this method, the whale is shown to be related to mammals and not to the structurally similar fish.

Comparisons with fossil structures and of life histories provide further evidence. If the early development (**embryology**) of two organisms shows a similar pattern, they are probably related. This has provided further evidence for the classification of whales: the early development of the whale is similar to that of mammals since both have internal development of their young. Once the young are born, the mother cares for them and nourishes them with milk that she secretes. Most fish hatch from the fertilised eggs released by the mother into the surrounding water. Usually there is no further contact between mother and young once the eggs are laid.

SUMMARY

A species is a natural group of organisms which freely interbreed to produce fertile offspring. The system of binomial nomenclature assigns two names to each species. The genus name may be common to one or more closely related species. The specific name is a qualifying description for the individual species within the genus. Scientific names are usually based on Latin or Ancient Greek and typed in italics (or underlined if handwritten).

Classification of organisms is hierarchical, with each group having diagnostic features. The groups all bear an evolutionary relationship to each other. Related species are grouped into a genus, related genera into a family, related families into an order, related orders into a class, related classes into a phylum or division and related phyla or divisions into a kingdom.

Homologous structures have a common origin, although they may not look alike and may perform different functions. Analogous structures have similar functions but different development. The decision to place an organism in a particular group is based on evidence from a variety of sources: careful study of internal and external structures to determine homologous structures; chemical analysis of proteins; comparisons with fossils; and study of embryonic development.

? Review questions

2.7 Define the term 'species'.

2.8 How do scientists name a species?

2.9 Explain why biologists use scientific names instead of common names.

2.10 Scientific names are usually derived from Latin or Ancient Greek words. Explain why this is the case.

2.11 *Dacus tyroni* is the Queensland fruit fly, which lays its eggs in soft-skinned fruit. When the larvae hatch, they use the ripening flesh for nourishment to complete their development. To which one of the following is the organism most closely related?

A *Rosana tyroni*

B *Pinuta dacus*

C *Dacus cucumis*

D *Tyroni rosana*

Explain your choice.

2.12 To what does the term 'diagnostic feature' refer?

2.13 Distinguish between convergent and divergent evolution.

2.14 Define the terms 'homologous' and 'analogous' as used by biologists to describe structures. Give an example of each type of structure.

2.15 What features are used by biologists to determine the relatedness of organisms?

2.16 Based on your own knowledge of their characteristics, set up a scheme to place the animals listed below into groups and subgroups. No scientific terms are needed.

baboon	bear	lion
clam	fly	frog
earthworm	horse	jellyfish
lobster	mosquito	prawn
emu	panther	oyster
sparrow	turtle	tuna
whale	snake	snail

2.17 The smallest hummingbird is called *Calyphi helenae* and the largest is called *Patagona gigas*. The hummingbird with the longest beak is called *Ensifera ensifera*, while the one with the smallest beak is called *Remophomiron microrhynchum*. The hummingbirds described above all belong to the:

A same genus but different species

B same family but different classes

C same genus but different classes

D same class but different genera.

2.18 Listed below are some common Latin and Greek root words used in naming animals.

a-	without	(Gk)
-cephalus	head	(L)
giga-, gigan-	giant	(Gk)
leuco-	white	(Gk)
natus	birth	(L)
ornitho-	bird	(Gk)
ptero-	wing, feather	(Gk)
-pus	foot	(L)
rhynchus	snout, beak	(Gk)

(a) Give as many physical characteristics as possible of the following species:

(i) *Macropus giganteus*

(ii) *Pteropus leucocephalus*

(iii) *Rattus leucopus*

(iv) *Ornithorhynchus anatinus*

(b) Suggest a common name for each species based on the descriptions you gave in part (a).

2.4 The kingdom debate

Not all organisms fit into the neat categories of plant or animal. For example, the unicellular organism *Euglena* has some plant-like features (it has chloroplasts and can photosynthesise) and some animal-like features (it can swim around freely like an animal; and in dark conditions reverts to a heterotrophic mode of nutrition). With the development of the microscope and biochemical techniques during this century, knowledge of organisms has increased enormously and many more groups with ambiguous features have been discovered.

To eliminate the uncertainty associated with the two-kingdom system, biologists have created classificatory systems composed of more than two kingdoms. Three-, four- and five-kingdom systems have been devised, and the debate continues as to the exact number of kingdoms that most accurately describe organisms and their relationships to each other. One system is not necessarily better than another. Each is an attempt to understand relationships between organisms and to describe and communicate information about the living world.

A five-kingdom system of classification is commonly used. This consists of **Monera** (the prokaryotes), **Protista**, **Fungi**, **Plantae** and **Animalia**. Even within these five kingdoms there are variations in the phyla/divisions which are placed within them. Thus some biologists place all algae in the Protista, whereas others include only the unicellular algae, and place multicellular forms in the kingdom Plantae. In this book the classification system used is as shown in Table 2.2.

Table 2.2 Characteristics of the five kingdoms

Phylum/division / Characteristic	Prokaryotic	Eukaryotic			
	Monera	**Protista**	**Fungi**	**Plantae**	**Animalia**
Nuclear membrane	absent	present	present	present	present
Mitochondria	absent	present	present	present	present
Chloroplasts	absent	present in some forms	absent	present	absent
Mode of nutrition	heterotrophic or autotrophic (chemosynthesis or photosynthesis)	photosynthesis or heterotrophic or combination of both	heterotrophic by absorption	photosynthetic	heterotrophic by ingestion
Multi-cellularity	absent	absent in many groups	present except in yeasts	present	present
Locomotion	absent in most forms	present in some forms	absent	absent	present
Nervous system	absent	absent	absent	absent	present except in sponges

With increased knowledge, new schemes for grouping organisms will continue to be proposed. A recent development places organisms into **domains** based on their genetic make-up rather than on physical characteristics. These domains are then subdivided into kingdoms. The three domains are the Archea (prokaryotic forms found in extreme environmental conditions of anoxia, high salt concentration, high temperature or low pH), the Eubacteria (kingdom Monera) and Eukarya (all other kingdoms).

SUMMARY

Systems of classifying organisms are designed to aid human understanding of the living world. Therefore all classification is human-made and thus artificial. Different systems of classifying organisms exist because:

- groups of people place different emphasis on particular characteristics of organisms; and
- new information is constantly being discovered.

Review questions

2.19 Classification is said to be arbitrary in nature. Explain this observation.

2.20 Explain why a two-kingdom system of classification is no longer considered appropriate.

2.21 Bacteria are classified as Monera. What diagnostic features would be used to describe a bacterium?

2.22 An organism has been found that has eukaryotic cells, is multicellular and heterotrophic. Into which kingdom would you place it? What further information would you require in order to be sure of your answer?

2.5 Identification keys

Biologists often use keys or flow diagrams to help them identify different organisms. Observable features are used to separate organisms into smaller and smaller groups until the organism can be identified on its unique features. Alternatives in such keys should be comparative (e.g. legs or no legs). These keys may be very general. The subdivision of members of the subphylum Vertebrata into their classes (Figure 2.5) is an example of this.

In using a such a key, a start is made at the top and the alternatives are worked through until the organism is identified. A decision is made about the characteristic at each branch point. Depending on the feature displayed, one of two pathways is followed to the next branch. For example, identifying a vertebrate with scales but no fins would involve the following steps:

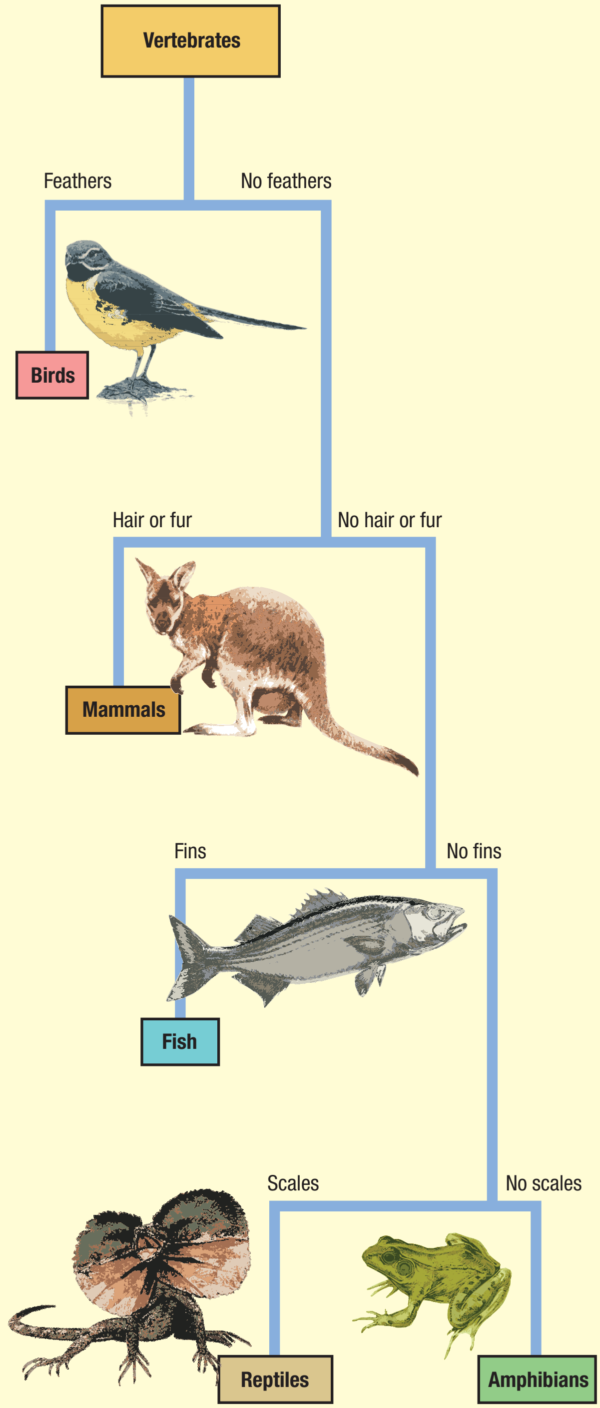


Figure 2.5 Subdivision of the vertebrates into classes

No feathers—No hair or fur—No fins—Scales and so would be keyed out as a reptile.

Keys with only two alternatives at each stage are said to be **dichotomous keys**. Rather than being shown diagrammatically as in Figure 2.5, keys may be in tabular form. In the example below, the key is specific for a group of species known to exist in a particular locality and therefore would not be useful in other localities.

Key to ironbark species of eucalypts in Brisbane (courtesy H. T. Clifford)

1.	Mature buds greater than 2 cm long	*E. sideroxylon*
	Mature buds less than 2 cm long—go to:	2.
2.	Leaves opposite	*E. melanophloia*
	Leaves alternate—go to:	3.
3.	Coppice leaves twice as long as broad	*E. siderophloia*
	Coppice leaves several times longer than broad—go to:	4.
4.	Mature buds about 1 cm long	*E. drepanophylla*
	Mature buds less than 1 cm long	*E. crebra*

Some keys have many choices at each step and thus are not dichotomous.

SUMMARY

A key is a tabular or flow-diagram system for identifying organisms quickly and accurately. A dichotomous key uses two alternatives for a particular characteristic at each step. Keys may be general, or may be specific to a particular group of organisms found in one locality.

Review question

2.23 Construct dichotomous keys to distinguish the koala, dingo, snake, lizard, turtle, emu and green tree frog:

(a) in the form of a table

(b) as a flow chart.

EXTENDING YOUR IDEAS

1. UB Two groups of frogs resemble each other very closely. One group lives on the lower eastern slopes of the Eastern Highlands. The other group lives on the top of these mountains. A biologist discovers that the frogs on the lower slopes breed in September–November, whereas those on the higher slopes breed in January–March.
   (a) Suggest possible reasons for the different breeding times of these two groups.
   (b) Would you classify the frogs as the same species? Explain.
   (c) What additional information would you require to validate your classification?
2. UB Using the tabular key to eucalypts at left, work out the scientific name of the specimen in Figure 2.6.

Figure 2.6 Narrow-leafed ironbark

3. UB Using the Latin or Greek roots or names provided, suggest a scientific name for the animal shown in Figure 2.7 on page 30. Explain how you derived the name.

ancylo	crooked	**gigas**	giant
albo	white	**gracil**	slender
-acis	pointed/barb	**macro**	large
amphi	on both sides	**meta**	between
arcatus	provided with a bow	**nocti**	night
australis	belonging to the south	**-onch**	barb, hook
bi	two, double	**-phaga**	eat
brachy	short	**psita**	tapping
capit -o, -a	head	**pseudo**	false
caud -a, -ata	tail	**philo**	loving

cheli	claw	**pus**	foot
crassi	thick	**tri**	three
dactylo	finger, toe	**trisho**	hair
di	two, separate	**virgata**	striped

4. IB Residents of the outer Brisbane suburbs can sometimes be confronted with small mouse-sized mammals inside their homes. It is important for these people to be able to recognise which is a house/field mouse and which is a native mouse, marsupial mouse or feathertail glider, because many of these native species are rare and should be released back into the bush.

   Here are some descriptions of mouse-like mammals found around Brisbane.

   Your aunt rings you saying that her cat has chased a 'mouse' into her house. She has caught it in a clear plastic biscuit barrel, and is not going to touch it or open the container, but she wants to release it if it is not a house mouse. What TWO questions could you ask her that would establish if her trapped species is a house mouse?

   1. **House mouse** ('field mouse')
      Introduced pest species *Mus musculus*

      Body length 75 mm; tail length 85 mm; weight 15 g. Typical mouse, usually olive-brown back and slightly paler belly. Very strong musky-mouldy scent. Small notch on inner side of upper incisors is characteristic.

   2. **Common planigale** (marsupial mouse)
      Planigale maculata

      Body length 80 mm; tail length 77 mm; weight 11 g. Mouse-sized, mouse-coloured. Flat head; pointed snout; cat-like teeth; inner 'big' toe on hind foot has no nail. Female has 'kangaroo-like' pouch and male has pendulous scrotum; both these features are lacking in the house mouse.

   3. **Common dunnart** (marsupial mouse)
      Sminthopsis murina

      Body length 90 mm; tail length 80 mm; weight 22 g. Large mouse-size. Sharply pointed snout; large bulging black eyes; delicate white hind feet; grey-brown head and body; belly pure white; cat-like teeth; inner 'big' toe on hind feet has no nail. Female has 'kangaroo-like' pouch.

   4. **Feathertail glider** (marsupial)
      Acrobates pygmaeus

      Body length 80 mm; tail length 80 mm; weight 13 g. Mouse-sized; grey-brown back; white belly; tail like a small feather (feature found in no other Australian mammal).

Figure 2.7 Striped possum

5. **Water mouse** (false water rat)

Xeromys myoides Body length 115 mm; tail length 95 mm; weight 40 g. Large mouse-sized; silky, slate grey back sharply defined by pure white belly; tail short, sparsely haired, without white tip.

5. IB CSIRO scientists studied a number of skull characteristics of the dingo, the dog and captive-bred hybrids between the dingo and the dog. On the basis of these characteristics each skull was allocated a composite score which ranged between 20 and 140. The results were plotted on the bar graphs below.

(a) Do the measurements from the dog and dingo samples (Graph 1) form two distinct groups? Explain your answer.

(b) Can you be certain that a skull with a score of 40 is that of a dog? Explain your answer.

(c) How do the skull scores of the hybrid group compare with those of the 'pure' dog and the 'pure' dingo groups?

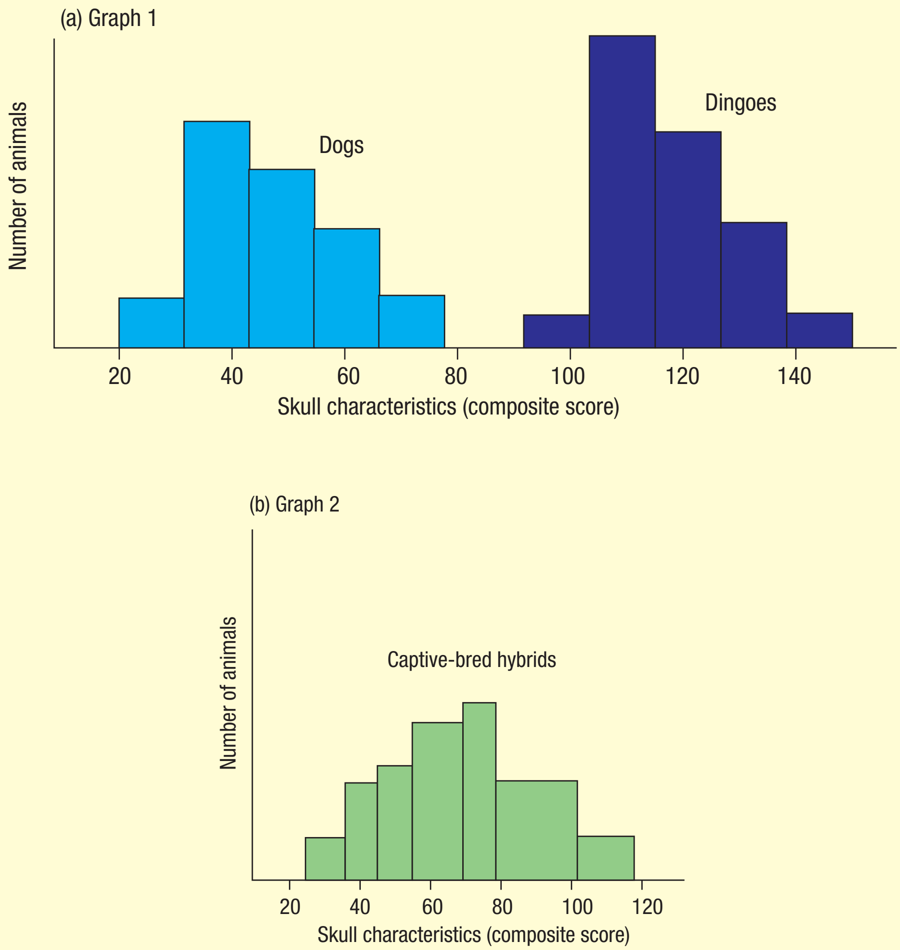


Figure 2.8 Skull sizes of: (a) dogs and dingoes; and (b) captive-bred hybrids

3 Overview of living organisms

3.1 Kingdom Monera

The members of the kingdom Monera are all bacteria and cyanobacteria. Some of the smallest existing organisms, they are between 0.5 and 10 μm in diameter. Although some forms exist as groups of cells or in long strands, there is no specialisation of different cells for a particular function as the cells are only loosely held together. They are so small that their internal structure can only be determined using very high-powered electron microscopes. Their cells have no true nucleus or other membrane-bound structures typical of other organisms. The entire cell is enclosed by a wall composed of the glycoprotein **murein** (or peptidoglycan).

3.1.1 Bacteria

In spite of their small size, bacteria have continued to dominate all environments throughout the existence of life on earth. They are found in such diverse habitats as the icy waters, snow and ice of Antarctica, the dark depths of the oceans, and near-boiling hot springs. Some have even been found in volcanic vents on the deep sea floor where temperatures reach 250°C. It has been estimated that:

- a single handful of soil contains more bacteria than the total number of people who have ever lived
- the skin of an average person has 10^5 bacterial cells per square centimetre

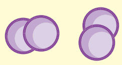
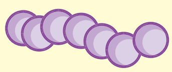
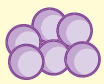
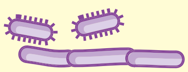
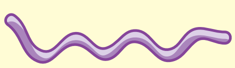
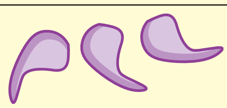
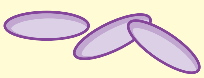
Bacterial shape		***Examples***
Cocci are spherical (singular: coccus)		Diplococci join together in pairs • *Diplococcus pneumoniae* causes pneumonia
		Streptococci join to form a chain • Many *Streptococcus* species infect the upper respiratory tract: *S. pyogenes* — scarlet fever *S. thermophilus* — gives yoghurt its creamy texture
		Staphylococci join together in bunches • *Staphylococcus aureus* (golden staph.) — different strains cause boils, pneumonia, food poisoning and other infections
Bacilli are rod-shaped (singular: bacillus)		• *Bacillus typhosis* causes typhoid fever • *Bacillus anthracis* causes anthrax • *Escherichia coli* lives in symbiosis in gut
Spirilla are spiral-shaped (singular: spirillum)		• The spirochete (a fine spirilla) *Treponoma pallidum* causes syphilis
Vibrio are comma-shaped		• *Vibrio cholerae* causes cholera
Rickettsiae are rod-shaped		• Rickettsiae cause typhus and are often carried on the body louse (a vector) (Note: they are similar in size to the smallest bacilli and cocci but they are classified into a different group because they cannot survive outside living cells; they are actually the smallest known cell)

Figure 3.1 Basic shapes of bacteria

- the human gut contains 10^{11} bacterial cells per gram of contents (the large intestine normally holds 1 kg of material).

Different types of bacteria have different forms of respiration (aerobic, anaerobic or a combination) and methods of gaining nutrition (chemosynthetic, photosynthetic or heterotrophic). The majority of bacteria are harmless, many are essential for the continued existence of life on earth and a few are **pathogens** (from the Greek *pathos* = suffering and *gignomai* = cause).

Bacteria can be grown on a culture medium such as agar jelly or a nutrient broth under controlled environmental conditions. Individual bacteria can grow and divide rapidly and thus produce colonies. The colonies for many bacteria have a characteristic colour and shape.

Case study 3.1 How large can you get?

Bacteria are generally so small that they are only visible when highly magnified under a microscope. The small size of bacteria and cells in general is related to their ability to move materials between the cell and the environment and from one part of the cell to the other. This is usually achieved by a process called diffusion where materials move from an area of their high concentration to an area of their low concentration. This takes time. The larger the cell the larger the distance between the centre of the cell and the outside environment. As cells become larger their surface area:volume ratio also decreases. The cell becomes more inefficient at exchanging materials with their environment. One way to overcome this problem is for a large cell to be long and flattened in shape (thus maintaining a large surface area:volume ratio) or to have a large internal water sac.

One bacterium, *Epulospiscium fishelsoni*, defies the size rules. It is half a millimetre long and can be seen without the aid of a microscope, is fairly fat and has no internal water sac. This bacterium, found in the gut of sturgeon fish in the Red Sea, is also unusual in that it nurtures its young inside itself and swims around in a similar manner to organisms with a much more complex cell structure.

The answer to how it survives lies in two factors. First it lives in a very hospitable environment. Inside the gut of the fish, the bacterium is maintained in a relatively constant environment free from predators. The sturgeon fish does all the hard work of collecting and digesting complex food molecules. The second factor is related to a remarkable attribute of its genes. This bacterium has tens of thousands of copies of its genes (25 times more DNA than is found in a human cell). Genes act by producing proteins. Enzymes—chemicals that mediate chemical reactions within cells—are proteins. As chemicals diffuse into its cytoplasm the genes can immediately direct their conversion to the bacterium's requirements through production of the appropriate enzymes. Little diffusion from one part of the cell to the other is necessary.

3.1.2 Cyanobacteria

Cyanobacteria are distinguished from other bacteria in that their chlorophyll, and process of photosynthesis, is similar to that of plants. They have often been classified in a separate group from the bacteria, the blue-green algae, because of this feature. In addition to the green pigment chlorophyll, they contain other pigments which give them their distinctive blue-green colour, although in some cases this ranges from almost black to reddish-brown. Cyanobacteria are also distinguished by their inability to reproduce sexually.

They are found in shallow estuarine waters where they may form dense mats; in fresh water such as lakes and dams; and in moist terrestrial environments. They are a familiar sight as the 'slime' found in gutters and waterlogged soil after heavy rain, and as the black colouration on stone buildings, graves and rocks.

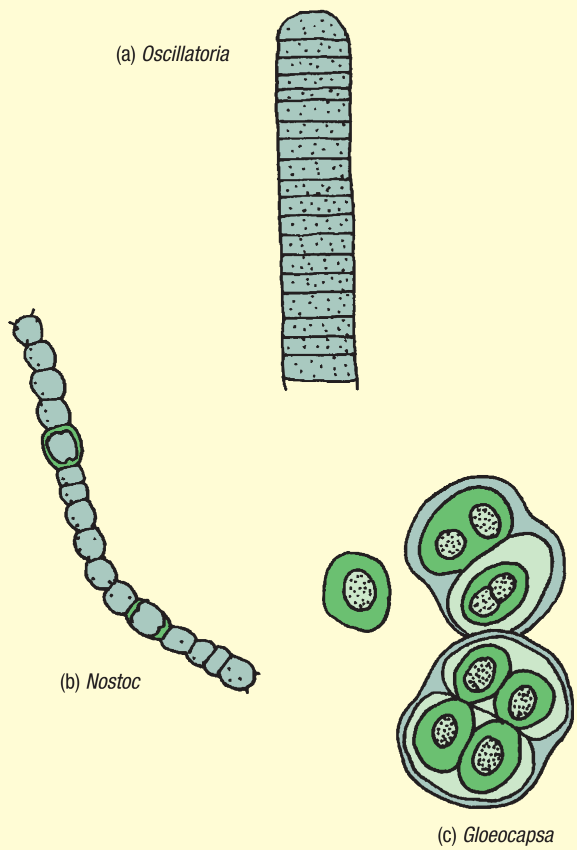


Figure 3.2 Some common cyanobacteria

SUMMARY

The kingdom Monera includes the bacteria and cyanobacteria. These organisms may be single cells or form loose colonies. The cells do not possess a true membrane-bound nucleus or membrane-bound organelles. The cell is surrounded by a wall composed of murein.

? Review questions

3.1 List the diagnostic features of the kingdom Monera.

3.2 What are the four main shapes of bacteria? Describe each.

3.3 What is a pathogen?

3.4 Suggest why there are so many different types of bacteria.

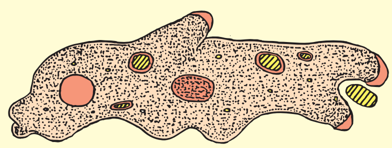
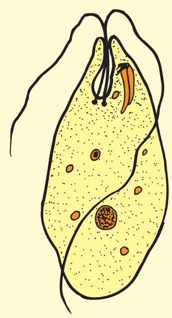
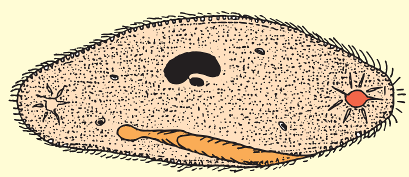
3.5 How do the cyanobacteria differ from the bacteria?

3.2 Kingdom Protista

Of all the taxonomic groups, the kingdom Protista is the most artificial in that it contains all eukaryotic organisms which are not fungi, plants or animals. Much is still unknown about this very diverse group. For the present time, therefore, biologists have grouped them together merely for convenience, until their relationships are further clarified.

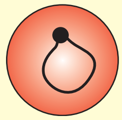
Because of their diversity, it is difficult to define the characteristics of Protista. They are plentiful in water and moist terrestrial environments. Most are unicellular, although some form loose aggregates of cells, or colonies. A few are truly multicellular with relatively simple body plans. Nearly all respire aerobically. Some are photosynthetic, some are heterotrophs that absorb organic molecules or ingest larger food particles, and others combine photosynthesis and heterotrophism. Although there is a myriad of free-living forms, others inhabit the body fluids, tissues and cells of hosts in either a mutualistic relationship or as parasites. Some parasitic protists are important pathogens.

Table 3.1 Animal-like and plant-like protists

PROTOZOA	• Aquatic or endoparasites • Unicellular • Heterotrophic eukaryote	
Phylum Rhizopoda (amoeboids)	• Move by pseudopodia • Irregular shape • Engulf food by phagocytosis anywhere across membrane • Mostly free-living	 e.g. *Amoeba proteus*
Phylum Zoomastigina (flagellates)	• Move using one or more flagella • Definite shape • Food intake at base of flagellum only • Free-living or parasitic	 e.g. *Peranema*
Phylum Ciliophora (ciliates)	• Move by cilia • Definite shape • Food intake in one place only, the 'gullet' • All free-living	 e.g. *Paramecium*

Phylum Apicomplexa
(sporozoans)

- No locomotion
- Definite shape
- All parasites
- Have complex life cycles



e.g. *Plasmodium* (signet ring stage in red blood cell)

ALGAE

- Photosynthetic eukaryote
- Cell walls composed of cellulose
- Mainly aquatic
- Bodies thalloid (no specialised stems, roots or leaves)
- Female reproductive organ different from that of plants with external fertilisation in the surrounding water
- All contain chlorophyll *a*
- Have different additional (accessory) pigments
- They are classified on the basis of their accessory pigments

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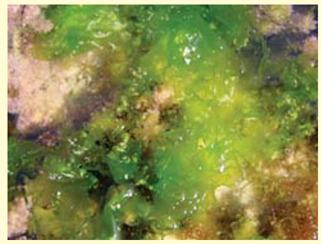
Division Chlorophyta
(green algae)

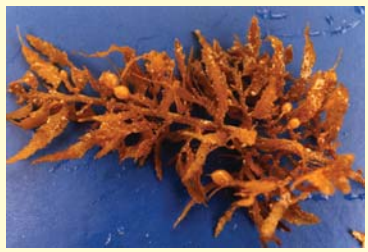
- Unicellular, colonial, filamentous or multicellular forms
- Green or yellow/green colour
- Mostly freshwater



e.g. *Filamentous* green alga and *Ulva*

Division Phyophyta
(brown algae)

- Complex multicellular algae
- Thallus may be filamentous or consist of a root-like **holdfast**, a stem-like **stipe** and leaf-like **blades**
- Brown or green/brown colour
- Almost entirely marine



e.g. *Sargassum*

Division Rhodophyta
(red algae)

- Few unicellular but most multicellular
- Most marine
- Some are coralline (cell walls are impregnated with calcium carbonate)
- Colour varies from pink through to red-brown

e.g. *Laurencia*

- A **pseudopodium** is a foot-like extension of the cell membrane that results in a flowing movement of the cell contents in the desired direction.
- A **flagellum** is an elongated whip-like structure composed of protein filaments enclosed by the cell membrane. Back and forward movements result in propulsion through the water.
- **Cilia** are minute hair-like extensions of the cell membrane of similar structure to a flagellum. Synchronised, wave-like motions collectively bring about locomotion or movement of food particles into the gullet.
- **Phagocytosis** is a process whereby the membrane of the cell encloses 'food' in its external environment to form a food vacuole. Large, insoluble particles are then digested intra-cellularly.

Protists are classified into three major groups:

- animal-like protozoans (nutrition is mainly by ingestion)
- plant-like algae (nutrition is mainly by photosynthesis)
- fungus-like moulds like the slime mould, an amoeboid protist that forms a spore-producing fruiting body, and the powdery mildews.

The Dinoflagellates and Golden Algae are two divisions of unicellular algae that are usually found floating on or near the surface of water where light is abundant. Microscopic algae, together with small invertebrate animals and the larval forms of larger animals, form the **plankton** (*planktos* = wanderer) of waterways. Photosynthetic members of the plankton community are termed **phytoplankton**.

SUMMARY

The kingdom Protista comprises a very diverse group of eukaryotes, most of which are unicellular. It is an artificial classification of all those eukaryotic organisms which are not fungi, plants or animals. Protists are divided into the animal-like protozoans, the plant-like algae and the fungus-like moulds. All live in 'moist' environments.

The Protozoa are heterotrophic protists which are divided into four main phyla. Three of these are distinguished by their mode of locomotion—the Rhizopoda move by pseudopodia, the Zoomastigina by flagella and Ciliophora by cilia. They include both free-living and parasitic forms. The Apicomplexa are all parasites of animals and exhibit complex life cycles involving both sexual and asexual phases. All depend on a moist environment for their survival.

The algae are aquatic plant-like protists that possess chlorophyll *a*. Other pigments may also be present and may block out the green colouration. A diverse group, they may be unicellular, colonial or multicellular. The body of multicellular algae is termed a thallus. In some brown algae the thallus forms a root-like holdfast, stem-like stipe and leaf-like blade.

?

Review questions

3.6 Why is the kingdom Protista considered an artificial taxonomic group?

3.7 List features of the protists which are fairly common to most members.

3.8 What is the basis for the subdivision of the kingdom Protista?

?

3.9 List the diagnostic features of the four phyla of protozoans.

3.10 The Apicomplexa have no known mode of locomotion. Why is this not important for their survival?

3.11 Although algae are plant-like in many respects, they are classified as protists. Give a reason for this.

3.12 On what basis are the algae classified?

3.13 Distinguish between plankton and phytoplankton.

3.3 Kingdom Fungi

Like plants and algae, the individual cells of fungi are enclosed by a cell wall. This cell wall, however, is made from **chitin**, a substance normally only found in animals. Fungi are heterotrophic—they must obtain their nutrients from other organisms.

Fungi grow on organic matter such as humus in the soil, or on dead trees. The main body of fungi is composed of fine filaments called **hyphae** (singular *hypha*). A mat of these hyphae is termed a **mycelium**. As they extend through the substrate, feeding hyphae (**rhizoids**) release enzymes that digest the organic matter present (extracellular digestion) and then absorb the nutrients. Fungi are either decomposers (e.g. bread mould), parasites (e.g. ringworm) or associated with plants (e.g. mycorrhiza). When conditions are favourable, fungi form fruiting bodies (a complex arrangement of hyphae) that produce and release reproductive spores. Classification of the fungi is based on these spore-producing structures.

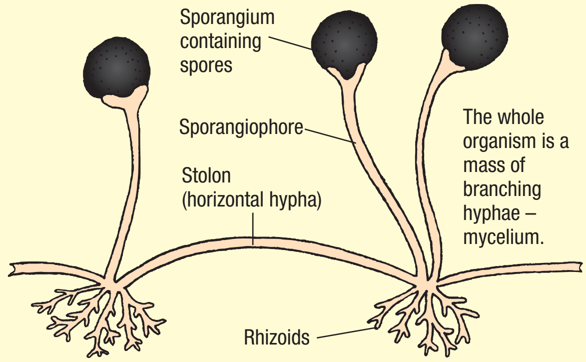
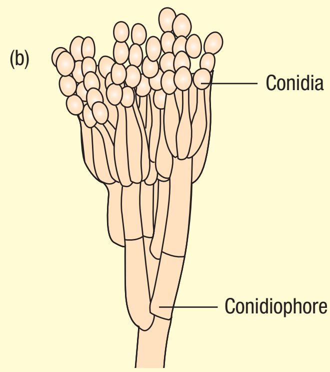
SUMMARY

Fungi are eukaryotic heterotrophs whose cells are surrounded with walls composed of chitin. All fungi, except unicellular forms, are composed of filaments called hyphae, which penetrate their organic substrate. Extracellular digestion is achieved by secreting enzymes into the substrate, and the small molecules thus released are absorbed by the hyphae. Fungi may be decomposers, parasites or found in association with a plant.

Fungi are classified on the basis of their spore formation. Division Zygomycota consists of the pin moulds. They reproduce asexually by spores produced in a sporangium. Sexual reproduction can occur between two different strains by conjugation.

Division Ascomycota includes the orange mould *Penicillium* and single-celled yeasts. These fungi reproduce both sexually

Table 3.2 Kingdom Fungi

KINGDOM FUNGI	• Heterotrophic eukaryote • Cells surrounded by a rigid wall of chitin • Non-motile • Some unicellular, but most are multicellular filaments • Body usually a mycelium of branching hyphae • Reproduction may be sexual or asexual • Reproduce by means of spores	
DIVISION ZYGOMYCOTA Pin moulds	• No septa in hyphae • Spores produced in **sporangia** supported by a vertical hypha used in asexual reproduction • Sexual reproduction may occur by union of two cells between adjoining hyphae of different individuals (**conjugation**)	 e.g. *Rhizopus stolonifera*, bread mould
DIVISION ASCOMYCOTA Yeasts, cup fungi and morels	• Septa in hyphae • Forms spores sexually inside long cells called **asci** (singular *ascus*) • Asexual reproduction by **budding** (yeasts) or spores produced in fruiting bodies called conidia	 e.g. *Penicillium* fruiting body
DIVISION BASIDIOMYCOTA Mushrooms and toadstools	• Septa in hyphae • Asexual reproduction rare • Sexual reproduction by spores formed on the outside of club-shaped **basidia** (singular *basidium*) which form the fertile layer of the large fruiting body	 e.g. gilled mushroom

- A single fungal filament is termed a **hypha** (plural *hyphae*), composed of a strand of cells. The end walls and membranes (**septa**) of individual cells of the hypha may be present or absent.
- **Rhizoids** are short, digestive hyphae that penetrate the food source.
- **Stolons** are long, horizontal hyphae.
- A **mycelium** is a mass of branching hyphae.
- The **fruiting body** is a structure formed from tightly packed hyphae that produce spores.

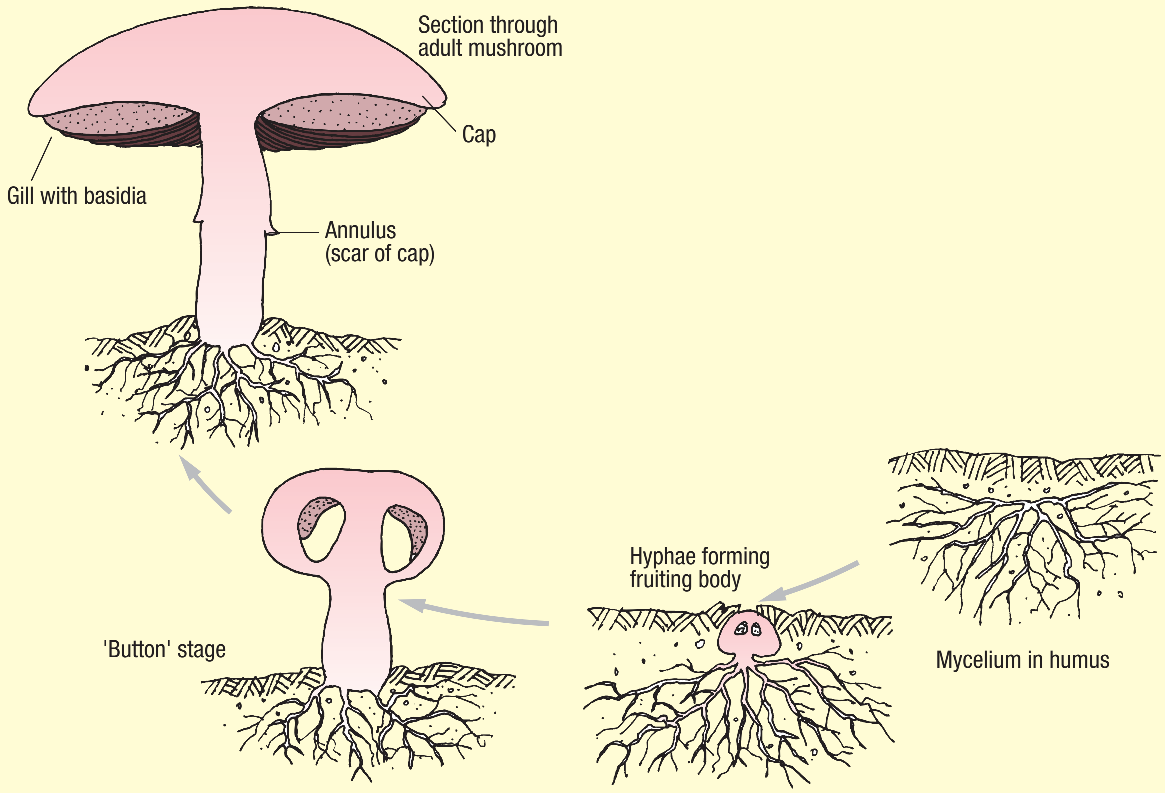


Figure 3.3 Structure of a typical gilled fungus

and asexually. Sexual reproduction involves spore formation inside a structure called an ascus.

Basidiomycota are characterised by the sexual production of spores on the outside of a club-shaped structure called a basidium. This group includes the mushrooms and toadstools, the bracket fungi and puffballs.

Review questions

3.14 Why are fungi grouped in a kingdom by themselves?

3.15 List the three divisions of fungi and name the reproductive structures on which the classification of each is based.

3.16 A mushroom has often been likened to an iceberg in structure. Explain this analogy.

3.4 Lichens

Lichens do not form a strict taxonomic group, but represent a mutualistic relationship between fungi and green algae and/or cyanobacteria. The fungus is an ascomycote or basidiomycote. Lichens have a very wide distribution and are found in all kinds of conditions, ranging from cold, exposed and dry situations to the humid tropics. The body of the lichen is called a thallus, of which there are three kinds:

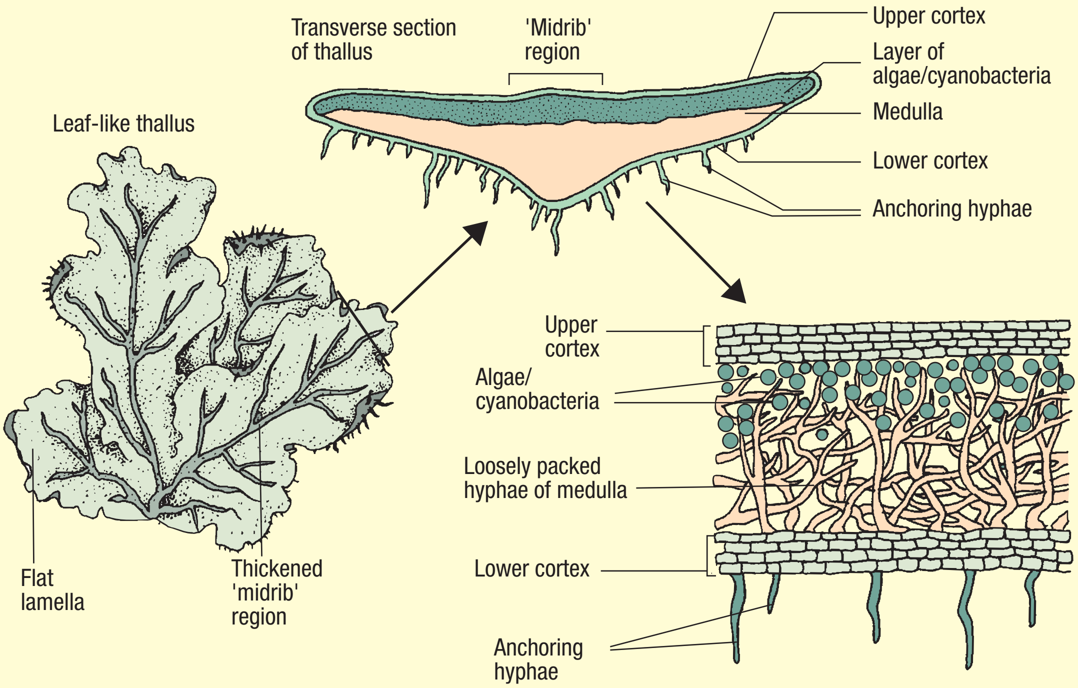
- crustose—encrusting, flattened structures on rocks, soil surfaces and bark of trees
- foliose—spreading and leaf-like
- fruticose—upright with many branches.

The thallus consists largely of an organised network of fungal hyphae from which fruiting bodies may periodically emerge. In its upper layers are many groups of small algae. The association is so intimate that the lichen resembles neither partner, both of which depend for their existence on the other. It is believed that the algae contribute organic food from photosynthesis, while the fungus is able to absorb water and mineral salts and attach the lichen to the substrate.

Lichens are slow growing and sensitive to pollution, particularly sulfur dioxide gas, a common product of industry. They are therefore useful pollution monitors, their numbers and variety increasing as distance from the pollution centres increases. Lichens are very important colonisers of rocky areas. They secrete an acidic substance which helps to erode the rock and so provide small pockets of soil which other plants then utilise. Some species are food for larger organisms. The dye litmus, which is an acid–base indicator, is extracted from species of the lichen *Rocella* found in North Africa.

SUMMARY

Lichens are the product of an obligate, mutualistic relationship between fungal hyphae and green algae or cyanobacteria. They are important colonisers of bare rock and are sensitive to pollution. Some provide a food source for other organisms; others are used in the production of the acid–base indicator, litmus.



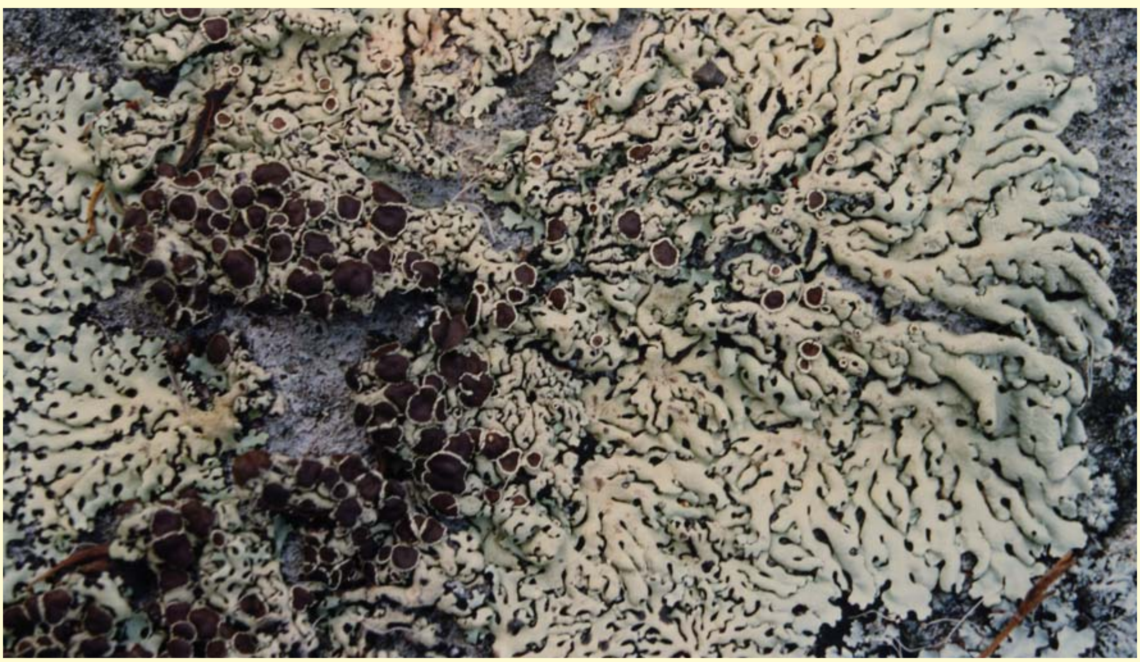


Figure 3.4 A crustose lichen

> **Review question**
>
> **3.17** Why are lichens not placed in a specific taxonomic group?

3.5 Kingdom Plantae

Plants are multicellular, photosynthetic organisms primarily adapted for life on land. Plants have different parts specialised for different functions. They usually have underground structures which are responsible for absorbing water and dissolved mineral nutrients from the soil, while also holding them in position. The above-ground structures tend to be green, because they contain the pigment chlorophyll in their cells; they are responsible for food production by photosynthesis. These structures are arranged in such a way as to maximise their exposure to light. Food produced in the photosynthetic cells moves to the underground parts and provides them with the energy they require to perform their functions.

The above-ground leaves are coated with a waxy material, the cuticle, which limits the amount of water that can be lost from the plant by evaporation. Small openings, the **stomata**, penetrate the cuticle. It is through these openings that gas exchange occurs between the air and the photosynthetic cells. Stomata are usually found on the undersurfaces of the leaves, further limiting evaporative water loss.

Plants have a life cycle where an asexually reproducing generation (the spore-producing sporophyte) is followed by a sexually reproducing one (the gamete-producing gametophyte). This is termed alternation of generations.

Plant cells also show special adaptations for surviving on land. Each cell contains a large vacuole which contains a watery substance, the cell sap. This is important in maintaining the water balance of the living cell and in providing hydrostatic support (i.e. a 'water skeleton') for the plant. The cell is surrounded by a wall composed of cellulose.

There are two distinct groups of plants—the bryophytes and the vascular plants. The bryophytes are all small plants that are limited to moist environments. Without a vascular system to transport water from the soil to the photosynthetic areas, they have to rely mainly on the ability of the cell walls to draw moisture from place to place between the soil and the outside of the rest of the plant. This same action can be observed when using paper to blot up water on a table. Although this capillary action is quite strong, the effects of gravity limit the extent to which the water can ascend upwards and thus the height of the plant. The gametophyte generation is the most obvious phase in the life cycle of these plants. The body of the plant (called a **thallus**) is anchored to the ground by fine threads called rhizoids. During sexual reproduction, the male gamete must swim to the female gamete through a film of water on the outside of the plant. This again limits these plants to a moist environment.

Vascular plants, as their name suggests, possess systems of vessels or tubes which enable rapid transport of materials around the plant. There are two types of vascular tissue. **Xylem** conducts water with dissolved minerals from the soil to the photosynthetic cells. **Phloem** transports organic compounds around the plant. Vascular tissue consists of supporting tissues and elongated cells placed end to end to form 'tubes'. The end walls of these cells are perforated, allowing movement of material from cell to cell along the tube. In xylem the conducting cells are no longer living and the cellulose walls are impregnated with a rigid material called lignin. Phloem, in contrast, consists of living cells.

The possession of an efficient transport system meant that the vascular plants could grow larger and extend their subterranean parts deeper into the soil to search for water. These plants could grow in drier parts of the land than their non-vascular counterparts. Thus the bryophytes are restricted to areas of abundant water supply, whereas the vascular plants have diversified and can grow in less hospitable areas.

The dominant phase of the vascular plants is the sporophyte generation. The presence of the vascular system has allowed the development of true **stems**, **roots** and **leaves**.

In the ferns the stem is usually a horizontal, underground rhizome. The leaves are relatively large and called fronds. Spore-producing sporangia are borne in clusters (each cluster called a **sorus**) on the undersurface of the frond. Spores germinate to form a small non-vascular gametophyte. Water is needed for the sperm cells to swim to the female structure, thus the habitat of most ferns is limited.

The seed plants have highly developed vascular tissue and a very reduced gametophyte generation. The female gametophyte, the ovule, remains embedded in the reproductive tissues of the sporophyte and, after fertilisation, develops into a seed. The male gametophyte is the pollen grain. The two main groups of seed plants are the **gymnosperms** in which the reproductive structure is a cone and the flower-bearing **angiosperms**.

Table 3.3 Types of plants

KINGDOM PLANTAE	• Terrestrial, photosynthetic eukaryotes • Cells contain chlorophyll in chloroplasts • Cells have large vacuoles containing cell sap • Cells surrounded by rigid cell walls of cellulose • Carbohydrates stored as starch • Fertilisation is internal, within the female reproductive structure	
DIVISION BRYOPHYTA Mosses and liverworts	• Body a thallus differentiated into simple 'stem' and 'leaves' • Thallus only a few cells thick • Simple root-like rhizoids anchor the plant and obtain water and nutrients for the plant • Alternation of generation—sporophyte anchored to and dependent upon the gametophyte (dominant form) for nutrition • Live mainly in damp, shady places	 e.g. liverwort
DIVISION PTERIDOPHYTA Clubmosses, horsetails, ferns	• Alternation of generations with a reduced gametophyte and prominent sporophyte generation • Sporophyte, a vascular plant with true roots, stem (an underground **rhizome**) and leaves (**fronds**) • Fronds bear spore-producing structures on their underside	  e.g. clubmoss e.g. fern
DIVISION SPERMATOPHYTA Seed-producing plants	• Complex vascular tissue in roots, stems and leaves • The gametophtye generation greatly reduced—the **ovule** in the female and **pollen grain** in the male • On fertilisation the ovule develops into a seed	
CLASS GYMNOSPERMAE Cone bearers	• Seed not enclosed in ovary • Reproductive structure is the cone • No fruit • Needle-like leaves	 e.g. pine
CLASS ANGIOSPERMAE Flowering plants—grasses, herbs, shrubs or trees	• Seed enclosed in ovary which develops as a fruit • Reproductive structure is the flower • Display a wide variety of flower and leaf structures	  e.g. everlasting daisy; iris

- **Sporophyte generation**—the asexually reproducing, spore-forming generation of a plant.
- **Gametophyte generation**—the sexually reproducing, gamete-forming generation of a plant.

SUMMARY

The characteristics of plants are related to their terrestrial mode of life. They have cells which:

- contain chlorophylls *a* and *b* in chloroplasts
- are enclosed by a wall composed of cellulose
- contain large fluid-filled (sap) vacuoles
- store carbohydrates in the form of starch.

In addition, plants have:

- a waxy coating (the cuticle) that covers the leaves and reduces water loss due to evaporation
- specialised openings (stomata) in the leaves that allow gas exchange but also allow water loss
- reproductive organs that protect the gametes and spores from drying out
- retention of the fertilised egg within the female reproductive organ during its development into an embryo, thus reducing dehydration
- a complex life cycle which alternates a sexually reproducing generation with an asexually reproducing generation.

Bryophytes include the mosses, liverworts and hornworts. They are non-vascular plants. The gametophyte generation is the dominant phase of the life cycle.

The vascular plants include the spore-producing pteridophytes (ferns and their allies) and the seed-producing spermatophytes. In both of these groups the sporophyte generation is dominant with true roots, stems and leaves. The two major groups of seed plants are separated on the basis of their reproductive structures. The gymnosperms produce cones, while the angiosperms produce flowers.

Review questions

3.18 How is the presence of a cuticle an adaptation to living on land?

3.19 Describe features of plant cells which are significant to the existence of plants as terrestrial organisms.

3.20 What features of the bryophytes restrict their size?

3.21 In what ways are the ferns better adapted for life on land than the mosses?

3.22 People who buy ferns as ornamental house plants sometimes return them to the nursery because there are dark spots on the undersurface of the leaves. As a biologist, what would you tell the customers?

3.23 Name the male and female gametophytes of seed plants.

3.24 What is a seed?

3.25 Name the reproductive structure of the conifers.

3.26 How would you distinguish between a fern, a conifer and a flowering plant?

3.27 Differentiate between pollen, seed and fruit.

3.6 Kingdom Animalia

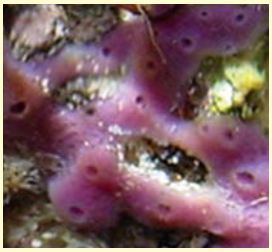
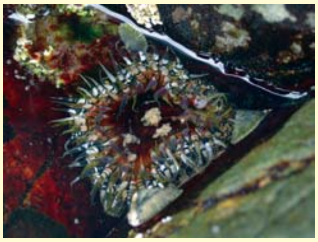
Animals are multicellular, heterotrophic organisms which exhibit locomotion at some stage in their life cycle. Animals depend directly or indirectly on plants and algae for their nourishment which they typically ingest. This means they eat other organisms or decomposing organic material either whole or in pieces. Most animals digest their food in an internal cavity and store excess food reserves in the form of glycogen or fat. The fundamental structure of most animals, therefore, is a tube (the alimentary canal) within a tube (the body wall).

The cells of animals, unlike other eukaryotes, lack surrounding cell walls. Except for the sponges, they are generally differentiated into tissues which are usually organised into structural and functional organs. Groups of organs form systems specialised for such functions as digestion, internal transport, gas exchange, coordination, excretion, movement and reproduction.

Animals must either seek out their food or have strategies to bring food to them. Either the entire organism needs to be mobile or parts of it must be able to move independently. Movement is achieved by specialised contractile (muscle) cells and requires some form of coordination which is usually controlled by nerve cells.

Reproduction in animals is typically sexual. Generally a small flagellated sperm, produced in the male gonads, fertilises a larger, non-motile egg to form a zygote. The zygote undergoes a series of cell divisions and differentiation in the process of embryonic development to produce a new individual. In some species the animal develops directly, through stages of maturation, into an adult. In others the life cycle may include larval stages. A larva is a free-living, sexually immature form which is different in appearance from the adult, usually eating different food and even living in a different habitat. Such larvae eventually undergo metamorphosis, a process which changes them into sexually mature adults.

Table 3.4 The animal kingdom

KINGDOM ANIMALIA	• Heterotrophic eukaryotes • Exhibit locomotion, at least at some stage of the life cycle • Cells lack cell wall and contain small vacuoles only • Carbohydrates are stored as glycogen	
PHYLUM PORIFERA Sponges	• Aquatic—mostly marine • No true tissues • Two layers of cells surround a central gastric cavity lined with flagellated cells that draw water and microscopic food through pores in the body wall • Body supported by spicules or fibres • May be solitary or colonial • Asymmetry	 e.g. pink sponge
PHYLUM CNIDARIA Hydroids, sea anemones, jelly fish, corals	• Aquatic—mostly marine • Body composed of many varied cells in two layers • Radial symmetry • Gastrovascular cavity with single opening to outside • 'Mouth' surrounded by tentacles containing stinging cells (**nematocysts**) • Two body forms – a motile **medusa** (jelly fish) and attached **polyp**	 e.g. anemone
PHYLUM PLATYHELMINTHES Flatworms	• Body flattened dorso-ventrally • Bilateral symmetry • Body consists of three cell layers • Acoelomate • Gut, when present, branched with single opening	 e.g. flatworm
PHYLUM NEMATODA Roundworms	• Uniformly cylindrical, elongated body tapered at both ends • Body of three tissue layers • Pseudocoelom • Bilateral symmetry • Two body openings	 e.g. roundworm
PHYLUM MOLLUSCA Shellfish	• Soft body composed of a head, visceral mass and foot • Body often covered by a shell • Three cell layers with a coelom • Bilateral symmetry	 e.g. giant land snail

PHYLUM ECHINODERMATA
Spiny skinned animals—starfish, sea urchin, sea cucumber

- All marine
- Pentameric symmetry
- Water vascular system part of the coelom from which extend tube feet ending in suckers
- Spiny skin

e.g. starfish

PHYLUM ANNELIDA
Segmented worms

- Cylindrical, segmented, elongated body
- Bilateral symmetry
- Three cell layers with coelom
- Bristles composed of chitin typically present

e.g. leech

PHYLUM ARTHROPODA
Joint-legged animals

- Segmented, coelomate body (haemocoel)
- Bilateral symmetry
- Chitinous, jointed exoskeleton covers entire body
- Legs jointed
- Double, solid, ventral nerve cord

Class Crustacea
Crab, prawn

- Mainly aquatic
- Body divided into cephalothorax and abdomen
- One pair of compound eyes on stalks
- Two pairs of antennae
- Many pairs of specialised appendages

e.g. soldier crab

Class Diplopoda
Millipede

- Terrestrial
- Distinct head with elongated trunk
- Simple eyes
- One short pair of antennae
- Trunk segments fused in pairs so there appears to be two pairs of legs per segment

e.g. millipede

Class Chilopoda
Centipede

- Terrestrial
- Distinct head with elongated trunk
- Simple eyes
- One short pair of antennae
- One pair of walking legs per segment; first pair modified as poison claws

e.g. centipede

Class Insecta
Insects

- Mainly terrestrial
- Head, thorax and abdomen
- One pair of compound eyes, not on stalks
- One pair of antennae
- Three pairs of thoracic legs; two pairs of wings typically present on abdomen

e.g. fly

Class Arachnida
Spider, mite, tick

- Terrestrial
- Cephalothorax and abdomen
- Simple eyes
- No antennae
- Four pairs of thoracic legs

e.g. huntsman spider

PHYLUM CHORDATA

At some stage in the life cycle possess:

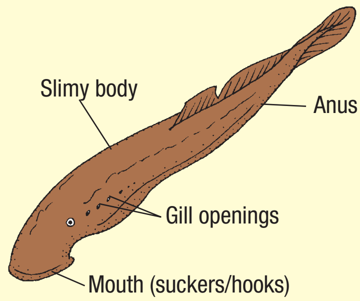
- **Notochord** (a solid, internal stiffening rod)
- Hollow dorsal nerve cord
- Paired pharyngeal gill slits
- Post-anal tail

SUB-PHYLUM VERTEBRATA
Vertebrates

- Notochord partly or wholly replaced by vertebral column in adults
- Clearly differentiated head with brain enclosed in a cranium
- Muscular ventral heart

Class Agnatha
Jawless fish

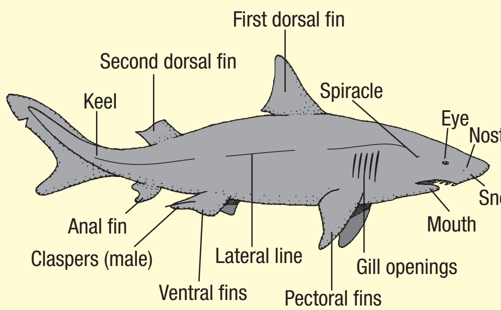
- Slimy skin
- No paired limbs
- No jaws
- Gill slits
- Weak, cartilaginous skeleton



e.g. lamprey

Class Chondrichthyes
Sharks, rays

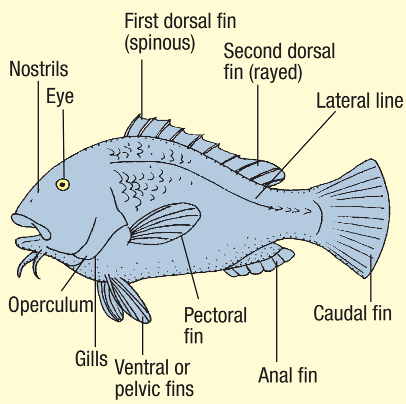
- Teeth-like scales of dentine
- Paired fins
- Gill slits
- Cartilage skeleton



e.g. shark

Class Pisces
Bony fish

- Scales of bone
- Paired fins
- Gill slits covered by operculum
- Bone skeleton



e.g. bony fish

Class Amphibia Frogs, salamanders	• Soft skin • Paired pentadactyl limb • Pharyngeal gills in tadpole, lungs in adult • Bone skeleton	 e.g. great barred frog
Class Reptilia Snake, lizard, turtle, crocodile	• Skin dry with horny scales and/or bony plates • Paired pentadactyl limbs (may be secondarily lost) • Bone skeleton • Lungs	 e.g. water dragon
Class Aves Birds	• Skin with feathers; legs with horny scales • Paired pentadactyl limbs, front pair modified as wings • Bone skeleton • Lungs	 e.g. black duck
Class Mammalia Mammals	• Skin bears hair with two types of glands • Lungs • Pinna (external ears) • Bone skeleton • Lungs • Mammary glands • Muscular diaphragm separates thorax from abdomen • Two pairs of pendactyl limbs	 e.g. kangaroo and joey

- **Radial symmetry**—the arrangement of body parts around a central axis so that division of the body across any diameter results in two similar halves which are mirror images.
- **Bilateral symmetry**—a body form where the right and left sides are approximate mirror images of each other.
- **Pentameric symmety**—the arrangement of the body around a central axis with five'spokes', thus five mirror images result from division of the body across any one of these diameters. Only the starfish and some of their allies show pentameric symmetry, and they start their development as bilaterally symmetrical. These organisms have a dorsal and a ventral surface.
- **Layers of cells** Early in embryonic life, cells group together and become arranged in layers which form the basic tissues:
  – ectoderm on the outside forms skin and nerves
  – endoderm on the inside forms the gut lining and its glands
  – mesoderm is found between these two layers and forms muscles, blood, the skeleton and other organs.
- **Body cavity** Animals with three layers of embryonic cells may develop a body cavity (**coelom**). In animals without a body cavity (**acoelomate** animals) the alimentary canal, or gut, in which digestion occurs is a simple sac with one opening. Movement of food within it depends upon the movement of the entire body. A body cavity allows the outer body wall to be separated from the alimentary system. Animals with a body cavity have a one-way alimentary canal with a mouth for ingestion of food and a separate anus for egestion (expulsion) of undigested food. The cavity may form between the mesoderm and the endoderm (**pseudocoelomate** animals). A true coelom forms within the mesoderm, with the result that muscle is associated with both the outer body wall and the gut. In these animals the gut can become specialised.
- **Segmentation** Animals with three cell layers may be segmented. During embryonic development their body is made up of a series of segments which at first are similar. Certain segments may become fused or specialised for a specific function, in which case segmentation may not be obvious externally. Segmentation has allowed modification and adaptation of various parts of the body, for example the modification into head, thorax (chest) and abdomen.
- **Exoskeleton** Structural support (skeleton) found on the outside of the animal.
- **Endoskeleton** Skeleton found within the animal.
- **Pentadactyl limb** Limb structure found in four-legged animals which ends in a five digit arrangement of fingers or toes. Fusion or loss of some of the elements of the limb may occur in some species.

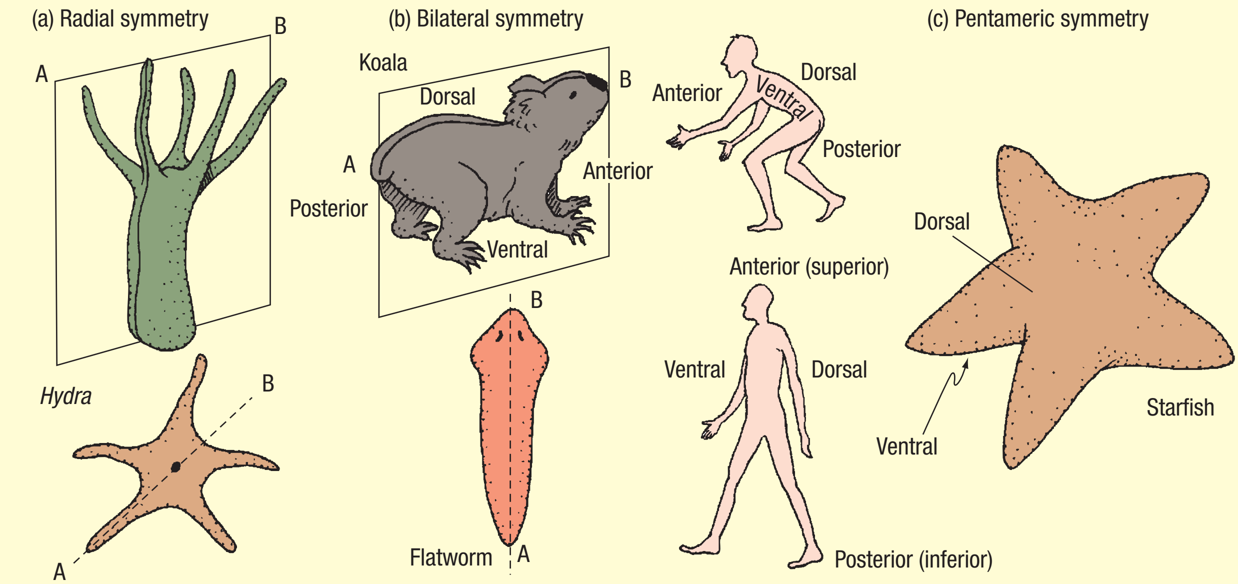


Figure 3.5 Symmetry in animals

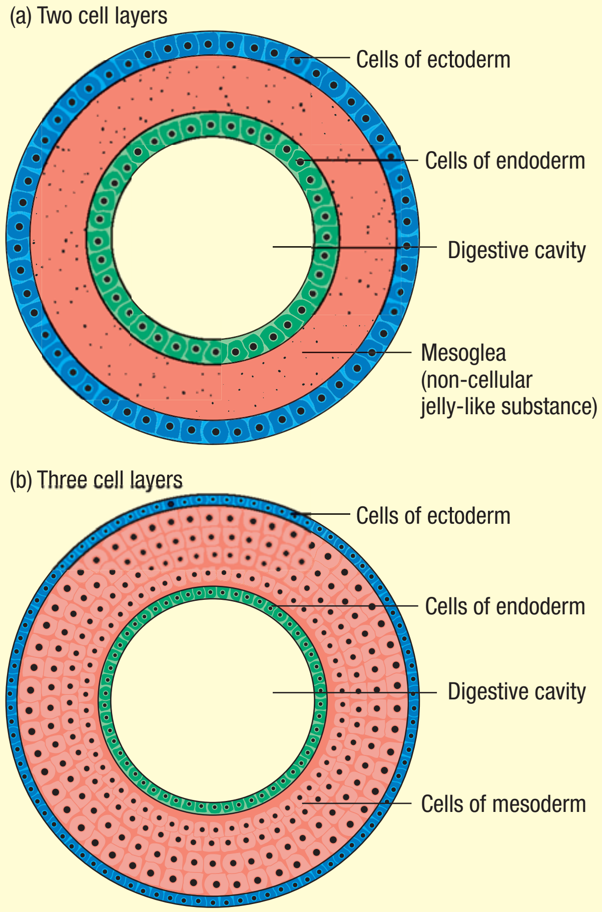


Figure 3.6 Transverse sections to show the number of cell layers in the body plan

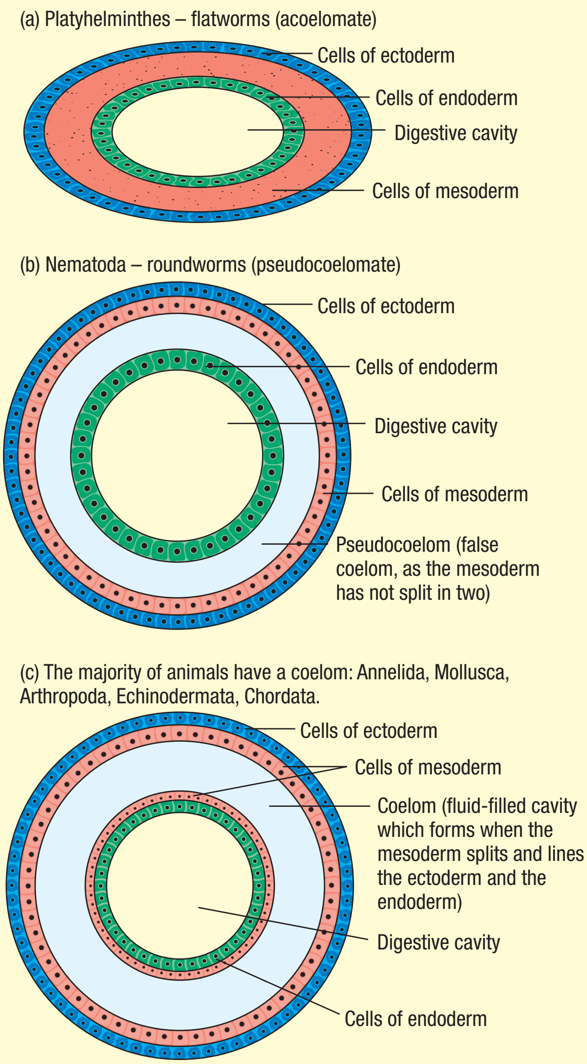


Figure 3.7 Transverse sections showing the arrangement of body cavities in three-cell-layered animals

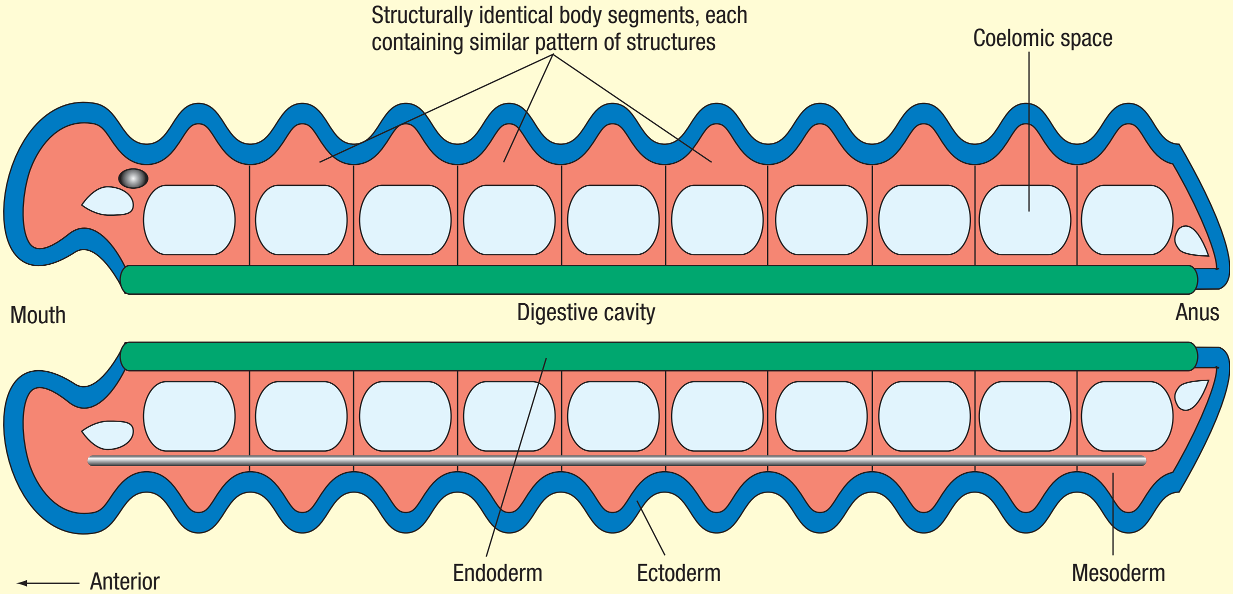


Figure 3.8 Longitudinal section showing the unmodified segmented body plan.

SUMMARY

Animals are heterotrophic eukaryotes which typically ingest food. Excess food is stored as glycogen and fat. Their cells, which lack cell walls, are organised into tissues in all except sponges. Organs and organ systems are specialised to perform specific functions in most other animals. Movement is typically achieved by special contractile cells coordinated by nerves. Reproduction is usually sexual, with the fertilised egg, or zygote, undergoing embryonic development to form either an immature adult or a larva which, after a period of independent living, undergoes metamorphosis to the adult form. Classification is based on the number of embryonic cell layers present, type of body cavity, segmentation and skeletal formation.

Review questions

3.28 Which features distinguish animals from all other organisms?

3.29 Why is mobility an important feature of animals?

3.30 Distinguish between radial and bilateral symmetry.

3.31 Into which phylum would you place an animal that has: an alimentary canal capable of independent movement which is separated from the outer body wall by a fluid-filled space; and a body with head, torso and limbs supported by an exoskeleton? Explain your answer.

3.32 A sponge that has been broken up in a blender, put through a sieve and then placed in a suitable environment will re-form into a sponge organism. What features of the sponge allow this to occur?

3.33 Describe the diagnostic features of the phylum Cnidaria.

3.34 During rainy periods a beautiful blue-striped, black, ribbon-shaped organism, about 10 cm long and 0.5 cm wide, can be found gliding along the forest floor in parts of south-east Queensland. Its surface is quite moist, to the point of being sticky, and it appears to have a definite front and rear end.

(a) Suggest the phylum to which this organism belongs.

(b) What other features would you need to observe (by microscopic examination or dissection, if necessary) to be sure that your answer was correct?

3.35 What features would you use to distinguish a nematode from an annelid?

3.36 An organism was found that had a jointed exoskeleton and its body in two main divisions—a cephalothorax and abdomen. It possessed six simple eyes and had four pairs of thoracic legs. Classify this organism to phylum and class, giving reasons for your classification.

3.37 How do the echinoderms differ from all other invertebrates?

? **3.38** What features are exhibited by all chordates?

3.39 Not all chordates are vertebrates. Explain this statement.

3.40 List one external feature diagnostic of each of the vertebrate classes.

EXTENDING YOUR IDEAS

1. UB 'Fairy rings' of mushrooms are often found on lawns after a wet period. Using your knowledge of fungal structure, explain this phenomenon.
2. UB A certain fungus produces four types of spores. Data obtained after studying spore production and germination are shown in Figure 3.9.
   (a) The information on the production and germination of spores tends to indicate that this specific species is reproductively best adapted to a:
   A. tropical climate
   B. hot desert environment
   C. region similar to that of Hobart
   D. climate of extremes of temperature.
   (b) The spore type which is least tolerant to temperature variation is:
   A. type I
   B. type II
   C. type III
   D. type IV.
   (c) The most temperature-tolerant germinating spores are:
   A. type I
   B. type II
   C. type III
   D. type IV.
3. UB Embryos of land plants are given some protection by the parent plants. Algal embryos develop in the water. Suggest reasons for this difference.
4. UB Vascular plants are characterised by a chemical known as lignin, which stiffens and supports the plant body as it grows upward towards light. What is the primary source of support for the photosynthetic portions of the multicellular seaweeds?
5. UB Compare and contrast the holdfast in algae, rhizoids in mosses, rhizomes in ferns and roots in flowering plants.
6. IB Arthropods are found in all environments and are the only invertebrates to adapt successfully to life on land. A key factor to their success is the cuticle which serves as a skeleton, covers the body surface and, in many insects, forms wings. One of the most critical functions of the cuticle is to limit water loss from the animal.

   The cuticle is secreted by the outer layer of body cells and has two main layers—the inner procuticle and outer epicuticle. The procuticle consists of a complex of sugar (chitin) which gives strength and flexibility, and protein which forms a binding matrix but reduces flexibility. Different proteins (and/or proportions of protein to chitin) can produce different properties of stiffness, elasticity and stretchability of the cuticle. In the process of sclerotisation, proteins are changed so that they become water-insoluble and darkened. This process stiffens the cuticle. If sclerotisation of the exoskeleton occurs with deposition of minerals (e.g. zinc), an extremely hard and strong structure is formed. The protein resilin forms a rubber-like cuticle and is found in regions where elasticity is necessary. Soft cuticle is highly flexible and stretchable because the proteins are not sclerotised.

   The outer epicuticle is rich in lipids which form the primary barrier to water loss. The upper surface (cuticulin) is sculptured. A relatively flat surface makes the animal glossy. The presence of microscopic knobs, spines or folds reduces the reflection of light from the surface and makes the animal

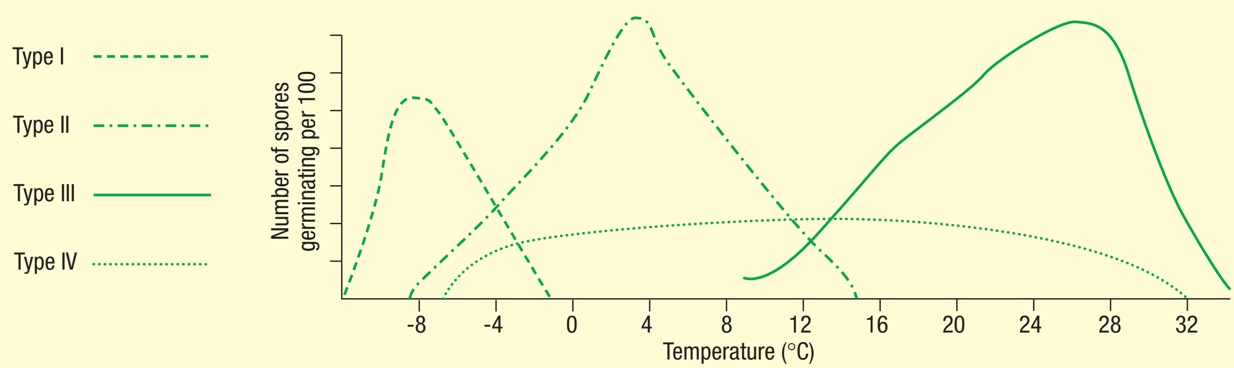


Figure 3.9 Spore production by a fungus

(a)

(b)

Figure 3.10 Rainforest plants

appear dull. Some species have heavy wax deposits (blooms) on their surface. The depth of this bloom has been shown to vary with climatic conditions in some species and is significant in water and temperature control. Light-coloured waxes reflect solar radiation. Some surface waxes produce elaborate colours and patterns.

(a) A beetle has very hard outer wings and fine (flying) underwings which are firm when extended but capable of being folded. Describe the possible composition of the cuticle for each type of wing.

(b) Some insects are able to survive well in desert conditions. Suggest the composition of cuticulin in these species.

(c) The hind appendages of the flea are used in jumping. They have special energy-storing pads at their tips to enhance jumping. What type of cuticle would you expect to find in these pads?

(d) Mandibles are mouthparts with a biting function found in arthropods. Some beetles are capable of cutting through such metals as lead and copper. What conclusions can you draw about the cuticle composition of these mandibles?

7. UB Carefully observe photographs (a) and (b) in Figure 3.10, which were taken by a student during a rainforest excursion.

   Although in different divisions, these organisms have features in common. Discuss these with reference to the photographs.

8. IS The only reliable means of identifying the different species of snake is to examine the body scales. Figure 3.11 shows the common types of scales on the various parts of the body and how they are counted.

   Both the freshwater snake (a completely harmless species) and the dangerous rough-scaled snake are found in the Upper Brookfield area on the outskirts of Brisbane. Superficially they are very similar, but they have different scale counts:

   Rough-scaled: mid-body 23, keeled dorsally, smooth laterally; ventrals 165–82; anal single; sub-caudals 50–54, single.

   Freshwater: mid-body 15, strongly keeled; ventrals 140–160; anal paired; sub-caudals 50–80, paired.

   Which two diagrams in Figure 3.12 illustrate the scale types of the freshwater snake? Give reasons for your answer.

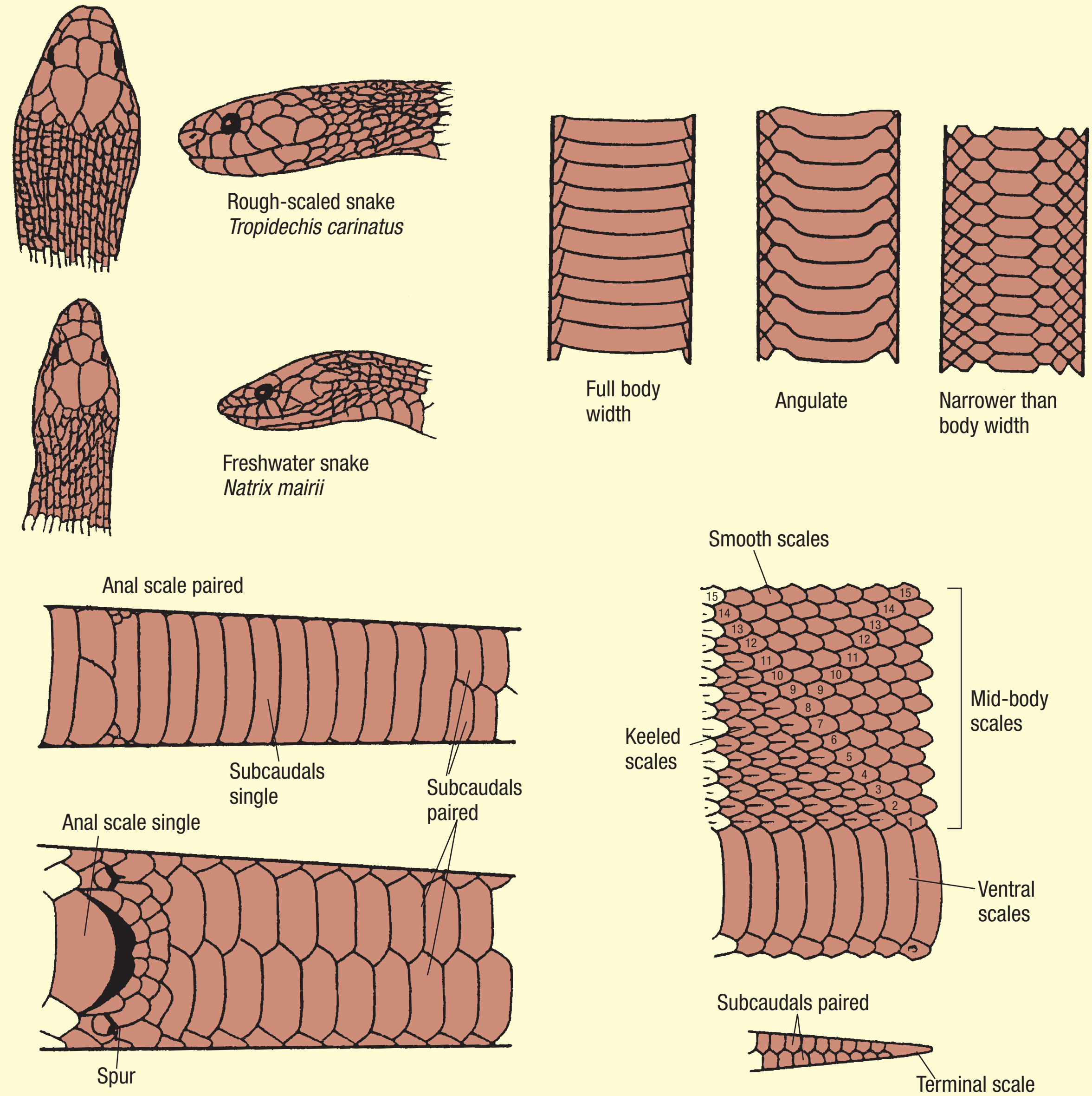


Figure 3.11 Features of the rough-scaled and freshwater snakes

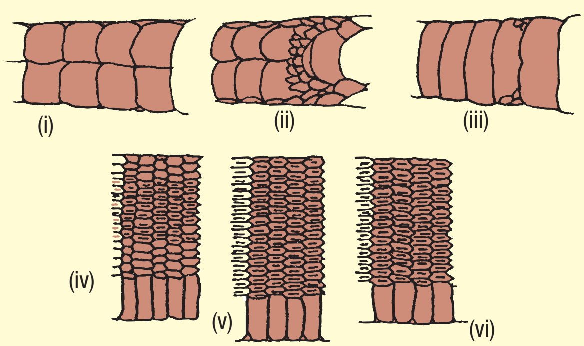


Figure 3.12 Scale features

4 Phylogenetic relationships

4.1 Underlying assumptions

This chapter will explore possible pathways in the development of the huge variety of organisms that exist today. Although it is not possible to physically go back millions of years in the past to actually see what happened at that time, evidence from observable phenomena linked to records locked into the earth's surface can give a highly probable picture of past events. Several underlying ideas are inherent in such a biological discussion. These will be described in greater detail in later chapters, as will the processes by which they bring about change, and include the following:

- The DNA molecule contains sequences of chemicals (genes) that are codes for the production of specific proteins. These proteins are responsible for the characteristics of an organism. The DNA molecule is the same in all living organisms. Differences in organisms are due to the number of DNA molecules and the exact sequencing of the sub-units making up the molecule. Humans, for example, have some genes that are the same as some bacterial genes.
- Within all members of a species there are the same types of genes. The exact specifications of the gene, however, may be slightly different. For example, in a particular plant a gene controls the characteristic of chlorophyll in the cells of the leaves. Some individuals, however, might produce less chlorophyll than others. The 'greenness' of their leaves would be different from others of their species. Changes in the structure of the gene are called mutations. Many factors, some environmental and other errors in cell activities, bring about mutations which occur regularly and randomly with respect to any particular gene. They are the cause of variations within a species. Mutations may have a beneficial, neutral or negative impact on the individual. If the mutation occurs in the reproductive cells of the individual, it can be passed on to future generations.
- All organisms are a result of reproduction of another organism. During reproduction genetic information is passed from parent(s) to offspring through the DNA. Individuals resulting from asexual reproduction will have exactly the same genes as the parent. They are **clones**. The only variations that are possible are a result of mutations. Sexual reproduction allows recombinations of variations of genes from each parent, even though they have the same types of genes. Thus these offspring can look and behave somewhat differently from either parent.
- There is competition for resources among the members of a species in a particular area. Those members of the group that are better able to use these resources will have a greater chance of surviving and producing and caring for offspring. The features they possess that give them this competitive edge may be passed on to their offspring. Members of the group without this ability will either die or be less likely to reproduce successfully. After time, some gene variations may disappear from the group.
- An adaptation is a feature that an organism possesses that allows it to survive in its environment. For example, insectivorous bats and kangaroos are both mammals. These bats catch insects in flight. The bat's teeth are all sharp prongs that prevent the insect escaping prior to being swallowed. The kangaroo, on the other hand, is a grass eater. It needs to cut off the grass and grind it up into small pieces prior to

Figure 4.1 The ability to roll the tongue is genetically determined.

(a) (b)

Figure 4.2 Teeth of (a) a bat and (b) a kangaroo

swallowing. Its front teeth are chisel-shaped cutting tools, while the back teeth have flat surfaces with sharp ridges that aid grinding. Both sets of teeth are adaptations for food gathering.

- The survival of one type of organism is dependent upon both the physical environment in which they live and other types of organisms. During an extended drought there will be a dramatic decrease in water availability. The plants in the area are likely to die back, leaving the plant-eating animals without food. Their numbers will be dramatically reduced. This will result in death of carnivores as their food and water supplies dwindle. Although the increased number of dead animals will be a boon for the scavengers, ultimately lack of water will also decrease their numbers.

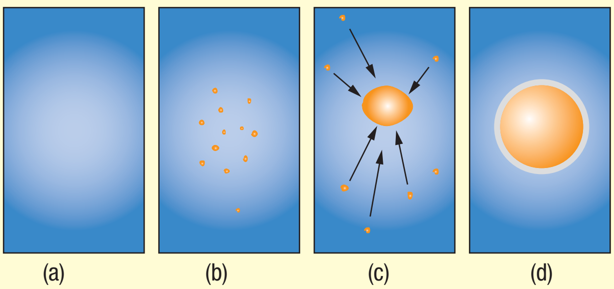
Figure 4.3 The effect of drought on kangaroos

- The environment of a particular species is subject to constant change. This change may be as a result of the species' activities. It takes in certain materials from the environment and eliminates other materials. Over time this may mean that the environment is no longer a suitable place for the survival of that species. The change can be seasonal, with changes in temperature and rainfall. Dramatic changes can occur as a result of prolonged drought, flooding or severe storms. Earth movements resulting in volcanoes or earthquakes can bring about catastrophic change to an environment, as can the impact of large meteorites.
- Those members of a species with certain variations to their characteristics will be better adapted to changing environments than other members of their group. They are more likely to survive.
- Different groups of a species are usually spread over a large area. Since each part of that area is unlikely to be exactly the same, each group could have slightly different variations in their genes. If something prevents the groups from reproducing with each other, new variations could develop in each group as a result of mutations. Over time these variations could become so different that the groups could no longer interbreed. They form new species.

4.2 Early earth

4.2.1 The formation of earth

One hypothesis states that life on earth came into existence only about 4 billion years ago. It is thought that this planet was formed, along with the rest of the solar system, about 4.6 billion years ago by the condensation of huge whirling clouds of cosmic dust and gases. Initially, particles probably collected at random, but as their mass increased other particles would have been pulled towards them by gravitational effects. As earth formed, the increased density created great pressure and heat, causing the planet to liquefy. This resulted in heavy elements (iron and nickel) concentrating in the centre as the core, with lighter materials remaining at the surface. Convection currents within this liquid mass released heat and gases from the surface. A thick, solid crust and a gaseous atmosphere were formed. The moving liquid mass underneath continued to push against the crust, and gases and molten material escaped through cracks in the surface. Sections of the crust were violently pushed against each other, causing folding and buckling of the surface. On some parts of the crust mountains were formed, on others huge basins, and in some places the crust sank back into the mantle and was re-liquefied.



(a) Cosmic dust grains collide and stick together and (b) move into the centre of the cloud, where they further clump together. Smaller particles (c) are attracted to larger ones, which collide and form the nucleus of a planet. This then attracts cosmic gases to its surface (d).

Figure 4.4 Possible events in the formation of the earth

Although the atmosphere contained the gases carbon dioxide, hydrogen, water vapour, methane and ammonia, little or no free oxygen is believed to have been present. For thousands of years rain storms covered the earth and lightning flashing through the atmosphere discharged large amounts of electrical energy. The rain caused erosion of the crust, and minerals dissolved in the water that collected in the basins. The oceans were born.

4.2.2 The first life forms

It is suggested that methane, carbon dioxide and ammonia from the atmosphere dissolved in the rain as it fell into the seas and that the energy from the sun and lightning was adequate for the formation of the first organic molecules. Once these simple organic molecules were formed, some of them clumped together and underwent further chemical reactions to form complex molecules—the building blocks of living things. Phospholipids were one of the types of complex chemicals that formed. Each molecule of phospholipid has a hydrophilic (water-attracting) head and a hydrophobic (water-repelling) tail. The only way that these molecules can form a stable structure in a water-based solution is for them to form a double-layered sphere with the hydrophobic tails sandwiched between the hydrophilic heads. As they did this they trapped some of the clumps of molecules and their watery environment inside the sphere. Further reactions within the 'droplets' resulted in a structure with characteristics different from their surroundings.

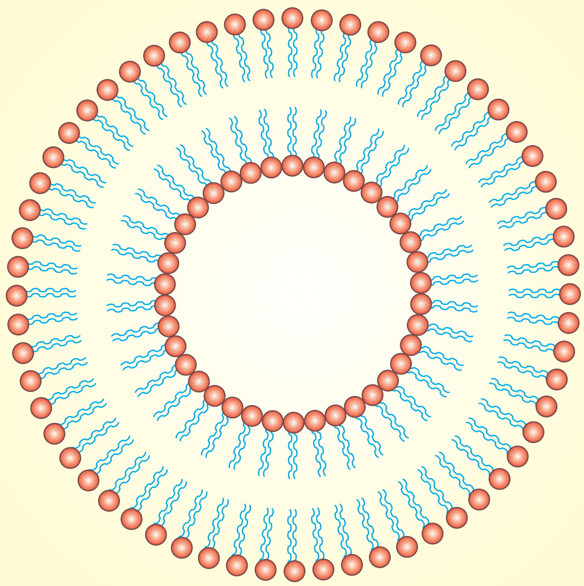


Figure 4.5 A microsphere of two layers of phospholipid molecules, enclosing, and surrounded by, a watery environment

Either before the 'droplet' stage or during its development came the ability of nucleic acids to replicate. The first living cells were ordered groups of chemicals which could reproduce and metabolise. They were very simple, distinctive chemicals bound together by a membrane which separated them from their surroundings. Such cells, with no internal compartments, are termed prokaryotic. Since it is highly likely that many different types of DNA were formed at this time, it can be assumed that not all of the cells formed were exactly the same. Right from the beginning there were probably different 'species' of cell.

Present-day prokaryotic cells include the archaebacteria, bacteria and cyanobacteria. The high levels of ultraviolet radiation believed to be present at that time would have caused many mutations (changes) in the nucleic acids, leading to further differences in types.

According to this theory the first living forms came into being by **abiogenesis** (i.e. from non-living matter) under very special circumstances related to the conditions that existed at that time. These organisms were either heterotrophic, feeding on the existing organic matter from which they had been formed in the primordial sea (sometimes referred to as a 'soup'), or chemosynthetic, using energy released by reactions to power the production of their organic molecules. Chemosynthesis exists in two forms—fermentation (where complex organic molecules are absorbed and then broken down to produce energy, often with the release of methane gas) or sulfate reduction (where energy is produced by the removal of oxygen attached to sulfur atoms with the subsequent release of hydrogen sulfide gas).

Fermentation can follow two different pathways as seen below, each releasing a small amount of energy:

glucose ⟶ pyruvate ⟶ lactic acid + a small amount of energy

glucose ⟶ pyruvate ⟶ ethanol + carbon dioxide + a small amount of energy

The carbon dioxide released in the second pathway can then be used by methane-producing bacteria (methanogens) by combining it with hydrogen, again deriving small amounts of energy in the process:

$$\text{organic molecules} \xrightarrow{\text{Fermentation}} \text{carbon dioxide}$$

$$\text{carbon dioxide + hydrogen} \xrightarrow{\text{Methanogens}} \text{methane}$$

In reduction reactions:

$$\text{sulfuric acid} \xrightarrow{\text{Reduction}} \text{hydrogen sulfide + oxygen + small amount of energy}$$

The evolution of the energetically more efficient process of photosynthesis represented an important breakthrough that altered the environment profoundly. In this process, pigments capture and transform the energy from sunlight into chemical energy that can then be used to convert simple inorganic molecules into sugars. In most photosynthetic bacteria (green and purple bacteria), the chemical energy transformed by their pigments is used to convert hydrogen sulfide and carbon dioxide into simple sugars and release sulfur:

$$\text{hydrogen sulfide + carbon dioxide} \xrightarrow{\text{Energy from sunlight}} \text{sugar + sulfur}$$

A different kind of chlorophyll pigment originated in the cyanobacteria. This allowed the conversion of water and carbon dioxide to sugar. This pigment, chlorophyll a, is also used to drive the photosynthetic process in algae and plants:

$$\text{water + carbon dioxide} \xrightarrow{\text{Energy from sunlight}} \text{sugar + oxygen}$$

4.2.3 Experimental evidence for the origins of life

Oparin (from Russia) and Haldane (from Britain) independently developed the theory of the origins of life in the 1920s but it was not tested until 1953. Two American scientists (Miller and Urey) produced simple amino acids (the building blocks of proteins) in the laboratory by circulating methane, ammonia, water vapour and hydrogen in a container through which they passed electric sparks (representing lightning). They successfully simulated the conditions on earth before the existence of life, according to Oparin's description.

Since that time all known amino acids, several sugars, lipids and the bases of the nucleic acids have been produced in the laboratory in conditions similar to that proposed for the ancient earth. When oxygen is introduced into the 'atmosphere', however, the types of organic chemicals which can be formed are limited. This suggests that the first life forms were anaerobic heterotrophs. The fact that many existing bacteria have this characteristic and will die in the presence of oxygen further supports this claim.

Recent experiments have shown that simple organic molecules can form more complex ones when they are dripped onto hot sand, clay or rock. It is thought that clay may have been particularly important in the formation of the complex molecules in the primordial sea, since clay has special properties that appear to help organic molecules to bind together. Discoveries of complex communities, with bacteria forming the base of the food web, surrounding extremely hot vents in the deep ocean floor add further support to this idea.

In further laboratory experiments, scientists have produced 'droplets' of chemicals which can respond to different environmental conditions—take in or release water, metabolise and divide.

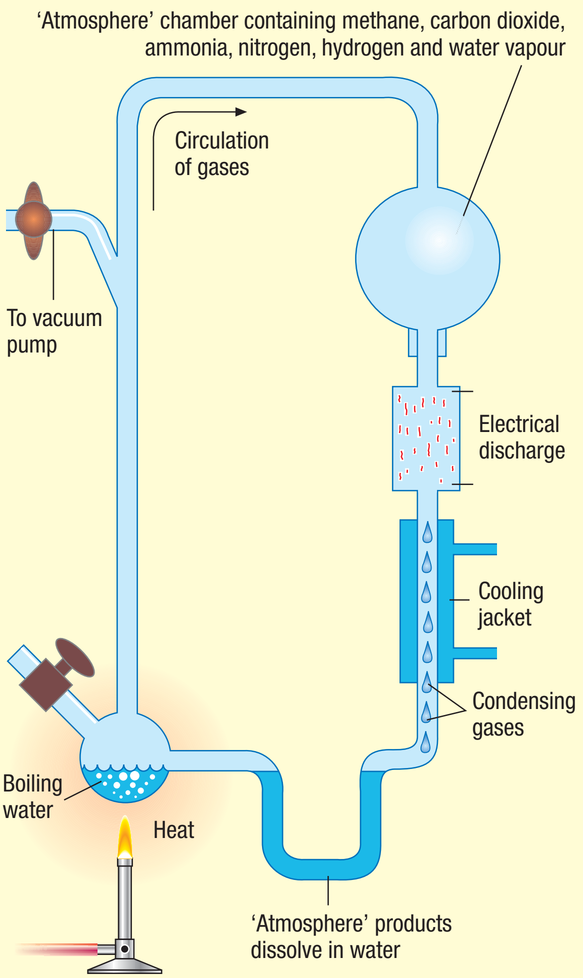


Figure 4.6 The Miller and Urey experiment

SUMMARY

The solar system is believed to have formed by the condensation of cosmic gas and dust.

The first living organisms on earth probably arose by abiogenesis in a unique set of circumstances which has not since recurred. These organisms were prokaryotic, and either anaerobic heterotrophs or chemosynthetic.

There is experimental evidence to support Oparin's theory of the origin of life.

Review questions

4.1 Why was the formation of oceans necessary for the synthesis of the first organic molecules?

4.2 What conditions are thought to have prevailed at the time of the formation of the first organic molecules?

4.3 List the four stages in the development of the first living organisms.

4.4 Why do scientists believe the first life forms were anaerobic?

4.5 Distinguish between a heterotrophic and a chemosynthetic organism. How would each derive its organic chemicals in the primitive sea?

4.6 Define the term 'prokaryote'. Name the prokaryotes which exist on earth today.

4.7 List evidence that supports Oparin's theory of the origin of life.

4.3 Development of the eukaryotic organism

According to Oparin's theory, one of the molecules that formed either in the 'soup' or in some of the primitive organisms was chlorophyll. Organisms containing this molecule were able to produce their own food by photosynthesis, which then provided a continuous source of organic molecules and released oxygen into the atmosphere. Eventually mutations arose in some of these primitive cells, enabling them to use the oxygen to release energy from their molecules (aerobic respiration). As the oxygen built up in the atmosphere, it reduced and limited the synthesis of organic molecules in the sea to the point that organisms would be unable to rely on them as a nutrient source. Thus the formation of living organisms brought about dramatic changes to the earth's atmosphere and thereby prevented recurrence of the conditions which originally allowed abiogenesis to occur.

Most scientists today accept the idea that photosynthetic and other cells were engulfed (swallowed up) by larger prokaryotes. These were not destroyed but remained within the larger cells as separate structures which performed specific functions, bringing the compartmentalised cell into being. This type of cell, where particular functions are carried out in special membrane-bound organelles, is termed eukaryotic. Thus chloroplasts (photosynthesis), mitochondria (aerobic energy-producing) and other cell organelles are believed to have originated by the symbiosis (living together) of different organisms within a single structure. The nucleic acid molecules responsible for reproduction and controlling the cell's activities somehow became membrane-bound to form the nucleus. How the nucleus formed, however, is subject to debate.

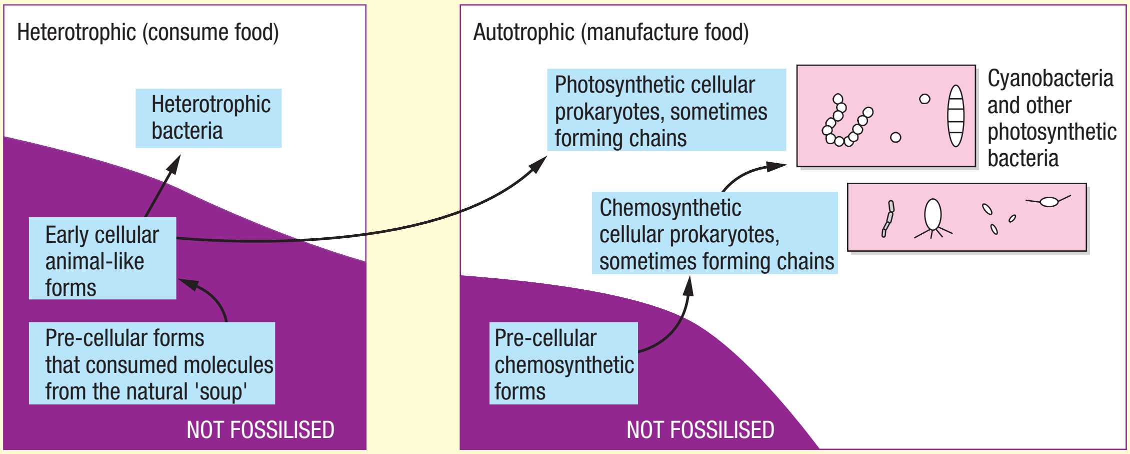


Figure 4.7 Possible sequence of the early evolution of the prokaryotes

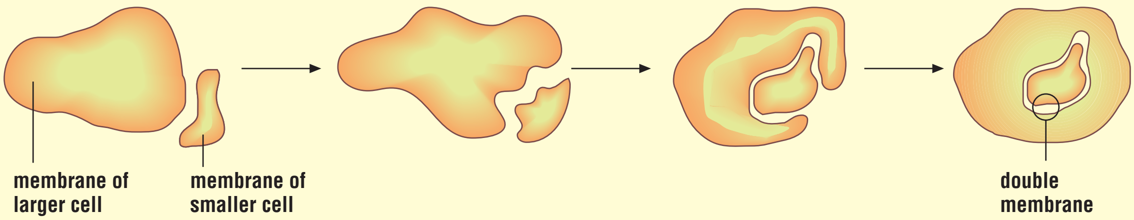


Figure 4.8 Endosymbiotic theory (A cell is engulfed by, and survives as an organelle within, the 'host' cell.)

One view of nucleus formation is that the cell membrane began to in-fold. Not only did the membrane enclose the DNA but it formed other membranous structures and channels within the cell. Another view is that the nucleus was formed by engulfing another prokaryote.

Studies of proteins' structure show that at least two groups of prokaryotes—the Archae and the Eubacteria—arose independently as the earliest life forms. The proteins in these groups are so different from each other and from all eukaryotic organisms that scientists group all living things into three

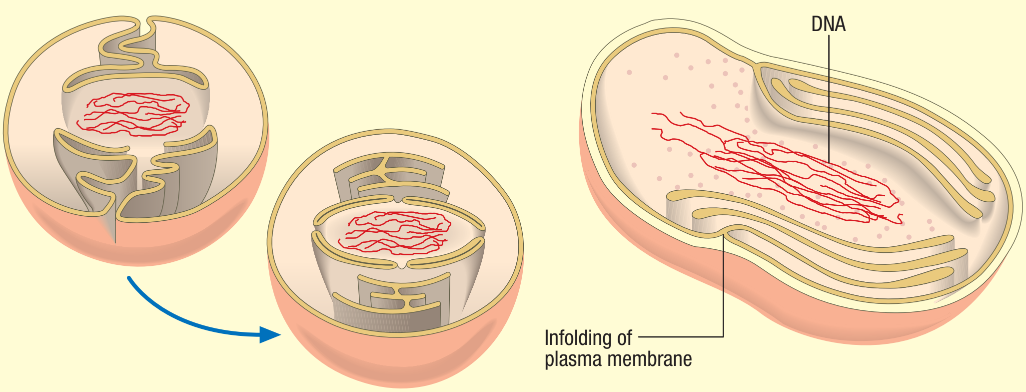


Figure 4.9 Infolding of the cell membrane to form the nucleus

different domains. These domains are the Archaea, Eubacteria and the Eukarya, each of which contains a number of kingdoms.

The Archaea include those prokaryotic forms that are found in extreme environmental conditions. They differ from the Eubacteria in the composition of the cell wall, cell membranes and ribosomes as well as basic proteins. The three main subdivisions of this group are the methanogens, extreme halophiles and thermoacidophiles. Methanogens are obligate anaerobes that live in swamps and release methane or marsh gas as a by-product of their metabolism, or in the digestive system of some herbivores where they break down cellulose. Extreme halophiles (*halophile* = salt-loving) are found in very saline environments such as the Dead Sea, where other organisms cannot survive. The thermoacidophiles abound in very hot, acidic conditions such as hot springs.

The Eubacteria are a very diverse group which includes:

- photosynthetic green and purple sulfur bacteria both of which are found in anaerobic lake and ocean sediments
- cyanobacteria, which display plant-like photosynthesis and release oxygen
- pseudomonads, a diverse group of heterotrophs found in all aquatic and terrestrial habitats
- spirochetes, which include the pathogens that cause syphilis and Lymes disease
- Gram-positive bacteria which are distinguished from Gram-negative bacteria by the ability of their cell walls to absorb Gram stain. Lactic acid bacteria, used in the manufacture of many foods, are included in this group.

One of the problems with the symbiotic theory of the formation of the eukaryotes is that modern Archeans and Eubacteria do not have the complex cellular machinery that allows the cell to wrap part of itself around another cell and engulf it. These organisms generally absorb nutrients from their surroundings. Some secrete digestive enzymes to break down complex chemicals in their surroundings.

Recently some bacteria have been found having some genes similar to those in eukaryotes that code for a flexible membrane. It has been suggested that an ancestral cell type (termed a chronocyte) having these genes engulfed both eubacteria (resulting in mitochondria and/or chloroplasts) and archaeans (resulting in the nucleus).

Evidence suggests that this happened about 2 billion years ago at the time that oxygen became abundant in the atmosphere. It has been proposed that the presence of oxygen, a gas that was poisonous to many of the organisms on earth when photosynthesis arose, was the driving force in this horizontal transfer of genes from one type of organism to another. All organisms other than the Archaea and Eubacteria are composed of eukaryotic cells. Fossil records show that the first single-celled eukaryotic organisms appeared approximately 2 billion years after the formation of photosynthetic organisms.

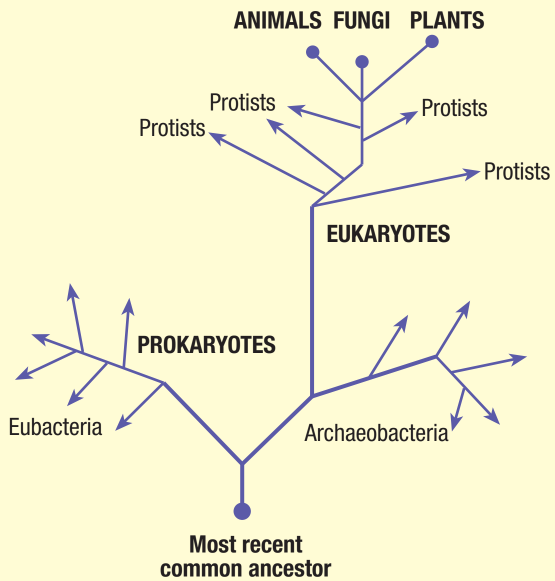


Figure 4.10 Possible relationships between the Archaea, Eubacteria and Eukarya based on nucleic acid analysis. The length of the lines indicates the degree of relatedness between the groups. (Adapted from Woese)

Mutations in the nucleic acids of the original organisms resulted in new life forms. In their turn, each of these new forms also had some effect on the environment. Influences such as changes in the earth's atmosphere, the development of climates, and movements of the continents have had profound effects on what types of organisms can exist in any particular place on the earth's surface. These gradual changes in organisms over time, originating from mutations, are termed evolution. Organisms that have features that enable them to survive in any particular environment are said to be adapted to that environment. If they do not possess these adaptations, they will not be able to survive there and will either die or move away to a more suitable environment.

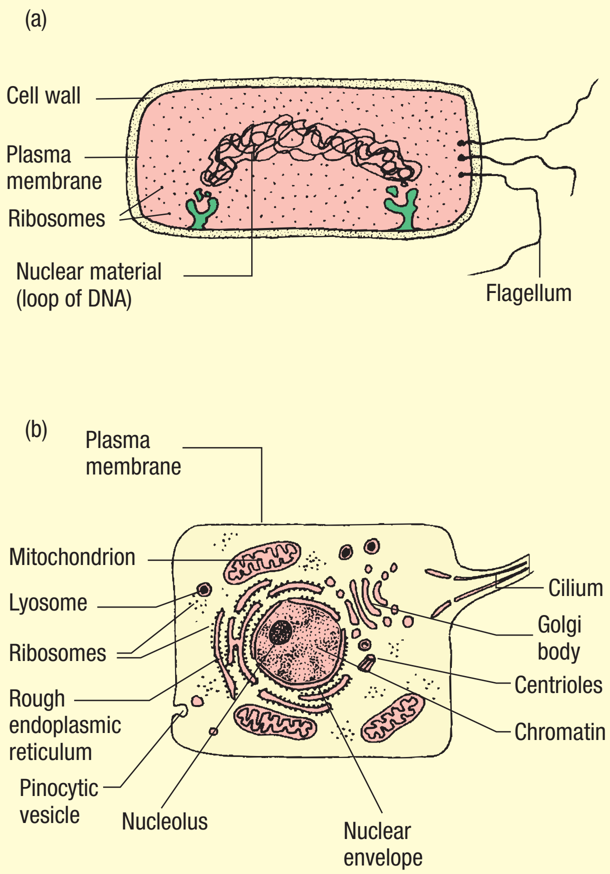


Figure 4.11 (a) Prokaryotic cell; (b) eukaryotic cell

SUMMARY

Eukaryotic cells are believed to have arisen by engulfing and incorporating different prokaryotic organisms into a single cell, thus becoming membrane-bound. All eukaryotes have a membrane-bound nucleus. As organisms evolve through mutations, their interactions bring about changes to the environment and thus pave the way for further evolutionary changes.

Review questions

4.8 Distinguish between a prokaryote and a eukaryote.

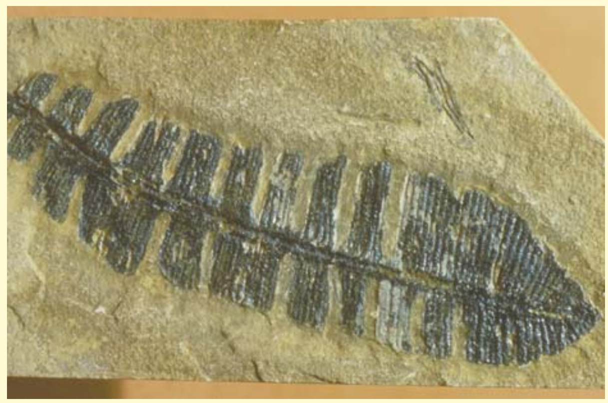
4.9 Describe the 'symbiotic theory' of the evolution of eukaryotes.

4.10 What major influence did the evolution of photosynthesis have on the earth's atmosphere?

4.4 Fossil evidence

The exact origin of life on earth will never be known, for scientists can only suggest the conditions under which it occurred. Evidence of changes in organisms over time can be seen in fossils (preserved remains of organisms, or traces of them such as a footprint or a chemical exuded from them). Scientists have developed techniques for estimating the age of rocks, and fossils have been found in rocks of various ages. To be preserved, an organism must be buried in a sediment of sand, silt or clay that prevents bacterial and fungal decay, or consumption by scavengers. Of course, most organisms that die will not become fossils, and there are great gaps in the fossil history.

(a)



(b)

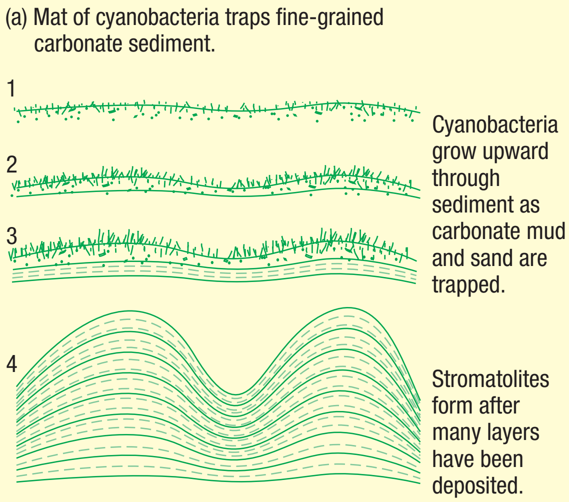
Figure 4.12 Fossils (a) cycad from the early Cretaceous; (b) fish (*Knightia alta*) from the Eocene

Fossil records do provide some support for Oparin's theory. The oldest evidence of life on earth is that of stromatolite (stone mat) fossils from the Pilbara area (Shark Bay) in Western Australia. They are estimated to be 3.5 billion years old. These structures are hard, dome-shaped rocks built by photosynthetic bacteria (cyanobacteria) which trap sediments. As the sediments accumulate around them, these cyanobacteria move to the surface where they continue to trap further fine matter. The actions of the cyanobacteria cause a mineral, calcite, to precipitate and this leads to the hardening of the sediments.

Stromatolites are still being formed in shallow saltwater areas such as Shark Bay and the Bahamas, in hot springs in the Yellowstone National Park in the United States, and in New Zealand. Since cyanobacteria are photosynthetic organisms, it is probable that the first life forms developed at a much earlier stage in the earth's history.

If Oparin's hypothesis is correct, the fossil record should show a progression from simple fossils to more complex ones. Although there are great gaps in the fossil record, this has generally been shown to be the case. Evolutionary biologists believe that the great biodiversity on earth today came about, over billions of years, through evolution of these simple early life forms in response to environmental changes.

According to the fossil record, animals were the first multicellular organisms to appear, followed by the fungi and then the plants. Members of all groups currently exist, showing that the specifications of each group were highly successful in their particular habitats.



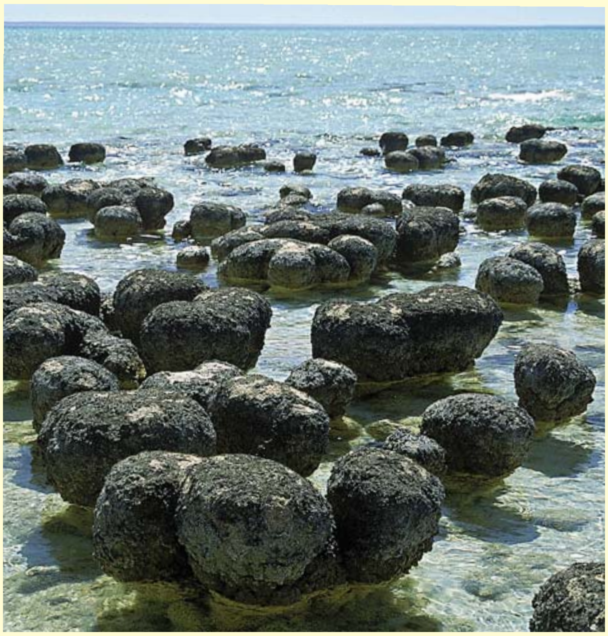


Figure 4.13 Stromatolites: (a) build-up of layers of sediment in the formation of stromatolites; (b) living stromatolites at Hamelin Pool (Shark Bay), Western Australia

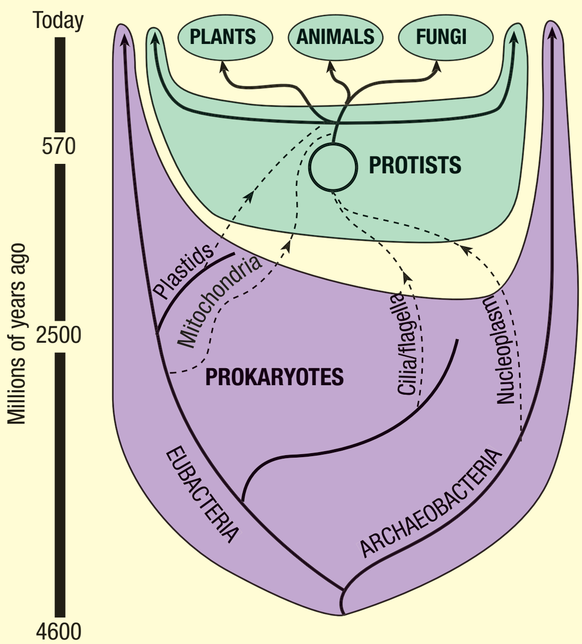


Figure 4.14 Past and present occurrences of living things (adapted from Margulis)

Figure 4.15 gives a diagrammatic summary of the history of life on earth. See also Chapter 22 for a more detailed study of evolutionary theories and evidence.

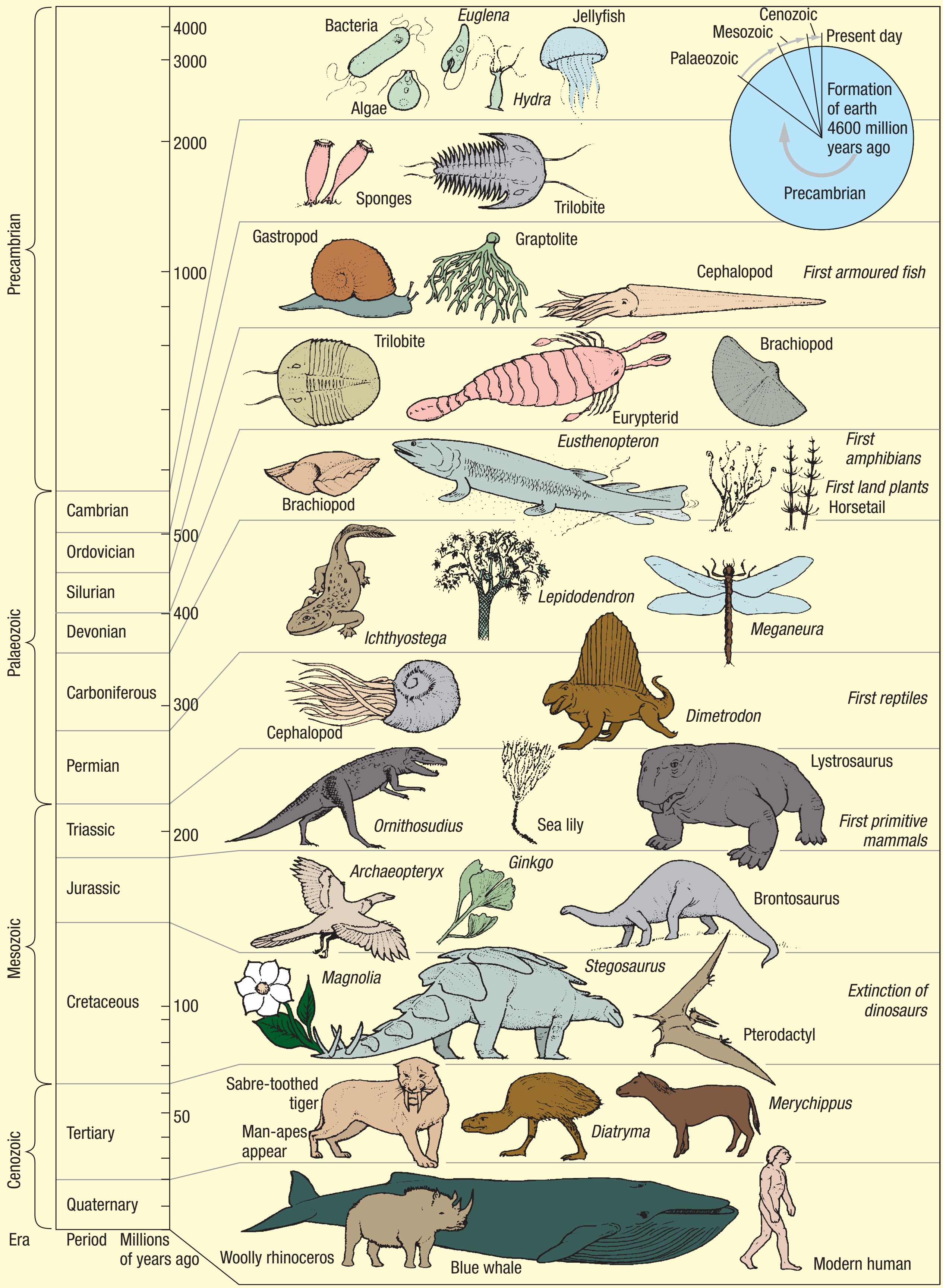


Figure 4.15 A possible history of life on earth

Table 4.1 Possible time-frame for events in the earth's history

Time (billions of years ago)	Event
0.5	
	Oldest known animal fossils
1.0	
	Origin of eukaryotes
1.5	
2.0	
2.5	Oxygen from photosynthetic bacteria accumulates in the atmosphere
3.0	Diversification of autotrophic bacteria
3.5	Oldest known fossils (probably anaerobic bacteria)
4.0	
4.5	Formation of earth

SUMMARY

Fossils are the preserved remains, or traces, of organisms. They can be formed only in situations where decay will not destroy the dead organism. For this reason, the fossil record is incomplete.

? Review questions

4.11 What is a fossil?

4.12 Why is the fossil record incomplete?

4.13 What is a stromatolite?

4.14 Describe the formation of stromatolites.

4.15 Does the fossil record support Oparin's theory? Explain your answer.

4.5 Development of the Protista

Modern protists developed from the first eukaryotic cells. Most, however, bear little resemblance to their early ancestors. They have undergone millions of years of refinement and adaptation to changing environmental conditions. Detailed examination of both their structure and DNA reveal that they exhibit an extraordinary array of shape, size, physiology and life style. A few, such as *Amoeba*, have probably remained so little changed over this immense period of time because they are very well adapted to their relatively stable habitat.

As seen in Chapter 3, there are three basic types of protists—the animal-like Protozoa, the plant-like Algae and the fungal-like moulds. All other eukaryotic life forms—the animals, plants and fungi—are thought to have evolved from primitive protists. It has been suggested that these macroscopic organisms are merely progressions of the protists that have allowed the gathering of sunlight with greater efficiency or versatility, or the ability to gather, engulf and process ever larger chunks of food.

4.6 The emergence of animals

4.6.1 Animal features

Animals are multicellular, heterotrophic organisms which exhibit locomotion at some stage in their life cycle. More than 1.5 million species of animals have been described, of which 95 per cent are invertebrates (animals without backbones). About a million of these named animals are insects. Every year thousands of new animals, including about 10 000 new insects, are discovered, particularly in tropical rainforests. At the same time, many become extinct through either natural processes or humans' destruction of natural environments.

The earliest known fossil animals were discovered in the Ediacaran Hills in South Australia. These representatives have been aged at about 670 million years old and are unlike any modern animals. The Burgess Shale formation in the Canadian Rockies, dated at about 530 million years ago, includes representatives of all living groups of animals. In the 120 million years between these two fossil formations the major phyla (see Section 3.6) had diverged from the ancestral protists from which they had evolved.

Although the early fossils indicate that the animals have an ancient origin, they do not provide any evidence of the sequence in which the various groups arose. Biologists have therefore relied primarily on studies of living animals to determine evolutionary origins. Fossil records, however, have

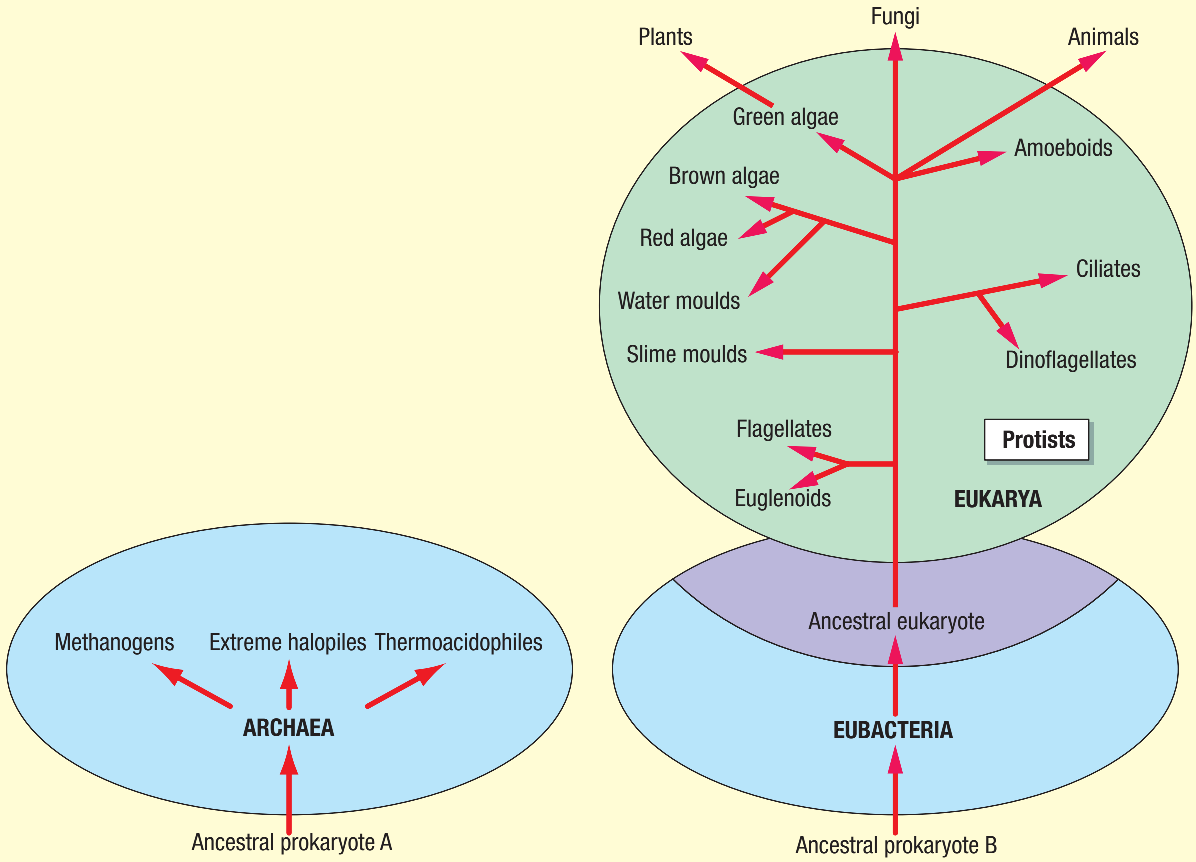


Figure 4.16 Possible evolutionary development of the eukaryotes based on nucleic acid analysis (ribosomal RNA). Further evidence for the close relationship between fungi and animals comes from the similarity between two of the proteins which bind the cells together.

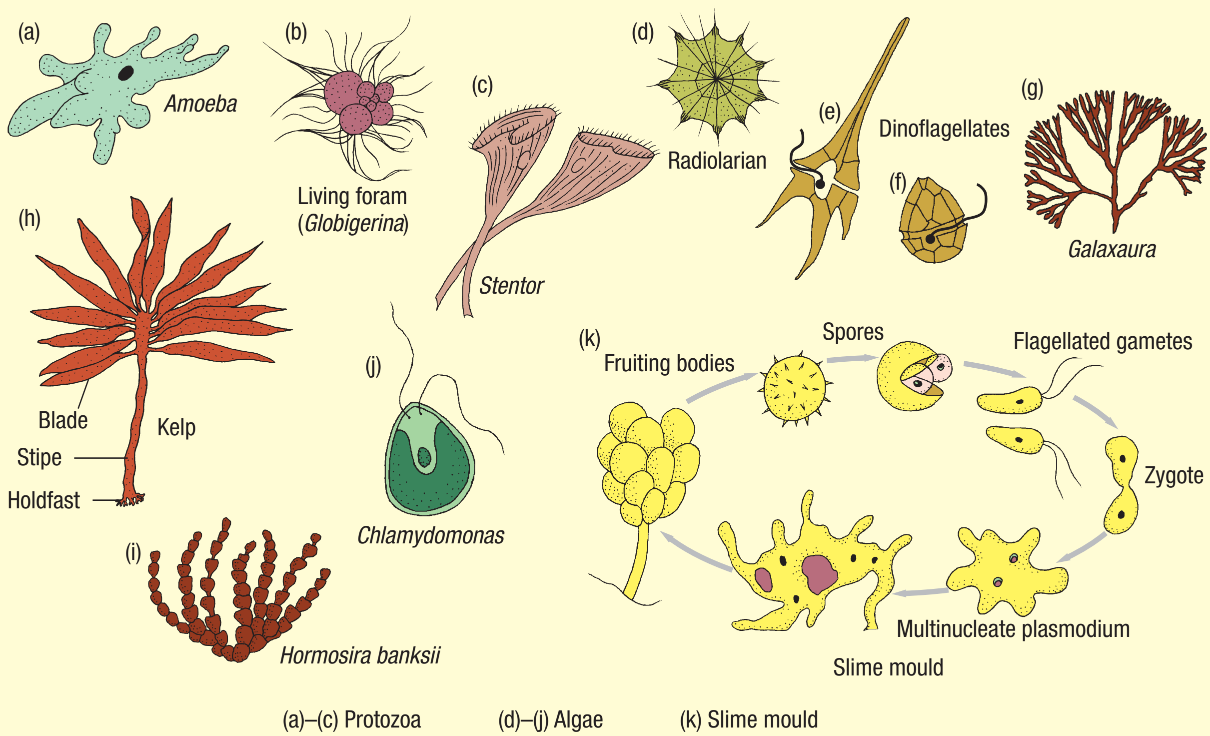


Figure 4.17 Diversity within the Protista

given biologists clues to the evolutionary history within phyla.

Features used by biologists to determine the relationships between the groups of animals include: the number of tissue layers into which the cells are organised; the basic body plan; the presence or absence of a body cavity; embryonic development; and comparisons of proteins and nucleic acids (DNA and RNA). Nucleic acid analysis is discussed more fully in Chapter 21.

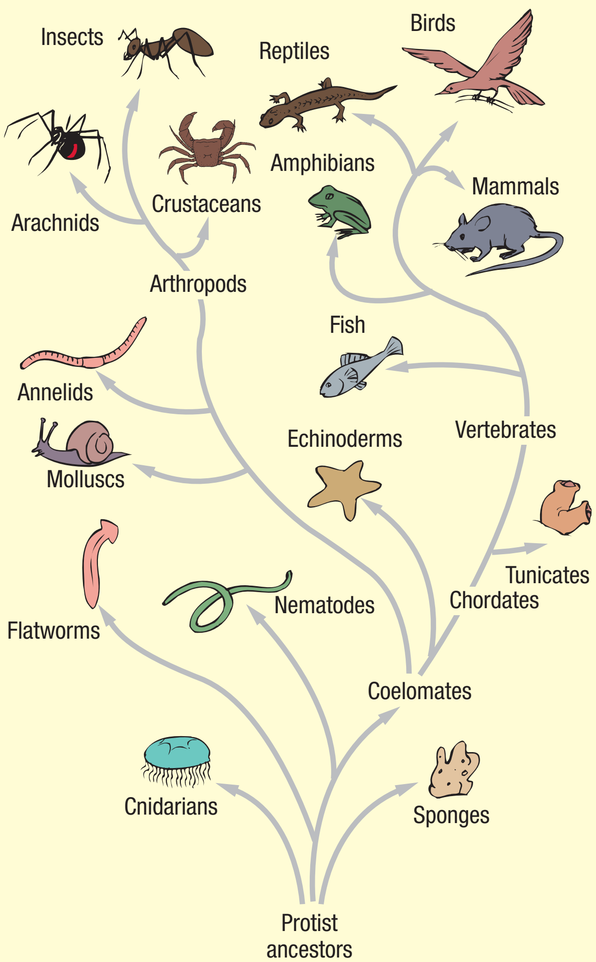


Figure 4.18 Probable evolutionary relationships between major groups of animals

SUMMARY

There is a 100 million year gap in the fossil record between the first animals and representatives of the major modern phyla. Biologists therefore rely on studying the living animals to determine their evolutionary history. These features include the organisation of cells and tissues in the basic body plan, embryonic development and chemical analyses.

Review question

4.16 Why do biologists have to rely upon characteristics of living animals to determine the evolutionary history of the phyla?

4.6.2 Trends in animal development

The further development of eukaryotic organisms took place over at least 2 billion years, with the first multicellular organisms appearing about 700 million years ago. The evolutionary steps in the development of multicellular organisms include:

- the ability of cells to attach to each other
- specialisation of cells for specific functions and thus the formation of tissues, organs and systems
- coordination of the different organs and systems
- mechanisms to ensure homeostasis of the whole organism.

It is most likely that animals developed from the amoeboid protozoans. All protozoans are heterotrophic but the amoeboids have the added distinction of a flexible cell membrane. This allows change of shape, an essential feature for locomotion and food gathering that do not require supplementary structures. Since it is very likely that there was competition between heterotrophs for resources such as food, this would create a selection pressure that favoured the development of more efficient and/or effective means of gathering, engulfing and processing ever-larger chunks of food. Simply becoming larger was not the answer. As a cell becomes larger, its surface area to volume ratio becomes smaller. Figure 4.19 illustrates this concept using a cube.

Nutrients taken in are required by all parts of the cell and waste products must be released. The movement of materials throughout the cell's cytoplasm would take such a long time in a very large single-celled organism that it is unlikely that it could survive. By increasing size by increasing the number of cells, the efficiency of the cell's ability to take in and distribute nutrients as well as discard wastes is maintained.

The first step in the formation of animals, therefore, was a mechanism to maintain contact between cells as seen in the sponges. Although this ability had developed in some algal protists, it has not been observed in Protozoa. Like other features, multicellularity has arisen independently in different groups of organisms. This prototype organisation paved the way for further 'design' and 'experimentation'. Innovation was added to innovation, each allowing exploitation of a different resource in a habitat or an entirely new habitat.

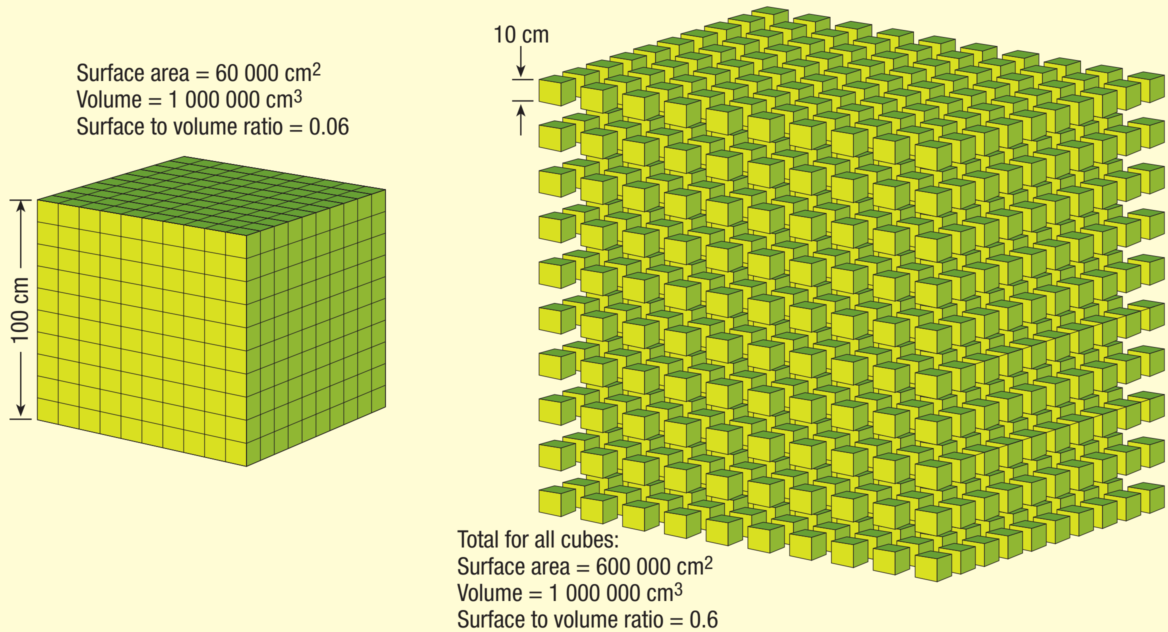


Figure 4.19 As a large cube is subdivided, the surface area:volume ratio decreases as the cubes become smaller.

Some of these 'designs' led to dead ends in terms of further development, even though they were extremely successful in their particular habitats. Representatives of these groups still exist.

Formation of tissues

From the emergence of multicellularity, three different lineages appeared. Whether or not one progressed into the other is unclear, although from a structural point of view there does appear to be some support for this viewpoint.

The sponges have two layers of cells surrounding a large central gastrovascular cavity. Numerous pores in this structure allow water and minute food particles to enter the central cavity. After gas exchange, the uptake of nutrients and release of metabolic wastes, the water leaves through a single, large pore at the top of the sponge. Although there is some specialisation of cells for specific functions such as covering, feeding and reproduction, the cells are not organised into tissues, organs and systems.

The Cnidaria (jellyfish, sea anemones and corals) also have two layers of cells but these cells are clearly organised into tissues (i.e. they are diploblastic) with an outer ectoderm and an inner endoderm lining the central gastrovascular cavity. Food gathering is a much more elaborate process, with active capture of prey using immobilising stinging cells (nematocysts). The prey is then drawn

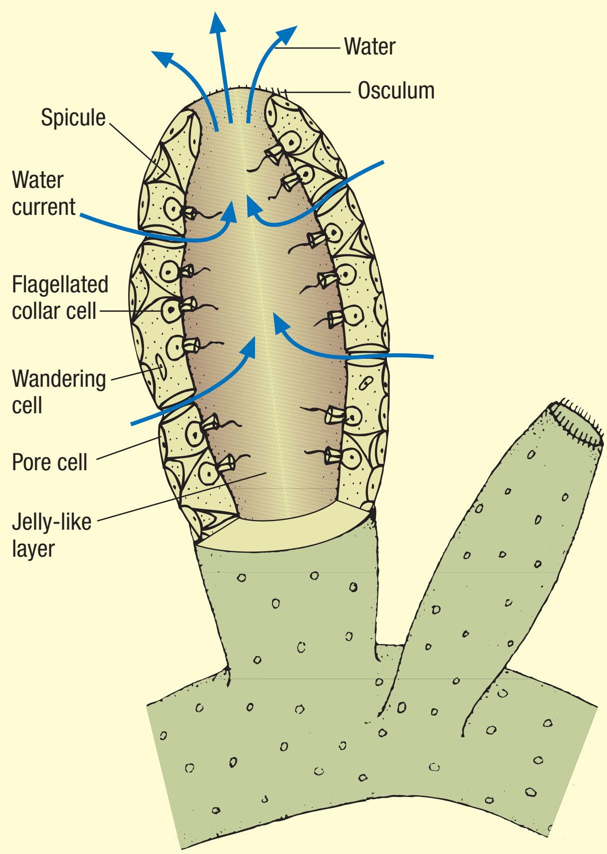


Figure 4.20 Cutaway view of a single sponge

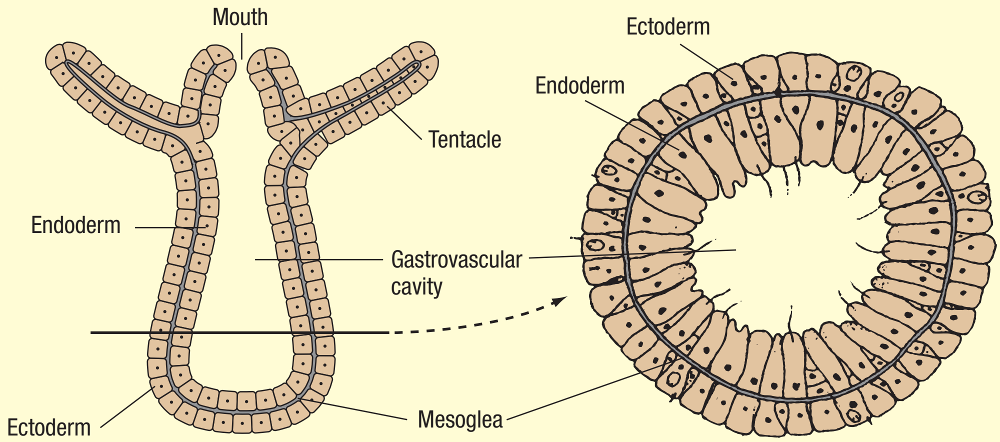


Figure 4.21 Section through *Hydra* showing organisation of cells and tissues

into the gastrovascular cavity, where it is digested by enzymes secreted from special cells. This method of gathering and engulfing food required the development of contractile ('muscle') cells and a means of coordinating activities (a primitive nerve net formed by the ectoderm and located in a jelly-like substance between the two tissue layers).

The third lineage of three basic tissue layers (triploblastic) paved the way for further developments of the body plan. The Platyheminthes (flatworms) display the simplest arrangement of these tissues. The outer ectoderm is separated from the inner, gut-lining endoderm by the mesoderm. This middle tissue layer allowed the development of distinctive muscle. Movement of material in the gut, however, was dependent upon movement of the entire body. With the increased number of cell layers movement of gases between the surrounding cells and the environment, and nutrients from the hollow gut cavity to the cells, would have been a problem. The fact that these animals were dorso-ventrally flattened, bilaterally symmetrical and had a highly branched gut, meant that the distance between cells and their essential resources was much reduced and so they could survive.

With bilateral symmetry a head, or leading end, developed. Special sensory cells developed in this area to sense the environment into which the animal was approaching. This requires a greater ability to integrate information which is supplied by increased development of the nervous system. Two concentrations of nerve cells (ganglia) are found at the anterior end. These act as a primitive brain, sending information to the rest of the body via a pair of ventral nerve cords. Further elaboration of this type of nervous system is seen in all the invertebrates.

With an increased number of cells, some became specialised to collect and dispose of metabolic wastes. A rudimentary excretory system came into being. As later organisms became even larger, this excretory system became better suited to dealing with the increasing amounts of waste material and in some later animals was also able to take part in the control of water levels.

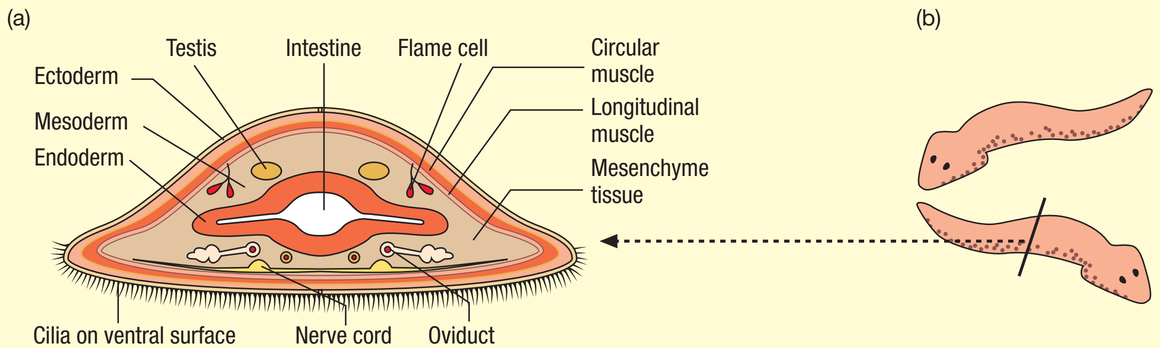


Figure 4.22 Flatworm: (a) transverse section showing tissue layers; (b) *Planaria*

The development of three embryonic tissue layers was a great breakthrough in the future evolution of animals. Studies have shown that, in the various groups of animals, cells of the:

- ectoderm can develop into skin and its associated structures such as chitin (the exoskeleton of the arthropods), shell (in the molluscs) and calcareous plates and spicules (as seen in the echinoderms) and the nervous system
- mesoderm can develop into muscles, cartilage and bone (the internal skeleton of the vertebrates), the excretory system, the vascular system and reproductive organs
- endoderm form the lining of the alimentary canal and urethra, the respiratory system, bladder and glands.

The framework for all organ systems and structural support mechanisms was now in place.

The body cavity

Further elaboration of the flatworm body plan would have been limited. Another group, the nematodes (roundworms), demonstrates a different organisation and means of ensuring successful movement of materials between cells. This body plan has a fluid-filled cavity (pseudocoelom) between the endoderm and the mesoderm. The fluid not only allows rapid distribution of materials between cells, it provides a hydrostatic support (allowing increase in size) and separates the gut from the other tissues. The last feature allowed the formation of a one-way gut with a true head and tail area. Since the gut has no musculature of its own, however, the movement of food still depends on the movement of the entire body.

These two three-layered groups continued to survive in their particular habitats but were effectively evolutionary dead-ends. They were successful 'experiments' that lacked the necessary basis on which further developments could be formed.

Another body plan based on three basic tissue layers also appeared. The difference in this plan is the formation of a cavity within the mesoderm layer, forming a true coelom. This results in muscle associated with both the outer body wall and the gut. In these animals the gut can become specialised. Different areas are modified for specific functions such as storage, digestion, absorption and elimination, since the gut can move quite independently of the rest of the body. All of the rest of the animal phyla have this body design. It has allowed a greater flexibility in what an animal eats and when it eats. The herbivores, for example, could eat large amounts of food, store it in a stomach and then find a safe place to hide from predators while they digested it over a period of time.

The presence of a coelom also allows:

- production of coelomic fluid, which provides both a hydrostatic skeleton and a circulating medium for the transport of matter
- a space for the enlargement of internal organs
- the possibility for increased regulation of water and dissolved chemicals within the cells (osmoregulation).

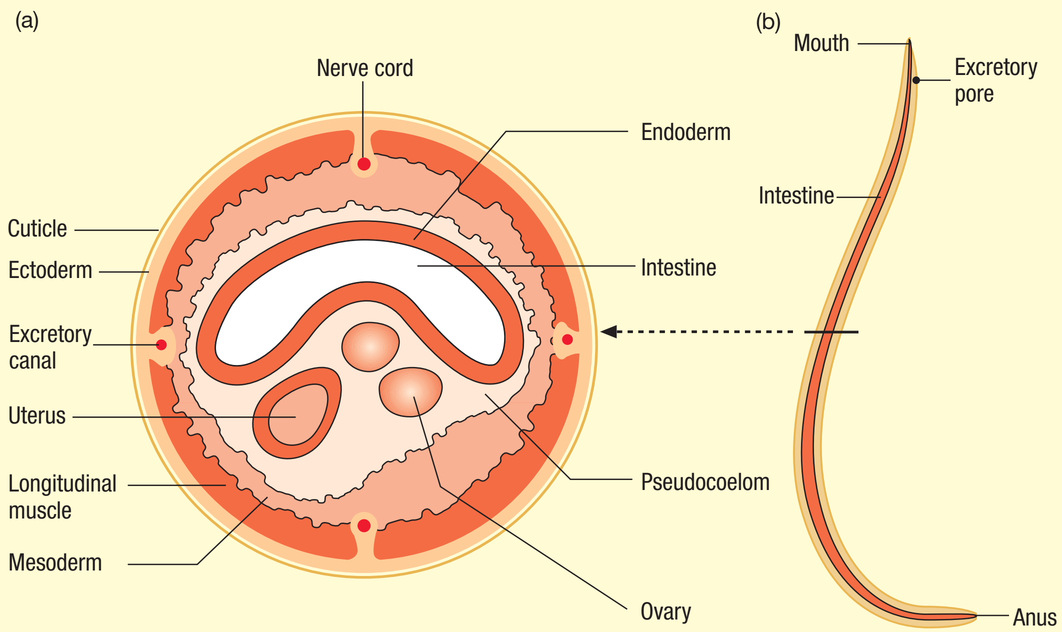


Figure 4.23 Roundworm: (a) transverse section of a female nematode; (b) entire

It appears that there was a divergence of the ancestral coelomate body plan based on the way in which the embryo developed. One group resulted in the formation of the Mollusca ('shelled' animals), the Annelida (segmented worms) and the Arthropoda (joint-footed animals). The other group is represented by the Echinodermata (spiny skinned animals) and the Chordata. Both groups have phyla that are not segmented (the molluscs and echinoderms) and both have phyla that are segmented (annelids, arthropods and chordates). Thus segmentation would, according to this schema, have arisen independently in two separate ancestral lines.

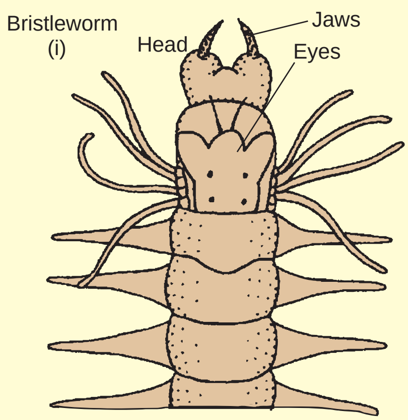
Segmentation

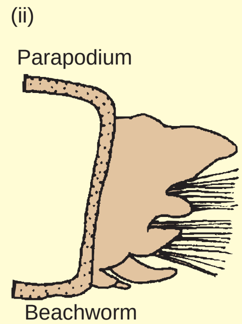
Animals with three cell layers may be segmented. Figure 3.8 shows a diagramatic representation of the segmented body plan. During embryonic development their body is made up of a series of segments which at first are similar. The annelids

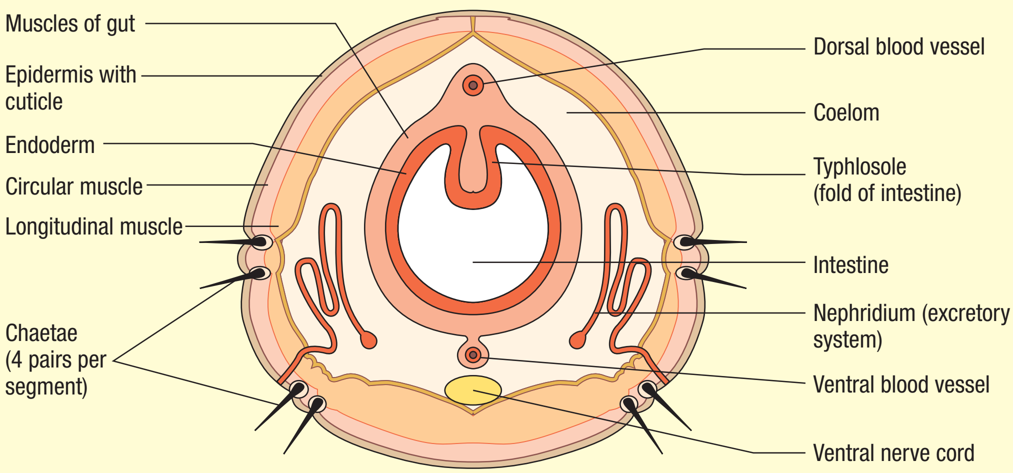
(a) Bristleworm

Earthworm

Leech



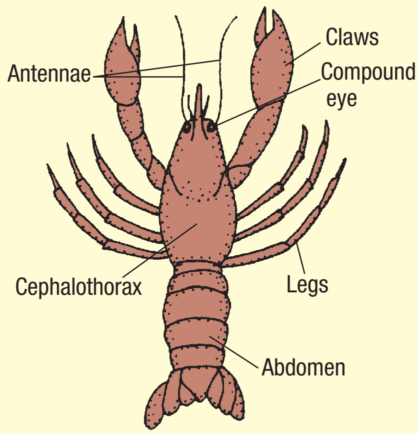




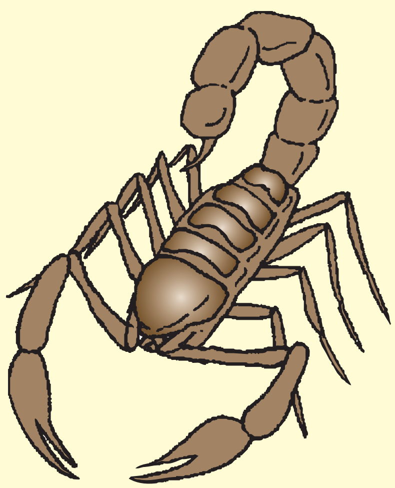
(b) *Lumbricus terrestris*

Figure 4.24 (a) Representatives of the phylum Annelida; (b) transverse section clearly demonstrate this, with obvious segmentation both externally and internally. Certain segments may become fused or specialised for a specific function, in which case segmentation may not be obvious externally.

Segmentation has allowed modification and adaptation of various parts of the body: for example, the modification into head, thorax (chest) and abdomen. In some arthropods, segmentation is not at first obvious in parts other than the abdomen. Examination of appendages such as mouthparts, however, clearly shows that several segments have been fused to form a head or cephalothorax (head and thorax joined together). In vertebrates, segmentation is very obvious during embryonic development, but in adults is only exhibited in the arrangement of the major nerves leaving the brain and the spinal chord.



(a)



(b)

Figure 4.25 Representative arthropods showing different modifications of the segmented body plan: (a) freshwater crayfish; (b) scorpion

SUMMARY

Animals are believed to have evolved from an amoeboid protist. Since the surface area compared to the volume of a cell decreases with increasing size, this limits the exchange of material between the cell and its environment. An increase in size demanded an increase in the number of cells. A variety of progressive changes occurred, many of which are seen in modern forms. The first step was that of multicellularity (as seen in the sponges, phylum Porifera). Elaboration of multicellularity resulted in the formation of separate tissue layers. Thus the phylum Cnidaria have two layers of true tissues (ectoderm and endoderm). A separate evolutionary line, which includes all other animals, has three tissue layers (ectoderm, mesoderm and endoderm). As the size of the animals increased, so did the need for greater division of labour among various parts of the body and thus coordination of the different parts. This has resulted in highly organised organs and systems and the development of the sense organs and nervous system. The basic tribloblastic body form, and organ development, is seen in the bilaterally symmetrical flatworms (phylum Playthelminthes). Two other lines emerged from the flatworm precursor—the roundworms (phylum Nematoda) with a cavity (pseudocoelom) between the mesoderm and the endoderm and the ancestor of all other animals that had a true coelom (i.e. a cavity within the mesoderm). The development of a coelom allowed the alimentary canal to move independently of the whole animal and saw the emergence of a one-way tube with parts specialised for different functions such as storage, digestion, absorption and elimination. The coelom allows rapid movement between the cells of the body, especially when filled with fluid, and provides a space in which internal organs can enlarge. The coelomic fluid also provides a hydrostatic skeleton, a circulating medium and the opportunity for osmoregulation. Embryonic studies show that two distinct ancestral animal lines developed a coelom. One resulted in the shelled animals (phylum Mollusca), the segmented worms (phylum Annelida) and the joint-legged animals (phylum Arthropoda). The other line developed into the spiny skinned animals (phylum Echinodermata) and the phylum Chordata of which the vertebrates are a major subgroup. Segmentation (an embryonic body plan based on similar repeating units) was the final major evolutionary breakthrough that allowed massive modification and adaptations of individual parts of the body. The basic form is seen in the annelids. A vast array of modifications of this plan is witnessed in the arthropods and chordates.

Review questions

4.17 In what ways are the members of the phylum Porifera more advanced than those of the Protozoa?

4.18 Describe features of the phylum Cnidaria which limited its evolution.

4.19 Of all of the animals, the phylum Platyhelminthes are the only ones that show extreme dorso-ventral flattening of the body. Explain the term 'dorso-ventral' and why it was an important feature of these animals.

4.20 All triploblastic animals, except the adult echinoderms, are bilaterally symmetrical. Explain how this would have influenced the development of the nervous system.

4.21 Although members of the phylum Nematoda have a body cavity and a one-way alimentary canal, this canal is unspecialised. Give a reason for this.

4.22 Distinguish between a pseudocoelom and a coelom.

4.23 List ways in which the development of the coelomic body plan paved the way for further evolutionary development of the animals.

4.24 Segmentation as a basic body plan was an important evolutionary breakthrough. Using the annelids and the arthropods as examples, explain why this was such a significant step in the further development of the animals.

4.25 Into which phylum would you place an animal that has: an alimentary canal capable of independent movement which is separated from the outer body wall by a fluid-filled space, and a body with head, torso and limbs supported by an exoskeleton? Explain your answer.

4.6.3 Diversification of form

The Paleozoic Era—extending from the Cambrian Period, starting 570 million years ago, to the end of the Permian Period, which ended 245 million years ago—was a time that heralded the diversification and emergence of a vast array of animals, many known only from their bizarre fossils. It was during this time that skeletons appeared in animals:

- the shells of molluscs that are secreted from a special outer layer of tissue called the mantle (see Figure 4.26)
- the ectodermal spines and plates that characterise the echinoderms (see Figure 4.27)
- the jointed external skeleton of the arthropods
- the internal jointed skeleton of the vertebrates.

A whole new part of the watery environment could be exploited with the advent of the jointed skeleton, for this allowed active swimming. The muscles had a solid framework on which to operate. The jointing in the skeleton allowed muscles to attach across joints and so produce elegant

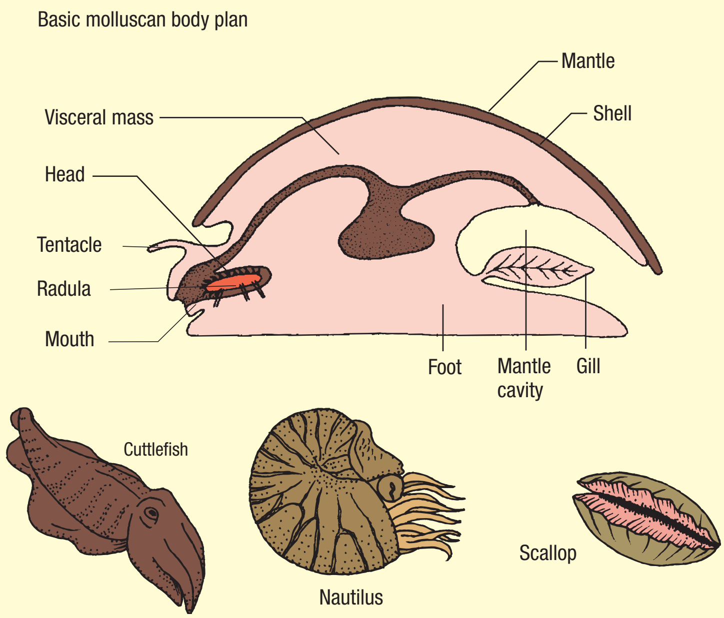


Figure 4.26 Representatives of the phylum Mollusca

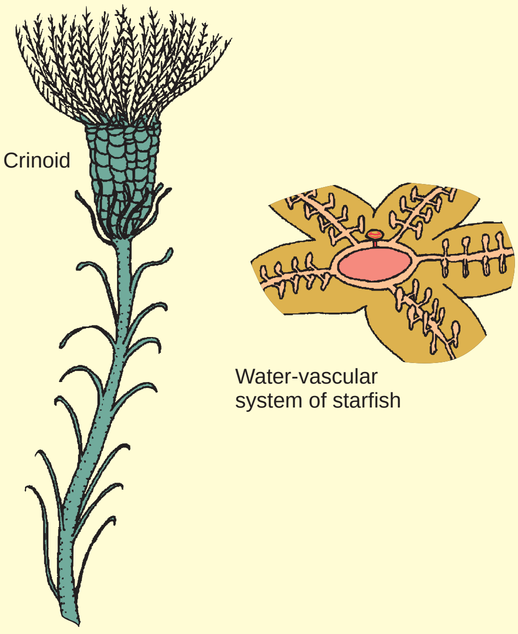


Figure 4.27 Representatives of the phylum Echinodermata

controlled movements of individual parts of the body. It is not surprising that many of these swimmers were predators.

The early arthropods were all aquatic, and some were like large scorpions. Many were the major predators of the waters. Their front appendages became modified as strong jaws and clasping claws that could hold and shed their prey. Their outer skeleton protected them from attack from other animals.

As the arthropods developed, segmentation also occurred in the other coelomate lines. Despite the vast differences in adult appearance, it is believed that the early echinoderms and chordates developed from a similar ancestral line. In both these groups, many aspects of the early embryonic development are very much alike and very different from that of the other coelomates. Since the origin of these two groups, however, each phylum has undergone significant changes. The echinoderms remained unsegmented, while the chordate line underwent segmentation during embryonic development.

Other significant differences between the arthropod line and the chordate line include:

- The skeleton is external and secreted by the ectoderm in the arthropods but internal and formed from the mesoderm in chordates.
- The nerve cord in arthropods is double, solid and lies ventrally in the body; in chordates it is single, hollow and dorsal in the body.
- Most of the coelom of the arthropods is used in the circulation of blood (i.e. it is a haemocoel) pumped by a dorsal heart, whereas the blood is circulated in a closed system of vessels pumped by a ventral heart in the chordates.

The body plan of a chordate in many ways can be thought of as an upside-down, inside-out version of the arthropods.

The early chordates, represented today by organisms like the sea squirt, had a primitive internal skeleton in the swimming larva only. This was represented by a rod of flexible material, the notochord. The adult was a bottom-dwelling organism. At some point in time the larval form of the protochordates did not transform into the 'adult' but started to reproduce. A more fish-like organism, such as the lancelet that survives today, emerged. Some of these swimmers were able to store calcium phosphate in their skin—this was the beginning of bone. A mutation that allowed the replacement of the notochord by a jointed vertebral column that enclosed the dorsal nerve cord, and an added 'skeletal box' (cranium) around the brain, resulted

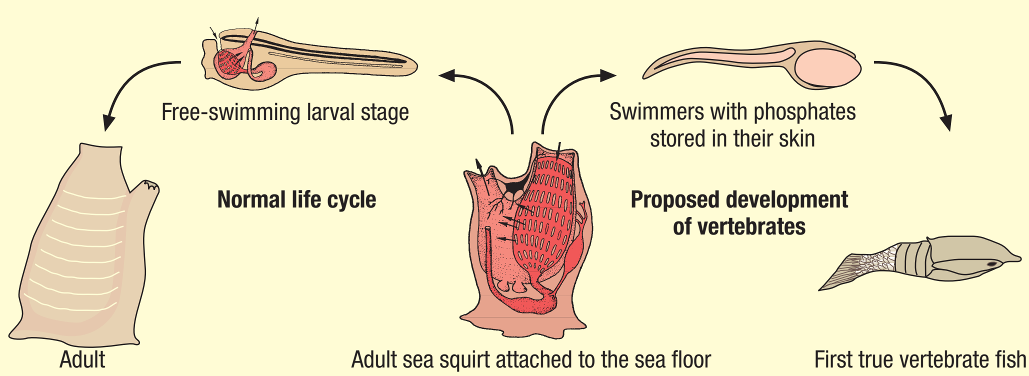


Figure 4.28 Possible development of the vertebrates

in the vertebrates.

All vertebrates (subphylum Vertebrata) have a jointed vertebral column. Associated with the vertebral column are segmented muscles which can move each vertebra separately. Since the notochord is a single flexible rod, locomotion is achieved by undulating sideways movements. The articulated vertebral column allows independent movement of different parts of the body and thus the formation of limbs becomes possible.

The first fish were small, jawless animals, many of which had a body design suited only to scurrying across the bottoms of waterways. Like the protochordates, they obtained oxygen by taking in water through their mouth and passing it out through slits in the pharynx. They developed, however, a more efficient method of gas exchange. Fine extensions of the tissues in these slits, rich in blood capillaries, developed to form gills. The larger the surface area of the gills, the more rapidly oxygen could be taken up and carbon dioxide released from the blood. A two-chambered heart pumped the blood returning from the body directly to the gills where gas exchanges occurred. The blood then passed through vessels to the body cells before returning to the heart. Thus the blood only passed through the heart once in a complete circulation through the body. Cartilaginous structures, the gill arches, supported the gills, allowing them to maximise their exposure to the surrounding water. The absence of jaws, however, meant that these fish were limited to eating small items of food. These first jawless fish did not have flexible fins to control their movements. The front part of their body was wide and gave them basic stability. The tail, flattened from side to side, gave them forward thrust.

Sometime during the next 130 million years several significant mutations occurred. The fossil

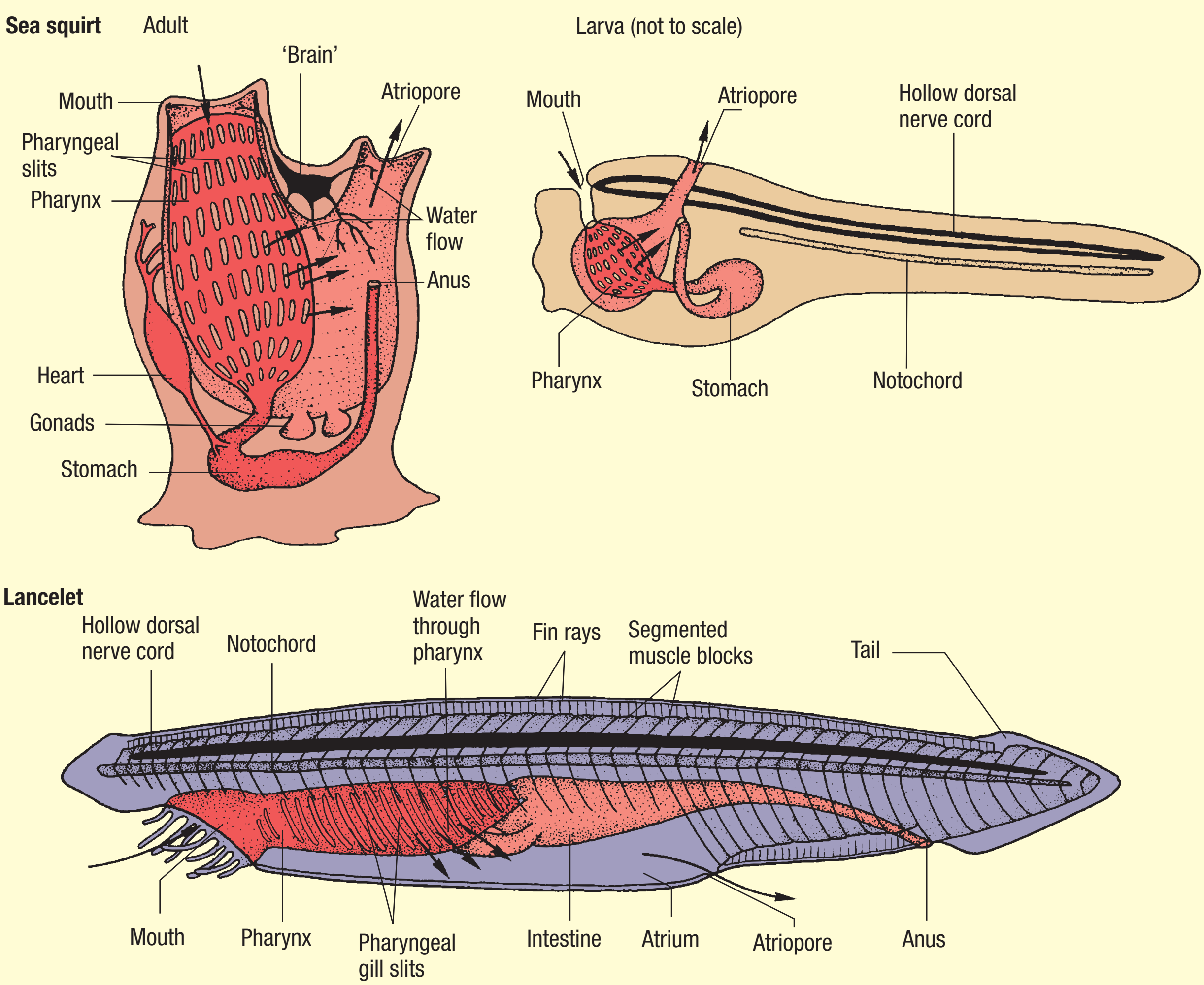


Figure 4.29 'Invertebrate' chordates

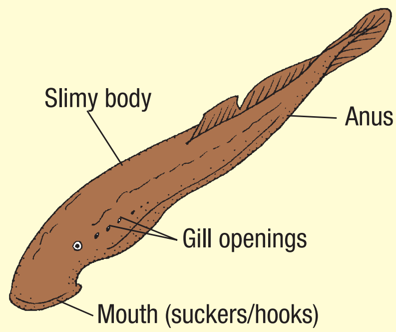


Figure 4.30 The lamprey, a modern jawless fish. It is an ectoparasite on other fish, attaching to its host with its suction-cup mouth and rasping through to skin with its tongue in order to suck up blood

record indicates a movement of the fish from the oceans to freshwater environments. The development of paired, mobile fins allowed stability and control during swimming. The origin of jaws opened the way for a wide variety of new ecological possibilities related to the ability to prey on other animals. The jaws have been shown to be modifications of the gill supports of ancestral fish—an existing structure changed to perform an entirely new function.

The earliest jawed fish had pairs of triangular fins down their body. In time these were reduced to just two main pairs—the pectorals at the front and the pelvics further back. These fish could now control their movement through the water. Over time the triangular shape of the fins became more rounded and even more mobile.

The advent of both of these design modifications—jaws and improved locomotory skills—heralded a diverse array of fish body shapes and forms. Large fish fed on small fish and these in turn fed on even smaller fish. The cartilaginous fish (the sharks and rays) became the dominant fish of the oceans. In the freshwater environment, the mutations necessary for replacing the cartilaginous with a bony skeleton occurred. Two different body forms arose. In one group, known as the ray-finned fish, the bones inside the fin became closely grouped at the base of the fins and then spread out into a ray. In the other group, the lobe-finned fish, the central fin bones grew stronger and the outer ones disappeared. The fins became oval or lobe-shaped. Both groups of fish have an outpocketing of the pharynx, the swim bladder, which is filled with gas and allows them to regulate their buoyancy at any depth of water. Many groups of the bony fish later returned to the sea.

Since bodies of fresh water are relatively shallow and, unlike the sea, can become stagnant or depleted of oxygen, the development of a swim bladder became an important adjunct to the gills. It enabled fish to gulp air from the surface and survive in stagnant water.

The lobe-finned group is represented today by a few species, including the Queensland lungfish. These fish could obtain air even when their bodies were not supported by water. It is thought that in some of these primitive fish, the 'limbs' allowed them to waddle from water pool to water pool as streams dried up, pulling themselves along the surface as they went. It is from this group that the

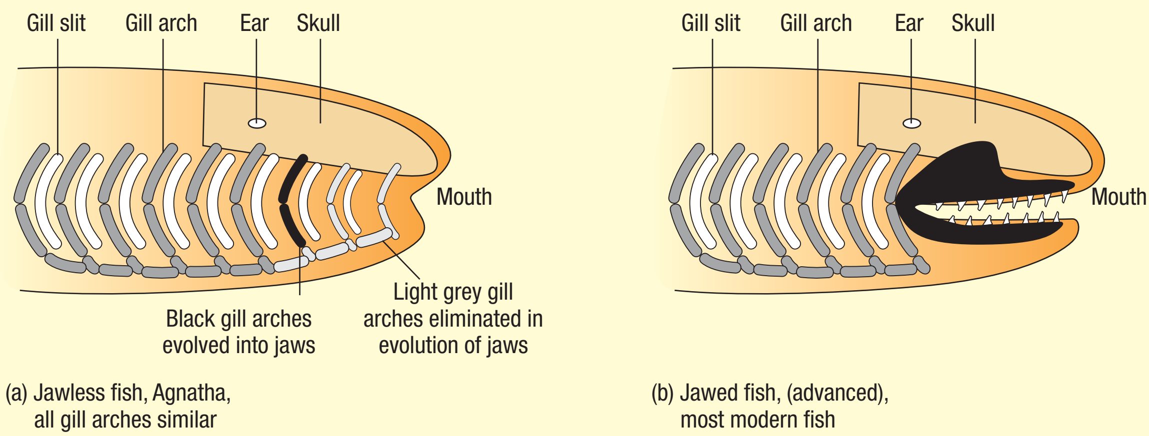
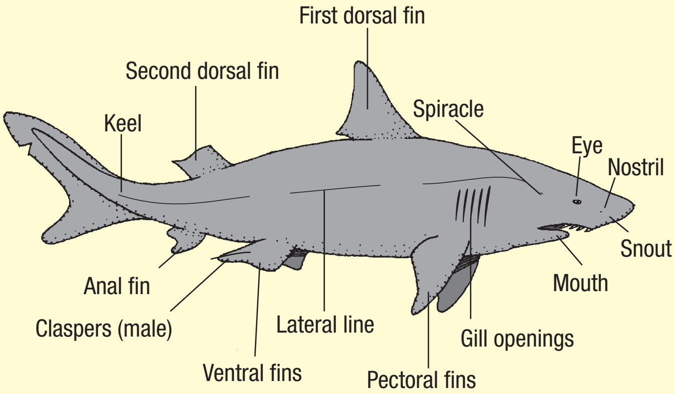
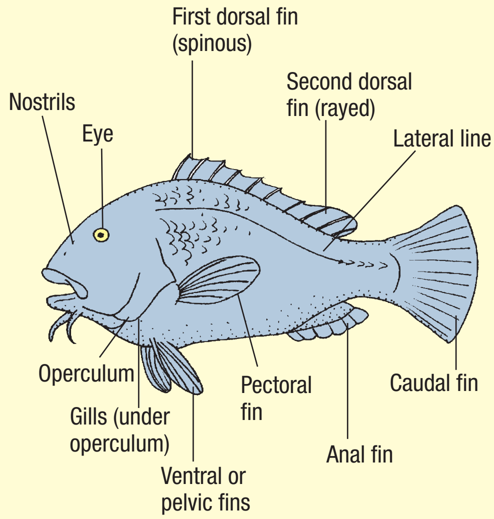


Figure 4.31 Origin of the vertebrate jaws from a pair of gill supports



(a) Cartilaginous fish



(b) Bony fish

Figure 4.32 Features of (a) cartilaginous and (b) bony fish

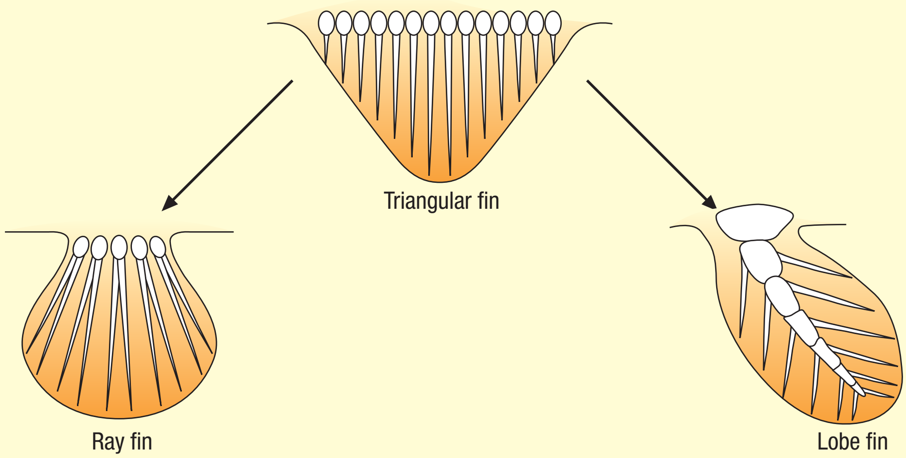


Figure 4.33 Development of the ray- and lobe-finned structures

Table 4.2 Significant developments in animals during the Paleozoic Era

Age (millions of years)		
286	Permian	Conifers Winged insects; reptiles
360	Carboniferous	Amphibians Seed ferns (ginkgo)
408	Devonian	Sharks and bony, ray-finned (modern) fish, lungfish; spore-bearing plants (ferns and allies) Large terrestrial arthropods
436	Silurian	Primitive jawed fish (ancestors of sharks, bony fish and lungfish); small spore-bearing plants Tracks of terrestrial arthropods; fossil scorpions
505	Ordivician	Euryptid (scorpion relatives) arthropods Jawless fish
570	Cambrian	Shelled molluscs, echinoderms, arthropods (trilobites)

first terrestrial vertebrates probably arose.

SUMMARY

The development of the segmented body plan and mutations that saw the formation of skeletons resulted in the evolution of and adaptive radiation of the molluscs, echinoderms, arthropods and chordates. This occurred over a period of 325 million years, during the Paleozoic Era. The early development of these animals occurred in the ocean. Although small jawless fish (which probably arose from a mutation that allowed larval forms of protochordates to reproduce) with bony skin plates were found at this time they were probably bottom scavengers. The major predators were the invertebrates with skeletons, particularly the arthropods. The formation of the jawed fish saw a shift in this pattern as these animals were then able to become the top of the food chain. Two lines of jawed fish survived—those that remained in the oceans to form the cartilaginous sharks and rays of today and those that adapted to freshwater conditions and developed bony skeletons and changes in fin structure. The latter group later re-inhabitated the seas. Climatic changes during the early Paleozoic Era resulted in changes to land forms and isolation of bodies of freshwater.

?

Review questions

4.26 Both the molluscs and the echinoderms have skeletons. Suggest why these two groups did not later become more dominant in the animal world.

4.27 The formation of a jointed skeleton allows much more precise movements which can aid both locomotion and food procurement. Explain why this is the case.

4.28 In what ways do the arthropod and chordate body plan differ?

4.29 Describe the changes involved in the change from:

(a) protochordate to vertebrate

(b) jawless to jawed fish

(c) ray-finned to lobe-finned structure in fish.

4.30 What is the primary function of a swim bladder in fish?

4.31 ‘A swim bladder can be considered as a pre-adaptation to life on land.’ Suggest a reason in support of this statement.

4.6.4 The invasion of land

That life forms were limited to an aquatic environment was not just a matter of body design. Certainly organisms needed particular features to overcome the effects of gravity (some form of skeleton), prevent dehydration (body covering, osmoregulation) and utilise gases that are no longer in solution. The main impediment to living on land, however, was the lethal amount of ultraviolet radiation present in the earth’s atmosphere. Water reflects and absorbs solar radiation. While organisms remained in the sea, they were safe from high frequency radiation that disrupts cell organisation.

The massive explosion of eukaryotic life forms during the Cambrian Period (540 million years ago) saw an ever-increasing number of algae. Like the cyanobacteria, many of these were single-celled, free-floating forms that drifted in the surface waters of the oceans taking in carbon dioxide and releasing oxygen. In shallow waters, larger multicellular algae developed. Most of the oxygen escaped into the earth’s atmosphere. As the oxygen built up, some of it drifted high into the atmosphere and formed the ozone (O_3) layer. This formed a protective shield reflecting a large proportion of ultraviolet radiation back into space. With the advent of the ozone layer, it was safe for organisms to leave their watery domains and invade land.

It is likely that some algae developed the ability to sustain short periods of time out of water in the inter-tidal zone, as occurs on present rocky shores. Other green algae and lichen could, like their modern counterparts, have taken up permanent residence in the moist soils of marshes and swamps adjoining freshwater lakes. This could have provided protection from the harsh terrestrial conditions for some small animals such as arthropods.

The fossil evidence suggests that the first organisms to become truly terrestrial were scorpion-like arthropods. With their exoskeleton, they were well protected from dehydration. Their jointed appendages held their bodies off the ground, allowing them to both pump air in and out of internal gas exchange areas and move effectively across the surface.

It has been hypothesised that as the jawed fish arose, they supplanted the arthropods as the major predators. The arthropods were possibly forced onto the land to escape being eaten. To allow increased growth, the arthropods have to periodically shed their exoskeleton and secrete a new one. It takes time for this new secretion to harden. Thus they would have been particularly vulnerable to attack during this process. By moving onto the shorelines to moult, they would have reduced the chances of being eaten. These scorpion ancestors may well have also, like modern horseshoe crabs, used this time of producing a new exoskeleton to reproduce before returning to the sea.

Although their skeleton provided pre-adaptation to terrestrial life, to live completely on land they needed the ability to breathe air, take in and assimilate different types of sensory information, decrease water loss in excretion and modify feeding and sexual behaviour. Since plants had not evolved at the time of the first traces of land arthropods (fossilised tracks), it has been suggested that many of these escapees from the water were detritus feeders (feeding on remains of living matter washed ashore or dead intertidal algae) and predators of the detritus feeders. Over time chance mutations saw the development of structures that allowed the full utilisation of a terrestrial environment.

The earliest fossils of whole animals included spiders. They were already well adapted to life on land, having a primitive gas exchange system called lung books that are still found in modern trapdoor spiders. Other arthropods present were scorpion-like creatures and some that were half way between insects and crustaceans.

The later evolution of plants provided a whole new range of feeding opportunities and environments for the arthropods, resulting in the huge array of terrestrial arthropods seen today. Vast swamplands were replaced by rivers and streams meandering through areas of stabilised soil occupied by forests of large spore-bearing plants and then later gymnosperms and flowering trees. These rivers carried and deposited sediments that further built up the land in places.

The success of the arthropods may be attributed to many factors. First, their segmented form gives scope for a wide variety of modifications by fusion of the segments. Appendages have become modified for functions such as food procurement, defence and locomotion. Mouthparts, which are modified appendages, have become adapted for feeding in a variety of ways: piercing (e.g. mosquito), sucking (e.g. housefly), biting (e.g. centipede) and chewing (e.g. beetles). Since the diet in the larval stages is usually very different from that of the adult, competition for food sources does not occur between these stages of any species. The division of labour (both externally and internally) of body parts into head, thorax and abdomen has led to greater efficiency of operation. This is coordinated by a well-developed central nervous system with brain formation. Finally, the evolution of winged forms opened a new habitat for the insects.

The evolution of the insects followed the development of terrestrial plants on which they rely for food. The range of foods available became diversified with the evolution of the angiosperms. The structure of each individual plant is so complex that it provides a variety of resources that can be exploited by many insect species with different requirements and adaptations. The possibilities for the survival of organisms with different random mutations were so abundant that it allowed for the great diversity of insect species. Insects possibly provided food for the first terrestrial verebrates and definitely for the first mammals, all of which display teeth specialised for an insectivorous diet.

In the 80 million years between the Silurian

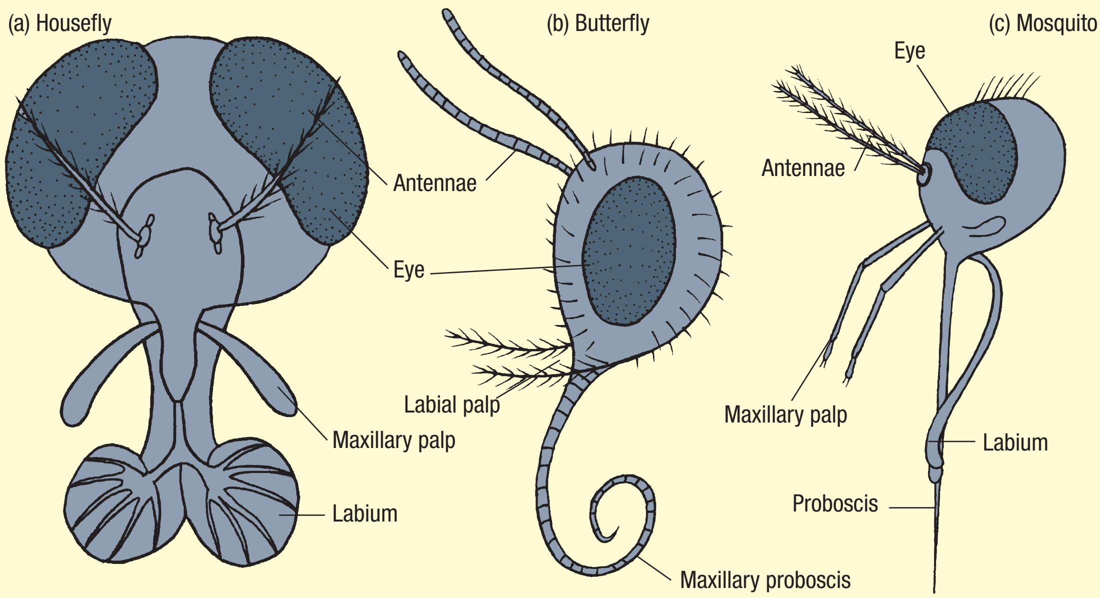


Figure 4.34 Mouthparts of sucking insects

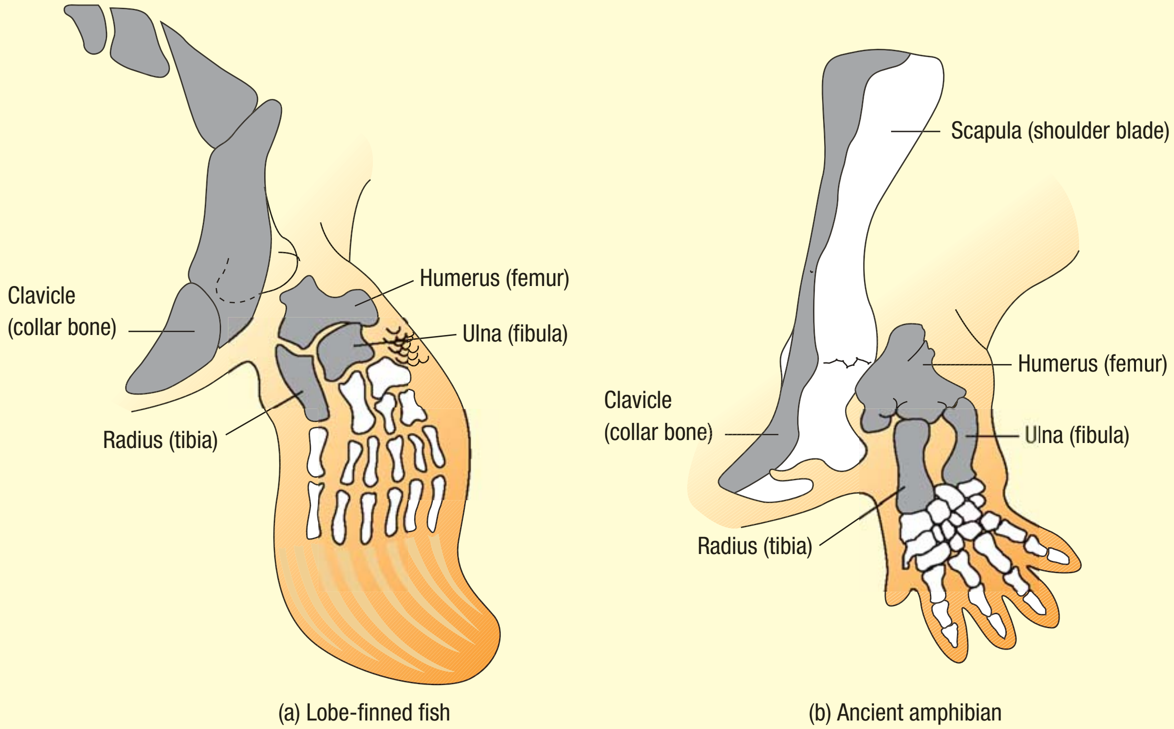


Figure 4.35 Resemblance between the limb structure of the lobe-finned fish and amphibians

Period and the Late Devonian the climate became drier. It is likely that bodies of freshwater started to dry up and the lobe-finned fish were forced to move from pond to pond. They already had a swim bladder that allowed them to take in air, and this would have acted as a primitive lung in their journeys across small stretches of land. Their lobe fins would have propped them up so that they were able to ventilate effectively while pulling their bodies along. It is from this group of fish that the amphibians are thought to have evolved. It did not require a huge change in the structure or arrangement of shoulder and limb bones of the lobe fin to produce the amphibian leg.

All terrestrial vertebrates (and those derived from them, such as the whale) are termed **tetrapods**. They have four limbs, terminating in separate digits. Each pair of limbs is suspended from a bony girdle (the anterior and posterior, or pectoral and pelvic girdles). The basic structure of each limb is similar and, since it terminates in five digits, it is termed a **pentadactyl** limb. Regardless of the modifications to this structure, such as fusion of bones to form a hoof, or development of wings or flippers, the limb of all terrestrial vertebrates is derived from this basic plan. It is a homologous structure.

The earliest tetrapods used their limbs to merely raise the body above the ground while using serial contraction of the body muscles to achieve locomotion (somewhat like a fish). Reorientation of the limbs under the body allowed them to act as vertical levers, reducing the number of muscles required to lift the body off the ground and thus developing them as the main means of locomotory action. Amphibians and reptiles show the primitive limb arrangement.

Water is a limiting factor for terrestrial animals. Most, therefore, have developed an impermeable outer covering which reduces water loss by evaporation. The pharyngeal gill slits, obvious only in very early embryonic development, have been replaced by an internal growth from the pharynx, the lungs. Gas exchange takes place predominantly through the moisture-lined surfaces of these internal structures. These animals have a pair of external nostrils for the exchange of gases between the lungs and the outside environment. The development of lungs is associated with a double circulation system: one set of vessels takes deoxygenated blood from the heart to the lungs and returns it to the heart (the pulmonary circulation), and the second set of vessels carries the blood around the body (the systemic circulation). This development required elaboration of the heart to pump the oxygenated and deoxygenated blood to different body localities.

The lung of the amphibians is little more than a

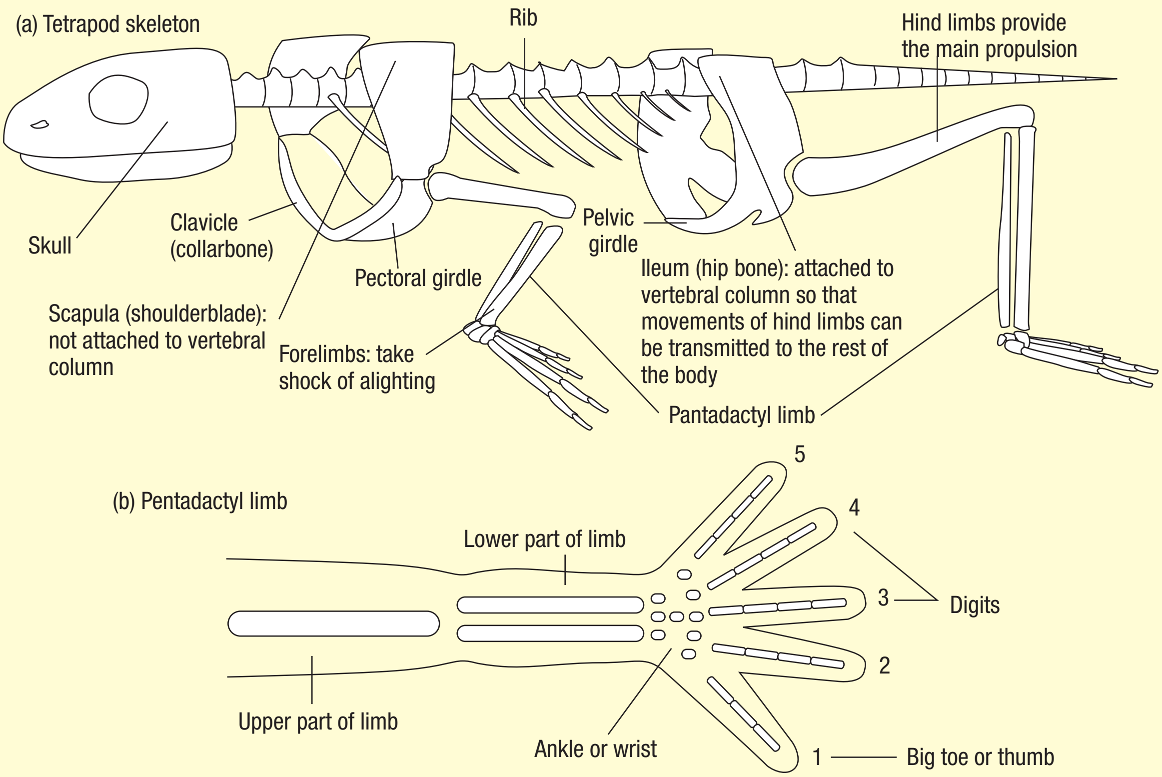


Figure 4.36 The tetrapod plan, showing pentadactyl limbs

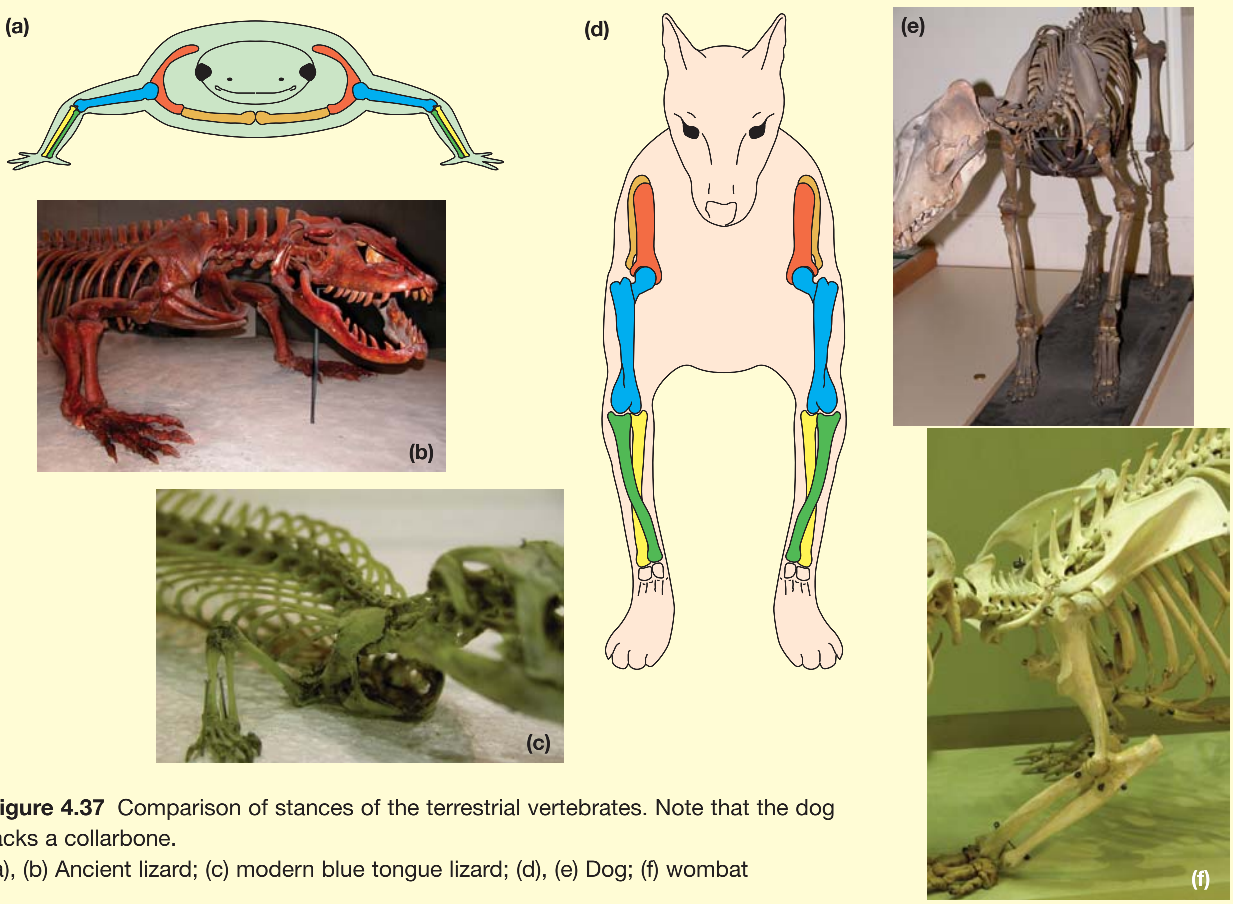


Figure 4.37 Comparison of stances of the terrestrial vertebrates. Note that the dog lacks a collarbone.
(a), (b) Ancient lizard; (c) modern blue tongue lizard; (d), (e) Dog; (f) wombat

swim bladder and does not have the surface area of the gills of their aquatic ancestors or the more advanced lungs of later vertebrates. In order to obtain adequate oxygen in their new environment they reverted to 'skin breathing', the major form of gas exchange seen in the lower invertebrates. This requires the skin to be moist and so limits the amphibians to moist environments.

Reproductive strategies of aquatic organisms can be relatively simple, because dehydration is not a problem. Eggs and sperm can be released into the water and both fertilisation and development are external. This is not the case for terrestrial animals, however. The amphibians overcame this problem by having two different stages—an aquatic developmental stage and a terrestrial adult phase. The eggs, which are fertilised externally in water, develop into a swimming larva (tadpole) which is a herbivore; the larva metamorphoses into the insectivorous, terrestrial adult (see Figure 1.9). There are, however, many variations to this pattern in modern amphibians. Some have internal fertilisation, while others have direct development from fertilised egg to adult.

The early adult amphibians were far more like salamanders than the frogs and toads that are the more common modern forms. They had an elongated tail and their locomotion was more like that of the reptiles. Mutations brought about the changes in the pelvic structure, allowing jumping locomotion, and the loss of the tail at a later date. During the Carboniferous Period, with no other vertebrate competitors, a broad spectrum of shapes, sizes and modes of life appeared among the amphibians. Some even attained the size and similar shape of alligators. It is not surprising, therefore, that changes that allowed a more competitive exploitation of the terrestrial environment away from a direct water supply occurred. Late in the Carboniferous Period another group of organisms, the reptiles, appeared. Towards the end of this period, the swamps that were a prevalent feature of the landscape began to dry up and many of the amphibians were unable to survive in the changed environment. With their well-developed lungs and dry, scaly skin, the reptiles survived and gradually spread over the continents.

All of the non-amphibian tetrapods have a special adaptation to terrestrial living. The whole of the zygote (fertilised egg) of amphibians contributes to the structures of the embryo. In reptiles, birds and mammals, part of the zygote forms the embryo, while other parts form extra-embryonic membranes. One of these, the amnion, becomes a fluid-filled sac which encloses the embryo and thus provides it with an individual aquatic environment. This is a significant adaptation for living on land. Fertilisation is always internal in these animals. Some—the reptiles, birds and a few mammals (e.g. the platypus)—lay an egg with a shell, and development is external. Others have internal development. Some snakes (e.g. the python) retain the eggs within the female, but this internal development differs from that displayed by the mammals.

Modern reptiles include the snakes, lizards, turtles and crocodiles. Fossil records suggest that they evolved 300–240 million years ago. Recent investigations suggest that the crocodiles and birds

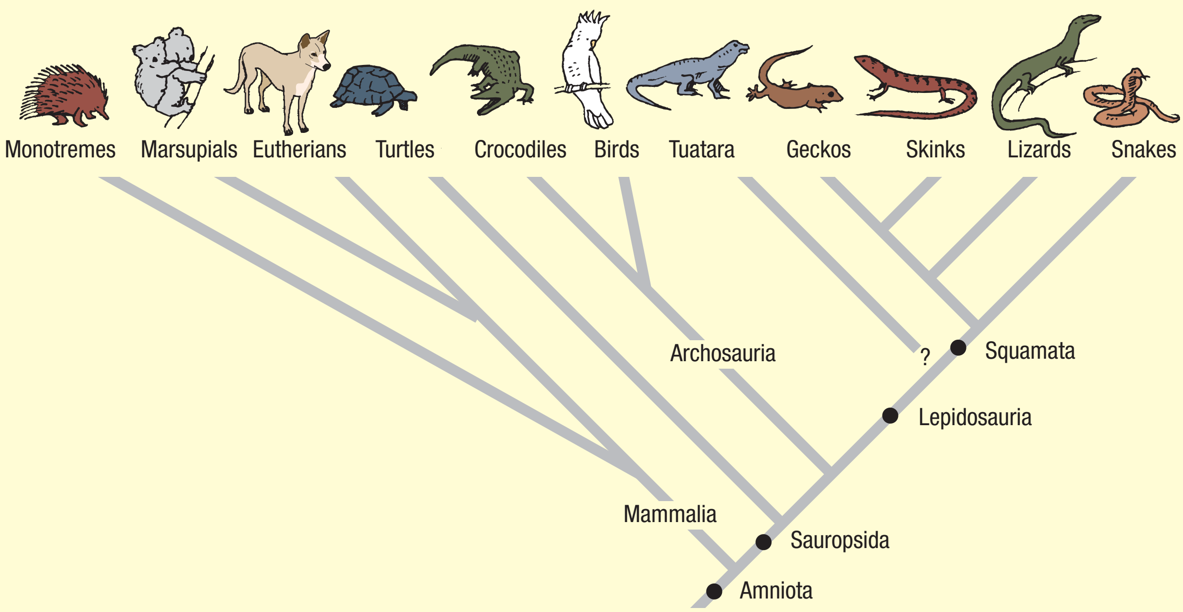


Figure 4.38 Possible evolutionary paths of the reptiles, birds and mammals

had a common reptilian ancestor whereas mammals, turtles, lizards and snakes were all derived from separate reptile branches.

The first reptiles were small, lizard-like animals that fed on insects. From this ancestral type, two major groups arose. One of these was the line that led to the dinosaurs, crocodiles and birds and modern reptiles. The other line resulted in the mammals.

The first expansion of reptiles was seen in the paramammals. The smallest of these animals were invertebrate eaters; medium-sized paramammals ate smaller ones, which were in turn eaten by larger ones. At this point there were no herbivorous vertebrates—they lacked the digestive system necessary to cope with grinding up and digesting cellulose. Over time the skull of these animals became stronger, with shorter snouts. This resulted in fewer teeth, which became modified to perform different tasks. A major breakthrough was the development of a soft palate that separated the air passage to the lungs from the food passage to the stomach. These animals, unlike all before them, could breathe continuously, even when feeding. They had a constant supply of oxygen. This adaptation eventually resulted in the formation of the endothermal mammals.

The accumulated mutations that occurred in this group over 50 million years resulted in an advanced form of paramammal. The most significant change was the development of massive plant-eaters. Both flesh- and plant-eaters of this time also began to change the way they stood and walked. The limbs were reoriented underneath the body. This required a greater coordination and balance and this change was accompanied by an increase in the size of the cerebellum, that part of the brain involved with balance. Some of these animals were true endotherms and it is thought that a few may have sported whiskers. The final step in becoming a mammal, however, was in the way the jaw is joined to the skull.

Two small bones, one attached to the skull and one to the lower jaw, hinge the jaw in all reptiles. In the mammals the lower jaw is hinged directly to the skull. The two small bones of their reptilian ancestors are incorporated into the middle ear. The ear drum vibrates against them and they amplify the sound vibrations passing to the middle ear.

During the time that the paramammals were dominant, the other reptiles were small insect eaters and scavengers of the river banks. The dinosaurs were a branch of this line of early reptiles. Their ancestors grew long, powerful tails and hind limbs longer than front ones. With time some changed to a bipedal straight-limbed stride, using the tail as a counter-balance to the head and body. Within a few million years they decimated both plant- and flesh-eating paramammals. These dinosaurs became the dominant form of animal life on land for about 150 million years (during the Jurassic and Cretaceous Periods of the Mesozoic Era).

Many different body forms emerged from within the dinosaur group. Some became plant-eaters. One group developed feathers which helped them to fly and provided insulation. Modern birds were later descended from this group. Like their ancestors, they have internal fertilisation but external development of the young in a shelled egg. This egg shell, unlike the leathery covering of the reptilian egg, is impregnated with calcium carbonate.

Almost every part of the bird's anatomy is adapted to enhance flight:

- The bones are not solid, but form a honeycomb of struts which provide a light but strong structure (similar to the support of large bridges).
- The loss of some structures, such as teeth, has reduced weight.
- The breastbone has a large keel for attachment of flight muscles.
- Birds have large pectoral (chest) muscles to power the flapping motion of the wings.
- They have a chemical system that produces high levels of energy for active, sustained flight.

The early mammals were small insectivores that, being endotherms, could hunt at night. Their bodies became covered in hair to help maintain body warmth. Their reptilian relatives, unable to control their body temperature, were only active during the day. They retained the reptilian reproductive strategy of laying shelled eggs. In the female, special sweat glands secreted a nutritious fluid (milk) into grooves. The newborn young had an immediate source of food. These early mammals were the ancestors of the modern monotremes (the platypus and the echidna).

In the middle of the Cretaceous Period two distinct groups of mammals appeared—the marsupials and the placentals. In both groups, the milk-producing sweat glands became grouped together to form mammary glands, each with a nipple or teat through which the milk is released. The earliest marsupials were primitive opossums that gave birth to undeveloped young that completed development attached to a teat within a pouch. The first placental mammals, able to retain their young inside the mother's body for full development, resembled shrews.

About 65 million years ago the dinosaurs, and many other life forms, disappeared. Only tropical plants, small terrestrial animals and freshwater organisms appeared to come through this time unscathed. There has been a great deal of controversy surrounding this period of mass extinction.

Recently several craters (whose origins date to about 65 million years ago) have been discovered around the world with clay boundaries containing large amounts of radioactive iridium (an element rare in the earth's crust but abundant in meteorites). One theory proposes that a series of asteroids collided with earth. According to this theory, the impact and explosion of the asteroids created a dense cloud of debris which blocked out sunlight for a period of time, resulting in the death of plants and collapse of food supplies for terrestrial and marine heterotrophs. The cloud would have also brought about changes of climate which added further stress to terrestrial organisms. Other, smaller mass extinctions have occurred at other times, and these are currently being linked to asteroid collisions. Whatever the cause, the surviving organisms and their later diversification have led to the modern life forms on earth.

Widely dispersed, small animals have a better chance of survival when food becomes scarce than larger ones. Many of the dinosaurs had reached massive proportions. The drastic reduction in plant life that would have been associated with a catastrophic event such as a series of large asteroid hits meant that there was not enough food to sustain the dinosaur populations. A 30-tonne brontosaurus would need the same amount of food as 100 000 rat-size mammals. The demise of the dinosaurs allowed the expansion of the mammals.

SUMMARY

The first terrestrial animals were arthropods. Scorpion-like animals came out of the water, at least for short periods of time, before the advent of the first plants. Their diversification, and the rise of the insects, however, did not occur until after plants were well established. Primitive amphibians are believed to have arisen from freshwater lobe-finned fish. Like the arthropods, they were pre-adapted to life on land. Both types of organisms could lift their thoracic cavities off the ground, allowing them to ventilate internal gas-exchange organs. The early terrestrial vertebrates were all herbivores. All terrestrial vertebrates (and those that have later returned to the water-like whales) are tetrapods with a pentadactyl limb. The development of the amniotic egg, a more advanced lung and waterproof skin released lines of early vertebrates from their reliance on water. Ancestral reptile lines came into being. Different groups of ancestral reptiles developed and ultimately resulted in the diverse groups of modern reptiles, the birds and the mammals. During the Jurassic and Cretaceous Periods of the Mesozoic Era, the dominant animals were the dinosaurs. They and many terrestrial and aquatic organisms became extinct about 65 million years ago, possibly as a result of asteroid impacts on earth. The surviving organisms are the ancestors of all modern forms of life on earth.

?

Review questions

4.32 Define the following terms:
(a) tetrapod
(b) pentadactyl
(c) amniotic egg.

4.33 An organism is described as a tetrapod.
(a) What kind of organism is it?
(b) Where does it live?
(c) List at least four other features of this organism.
Give reasons for each of your answers.

4.34 List, with reasons, the changes that animals went through from being a fish to the first true mammal.

4.35 Over the time of earth's history there have been periods of mass extinctions where many types of organisms have perished. Give at least two reasons why mass extinctions have occurred.

4.36 Suggest one biological reason for the extinction of the dinosaurs after a massive physical catastrophe.

4.6.5 Australia's unique mammals

There are three subclasses of mammals: monotremes, marsupials and placental mammals. Monotremes (represented by the echidna and platypus) lay a shelled egg. The echidna incubates this in a primitive pouch. It then carries the young in the pouch until its spines develop. The platypus builds a special nest tunnel where the egg is incubated. In monotremes the milk-producing cells are not grouped into typical mammary glands. Instead, the milk oozes out at the base of tufts of hair and the baby licks the milk-laden fur rather than sucking directly from a teat or nipple.

Marsupials (*marsupium* = pouch) are those mammals which have a short gestation period (pregnancy), and the young are born at a very undeveloped stage. They make their way unaided to the abdominal pouch and attach to a nipple which provides the nourishment to complete their development, since most marsupials do not develop a true placenta.

The placenta is an extra-embryonic structure which allows exchange of food, gases and wastes between the blood supplies of the embryo and the mother. The placental mammals, due to the formation of an efficient placenta, give birth to young at an advanced stage of development. Many of these animals have unique adaptations which have enabled them to return to an aquatic environment (e.g. the dolphin) or to adopt an aerial existence (e.g. bats).

Australia is the only continent that has representatives of all three groups of mammals. At one time the ancestors of modern marsupials lived in most areas of the world. As the placentals evolved, the marsupials were unable to compete successfully with them for resources, and in most regions marsupials became extinct. It was believed that they survived in isolated areas mainly because the placentals failed to reach them. There is new evidence of fossil placentals from Australia, however, which may cause this idea to be revised.

According to the continental drift theory, the great landmasses were originally joined. Each of these landmasses is associated with a solid crustal plate which can be added to or removed at its borders as a result of activities beneath the earth's crust. These actions caused the plates, carrying the continental landmasses, to drift apart until they eventually came to their present positions. These movements are still taking place.

South America and Australia are thought to have separated from the general landmass before the evolution of the placentals. Australia had been isolated for some 120 million years before the ancestors of the Aborigines arrived, and until then virtually no placentals had found their way to this continent.

Although one species of marsupial exists in North America and a few survived the later arrival of placentals in South America, the marsupials diversified on the Australian continent, occupying a wide range of environmental conditions. As a result of similarities in habitats, many of these animals look structurally similar to placentals. This similarity in appearance is an example of convergent evolution. Table 4.3 shows some examples of this convergence.

There are several placental mammals native to Australia. These include several groups of rodents (rats and mice) and bats. The rodents' ancestors probably crossed the sea from the Asian mainland by island-hopping on natural rafts of timber or other debris washed out to sea by flooding rivers. There

Table 4.3 Some examples of convergence due to habitat utilisation by marsupials and placentals

Diet	Habitat	Placental	Marsupial
Carnivore	terrestrial	cat	Tasmanian devil
	burrower	fox	marsupial mouse
	arboreal	panther	native cat
	freshwater	otter	platypus (monotreme)
	marine	sea leopard	
	aerial	vampire bat	
Omnivore	terrestrial	pig	bandicoot
	burrower	badger	
	arboreal	monkey	opossum (South America)
	freshwater	water rat	water opossum (South America)
Insectivore	terrestrial	anteater	numbat
	burrower	mole	marsupial mole
	arboreal	tree pangolin	
	aerial	insectivorous bats	
Herbivore	terrestrial	sheep	kangaroo
	burrower	rabbit	wombat
	arboreal	sloth	koala, possum
	freshwater	hippopotamus	
	marine	dugong	
	aerial	fruit bat	
	glider	squirrel	sugar gliders

were probably several landings on different parts of the northern coast at different times and each group would have adapted, over long periods of time, to the particular habitat into which they were flung by chance. Thus a unique Australian population of rodents developed. Similar chance arrivals of bats, possibly blown off course in windy conditions, have led to several species of bats now fully adapted to a variety of Australian habitats.

Animals that are native to Australia (or any area) are termed **indigenous**. The animals brought into this country either deliberately (e.g. horse, cattle, sheep, rabbit, fox, dog, cat) or accidentally (e.g. ship rat and house mouse) are **exotics**, and if they escape from human custody and survive as wild animals they are termed **feral**. Feral animals (such as cats, camels, goats, pigs, buffalo) have caused considerable environmental damage.

Case study 4.1: Indigenous Australians and the dingo

There is considerable debate about when the first humans arrived in Australia. New techniques in fossil ageing suggest that it may have happened more than 100 000 years ago. There were possibly three waves of immigration (from Indonesia and China), as suggested by marked differences in fossilised human bone from different localities. Although some boat travel must have occurred, the sea level would have dropped during the last glacial period (78 000–10 000 years ago) and land bridges may have connected parts of Indonesia with Australia, allowing easier access. There is an increased amount of charcoal associated with fossils from this time, which may be attributed to the fire-culture hunting methods of these early immigrants.

Burning has changed the Australian landscape. Rainforest has been replaced by fire-tolerant species in many parts of the country. It has been suggested that burning created environmental instability and that the vegetation changes could have altered stream flow and lake levels to such an extent that a drought-prone environment resulted. Changes in vegetation and water availability have a marked effect on the animals that can survive in any particular area. Certainly there was a marked increase in the extinction of many large Australian animals between 100 000 and 35 000 years ago.

The dingo, long thought to be the companion of the first Australian immigrants, evolved from the wolf and was first domesticated by the peoples of Asia. In western Asia they were subjected to artificial selection and some 600 breeds can be traced to dingo origins. In eastern Asia (particularly Thailand) the dingo was not selectively bred and thus has remained virtually unchanged for at least 5500 years. During that time they were transported by seafarers (probably as a source of fresh food) to other parts of the world, including Australia.

Fossil records suggest that dingoes were introduced to Australia about 4000 years ago. They have contributed to the extinction of the thylacines and mainland devils by out-competing them for resources in times of drought. Their numbers were, however, probably too low to make a great impact on the Australian fauna until the immigration of Europeans who brought rabbits and stock with them, providing an easy food source. The development of artesian bores for watering stock also resulted in an increase in populations of many species of wallabies and kangaroos, and this provided further food for the dingoes.

It is now considered that the dingo is responsible for the decimation of many small Australian marsupials. Although this carnivorous animal has had an impact on the Australian environment, the environment has also influenced it. Changes in the dingo over the past 4000 years have been such that it is now considered to be a separate subspecies from its Asian precursor.

SUMMARY

There are three subclasses of mammals: the egg-laying monotremes, the marsupials that give birth to undeveloped young and the placental mammals that are able to give birth to developed young. The latter group was able to utilise its habitats more effectively than the marsupials and began to replace them in nearly all areas of the world where both coexisted. It is thought that the movement of the earth's plates, resulting in the isolation of the Australian plate from other continents, occurred prior to the development of the placentals. On this continent, with no competitors, adaptive radiation of the marsupials meant that they filled all habitats and heterotrophic parts of the food chain which has been paralleled by the placentals on other continents. This is known as convergent evolution.

?

Review questions

4.37 List the reproductive strategies of the three subclasses of mammals.

4.38 Explain why there are so few placental mammals indigenous to Australia.

4.39 Describe an example of convergent evolution between a marsupial and a placental. In your answer describe each animal, the habitat in which it lives and the structural features it has that allows it to survive successfully in that place.

4.40 Giving examples, distinguish between animals that are indigenous, exotic and feral to Australia.

4.7 Kingdom Plantae

4.7.1 General structure

Plants are multicellular, photosynthetic organisms primarily adapted for life on land. They probably evolved from aquatic green algae. Many adaptations would have been required for organisms to make this transition from water to land, and plant characteristics reflect this change in mode of life. The general structure of plants was described in Chapter 3, page 40. It is possible that the evolution of the plants was 'driven' by the need to become more and more efficient at obtaining essential nutrients from the environment and transforming them into 'food' through the process of photosynthesis. Evidence of this is seen in the general structure of modern plants, particularly in the development of the vascular system.

Two distinct groups of plants—the bryophytes and the vascular plants—evolved not long after their transition onto land. Vascular plants possess systems of vessels which enable rapid transport of materials around the plant.

There are two types of vascular tissue. **Xylem** conducts water with dissolved minerals from the soil to the photosynthetic cells. **Phloem** transports organic compounds around the plant. In both types, the individual cells align themselves to form long, continuous tubes between the cells of the root and the leaves. In xylem, there are two types of water-conducting cells: **tracheids** and **vessels**. Tracheids are primitive, elongated cells with tapering, perforated ends. These ends interlock, providing both extra strength and a water-conducting tube. The cells (elements) of the vessels have lost their end walls and become fused together to form a continuous conducting tube.

Photosynthesis is a complex set of reactions in which large organic molecules (carbohydrates) are formed from small inorganic molecules (carbon dioxide and water). This process requires a large amount of energy. Special pigments (chlorophylls *a* and *b*), contained within green structures termed **chloroplasts** in plant cells, trap light energy. This is converted into chemical energy, which is used to make glucose, a simple carbohydrate. Oxygen is also produced as a by-product. The overall process can be summarised as:

$$\text{carbon dioxide} + \text{water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose} + \text{oxygen}$$

The spaces between the internal cells of a plant are rich in water vapour. Carbon dioxide, contained in the air that passes through the stomata, forms a solution with the water. It is in this form that it passes into the cells and is used in photosynthesis. The oxygen that is produced in the reaction is either used by the plant cells for respiration or released into the environment through the stomata.

In the presence of minerals absorbed from the

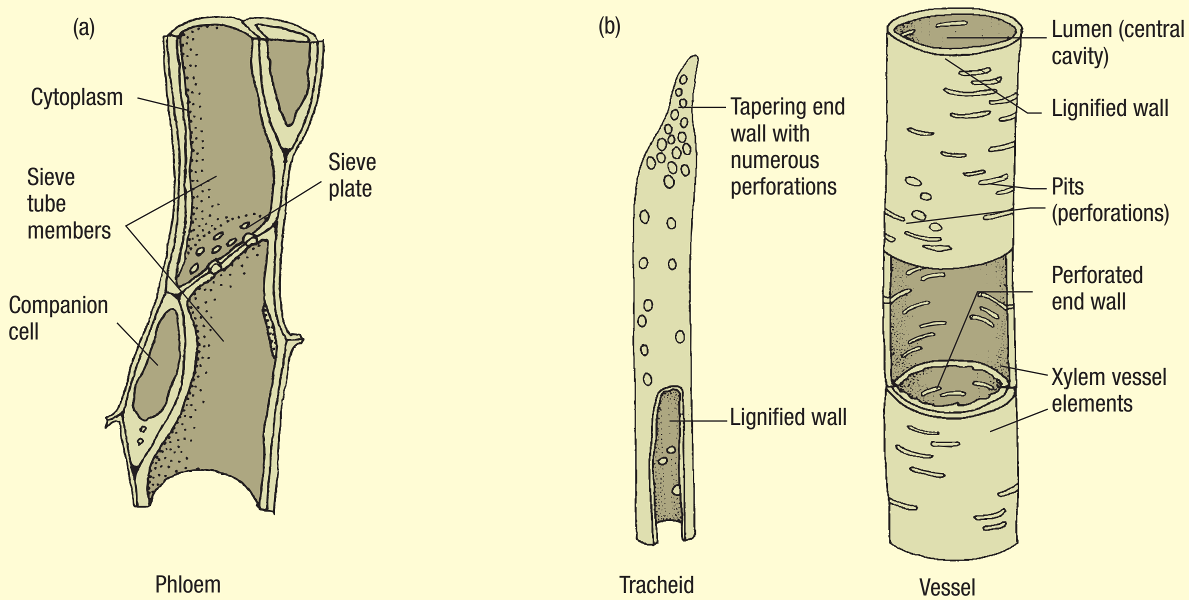


Figure 4.39 (a) Phloem and (b) xylem

soil, further chemical reactions take place within the cells, converting the glucose into other organic substances needed by the plant, such as proteins, oils and nucleic acids. Any excess glucose is stored as a complex carbohydrate, starch, within the cells. Starch is a colloidal substance, which means that it remains suspended in the cell contents without forming a solution. Thus it does not affect the concentration of solutions in the cell and so does not upset the water balance. This is a significant feature in an environment in which water may not be abundant.

4.7.2 Reproduction

Plants have a life cycle in which an asexually reproducing generation is followed by a sexually reproducing one. This is termed alternation of generations. The cells of the two alternating generations differ in the number of chromosomes they contain. The asexual phase is termed **diploid** or *2n* because its cells contain two of each type of chromosome (*n* represents the number of types of chromosomes). The sexual phase is termed **haploid** or *n* because its cells contain only one of each type of chromosome.

The diploid (*2n*) plant is called the **sporophyte**, because it reproduces asexually by producing spores. The haploid (*n*) spores are formed by a type of cell division called **meiosis**, or reduction division. Each pair of chromosomes separates, so that each of the four daughter cells contains half as many chromosomes as the mother cell—one from each pair.

Each spore that is released from the sporophyte can grow to form a plant in which all of the cells are haploid. The haploid (*n*) plant, which differs in appearance from the sporophyte, is termed the **gametophyte** because it produces male and female gametes. This time the type of cell division is **mitosis**, whereby each daughter cell has the same number of chromosomes (*n*) as its mother cell. The female gametes, or eggs, are retained in the protective structures in which they are formed. The male gametes, or sperm, are transported to the egg in a fluid medium. Fertilisation is the union of a sperm and egg to form a zygote. Thus reproduction in the gametophyte generation is sexual.

The zygote has two of each type of chromosome (one from the sperm and one from the ovum), so it is diploid (*2n*). The zygote grows and develops into the next sporophyte generation. The growth of the

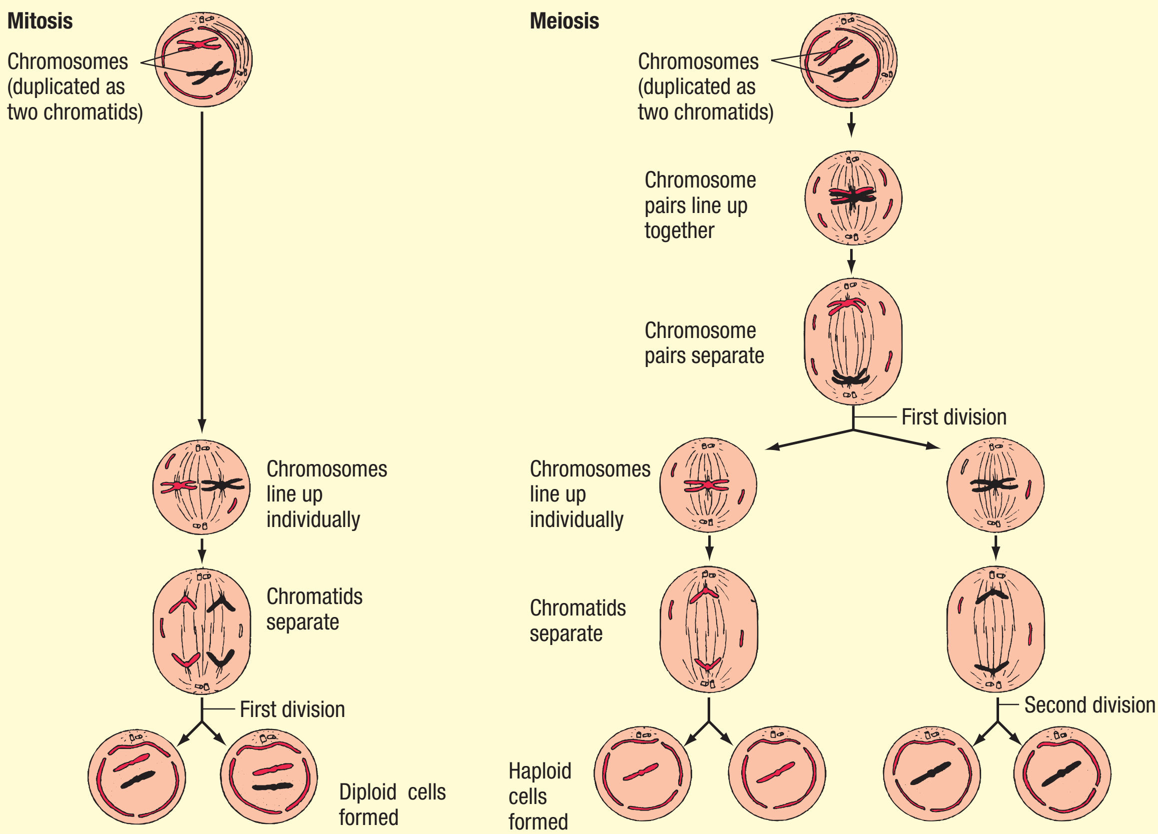


Figure 4.40 Mitosis and meiosis in an animal cell. A homologous pair of chromosomes is illustrated. Mitosis in plants may involve production of haploid cells from a haploid mother cell, or diploid cells from a diploid mother cell.

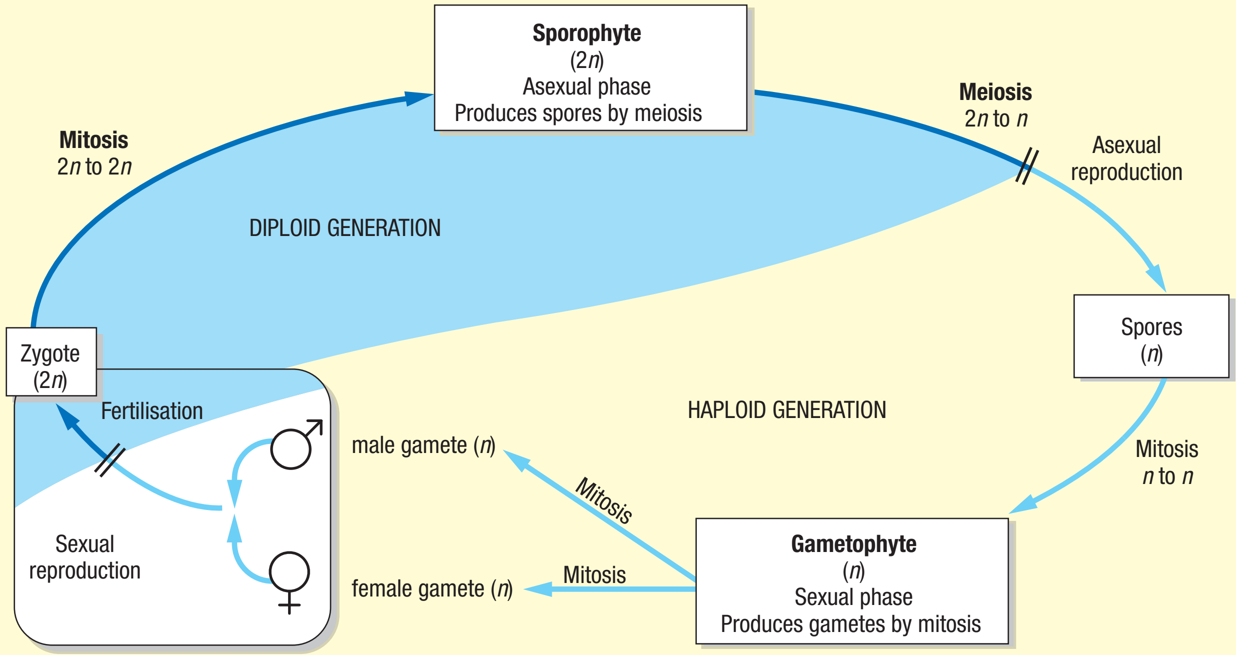


Figure 4.41 Generalised plant life cycle showing alternation of generations

gametophyte from the spore and the sporophyte from the zygote involves the change from a single-celled form to a multicellular organism. To achieve this, the cells divide by mitosis, ensuring that the daughter cells have exactly the same numbers and types of chromosomes as the original 'mother' cell.

Figure 4.41 shows this alternation of generations diagrammatically in a generalised plant life cycle.

In sexual reproduction, variations in characteristics of individuals can occur. In changing environmental conditions sexual reproduction may be important for the survival of the species since some of the offspring are likely to have characteristics which suit them to the changed conditions. Individuals with characteristics that best suit them to the environment will grow and compete for resources more effectively than other individuals without these specific characteristics. Therefore in the asexual phase they will produce the most spores. The asexually reproducing stage ensures that a large number of individuals with desirable features will be retained within the population, since no variations

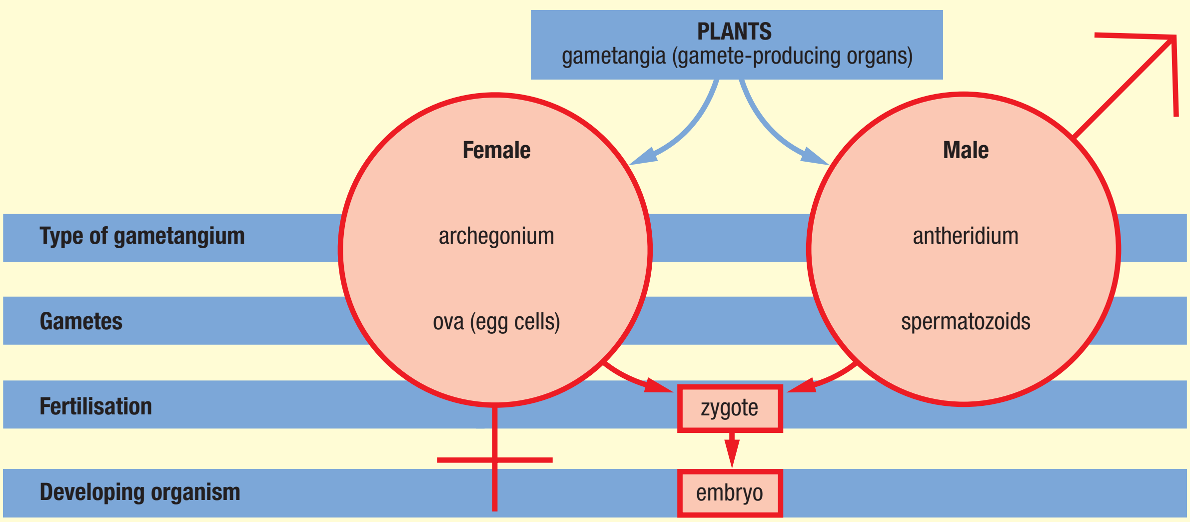


Figure 4.42 Summary of reproductive structures found in plants

of features will occur.

Plants have multicellular reproductive organs with a non-dividing (sterile) outer layer of cells which protects the enclosed structures from desiccation. **Gametangia** (singular *gametangium*) are the gamete-forming organs. The male gametangium is known as the **antheridium** and the female gametangium is the **archegonium**. The eggs are fertilised while they are still contained within the archegonium, which then protects the developing embryo. The spore-producing structures are termed **sporangia** (singular *sporangium*).

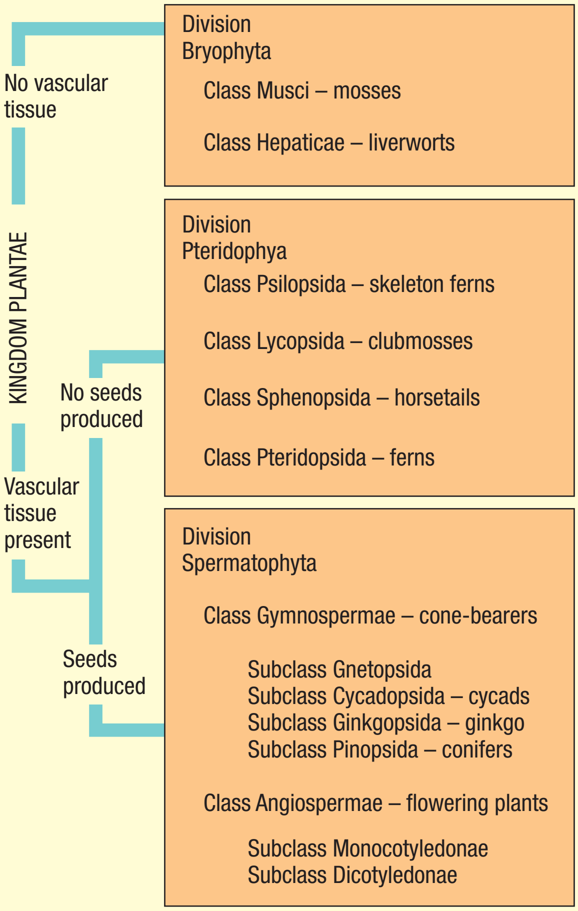


Figure 4.43 Classification of plants

4.7.3 Classification of plants

Plants may be classified in a variety of ways. One method of classification is shown in Figure 4.43.

SUMMARY

The characteristics of plants are related to their terrestrial mode of life. They have specialised cells which perform different functions such as movement of materials in solution from the soil to the rest of the plant, photosynthetic cells, cells surrounding stomata to allow gas exchange and reproductive cells. Their reproductive organs protect the gametes and spores from drying out. Further reduction of dehydration is achieved by the retention of the fertilised egg within the female reproductive organ during its development into an embryo. They have a complex life cycle which alternates a sexually reproducing generation with an asexually reproducing generation.

Review questions

4.41 Why do plants need to have different structures specialised for specific functions?

4.42 What is meant by the phrase 'alternation of generations'?

4.43 Distinguish between the sporophyte and gametophyte generation.

4.44 What is significant about an organism having both a sexually reproducing and an asexually reproducing phase in its life cycle?

4.45 Describe the significant differences between mitosis and meiosis.

4.46 Explain why growth in both plant generations involves mitosis.

4.7.4 Algal origins

The plants are believed to have evolved from the green algae. Some scientists even suggest that the plant precursor was a single species of green algae, a close relative of which exists in present-day unpolluted lakes. Although there are many differences between the green algae and plants, the similarities are striking enough to place them as ancestors. Differences are:

- plants consist of specialised cells and algae have few specialised cells
- algae lack leaves, stems and roots found in the majority of plants
- most algae have external fertilisation, while all plants have internal fertilisation.

These differences can be attributed to the fact that plants are adapted for life on land and algae are adapted for life in water. Similarities between the two groups include:

- both have the same photosynthetic pigments, chlorophyll *a* and *b*, which are found on membranous stacks within the chloroplast
- both have cell walls that contain cellulose
- both store energy as starch.

Some present-day green algae have some features in common with primitive land plants. The freshwater alga *Fritschella*, for example, has some filaments that are prostrate with rhizoid-like structures projecting into the soil for support, while other filaments are erect. Even more plant-like in appearance are members of one group of green algae called the charophytes such as *Chara* and *Nitella*.

Most of the multicellular algae can reproduce both sexually and asexually. Generally the adult plant is haploid and relatively unspecialised cells produce spores that can grow directly into another alga. Other cells may produce gametes that are released into the water and upon fertilisation produce a diploid zygote. This zygote then undergoes meiosis, followed by mitosis to produce another adult form. Some green algae, e.g. *Ulva*, have an alternation of generations, that is one generation produces spores and the other produces gametes. Both generations, however, look alike.

Although the female gametangium of algae does not contain a protective layer of cells typical of the plants, a few green algae (the charophytes) retain the fertilised egg and the embryo develops while still attached to the 'parent'. In some of these algae, the zygote does not undergo meiosis but produces a diploid organism that produces spores by meiosis. By delaying meiosis, the number of spores that can be produced by the single zygote can be amplified. This would be a useful adaptation for any plant living in harsh terrestrial conditions.

It is probable that an algal ancestor of plants developed alternation of generations where both the gametophyte (haploid) and sporophyte (diploid) generation was a simple branched filament similar to that of the newly germinated moss spore. It is likely that this ancestor was a charophyte, or gave rise to both the charophytes and plants since:

- like plants, charophytes exhibit delayed meiosis and the formation of a diploid sporophyte generation
- the charophytes are the only green algae that have a similar proportion of cellulose in their cell

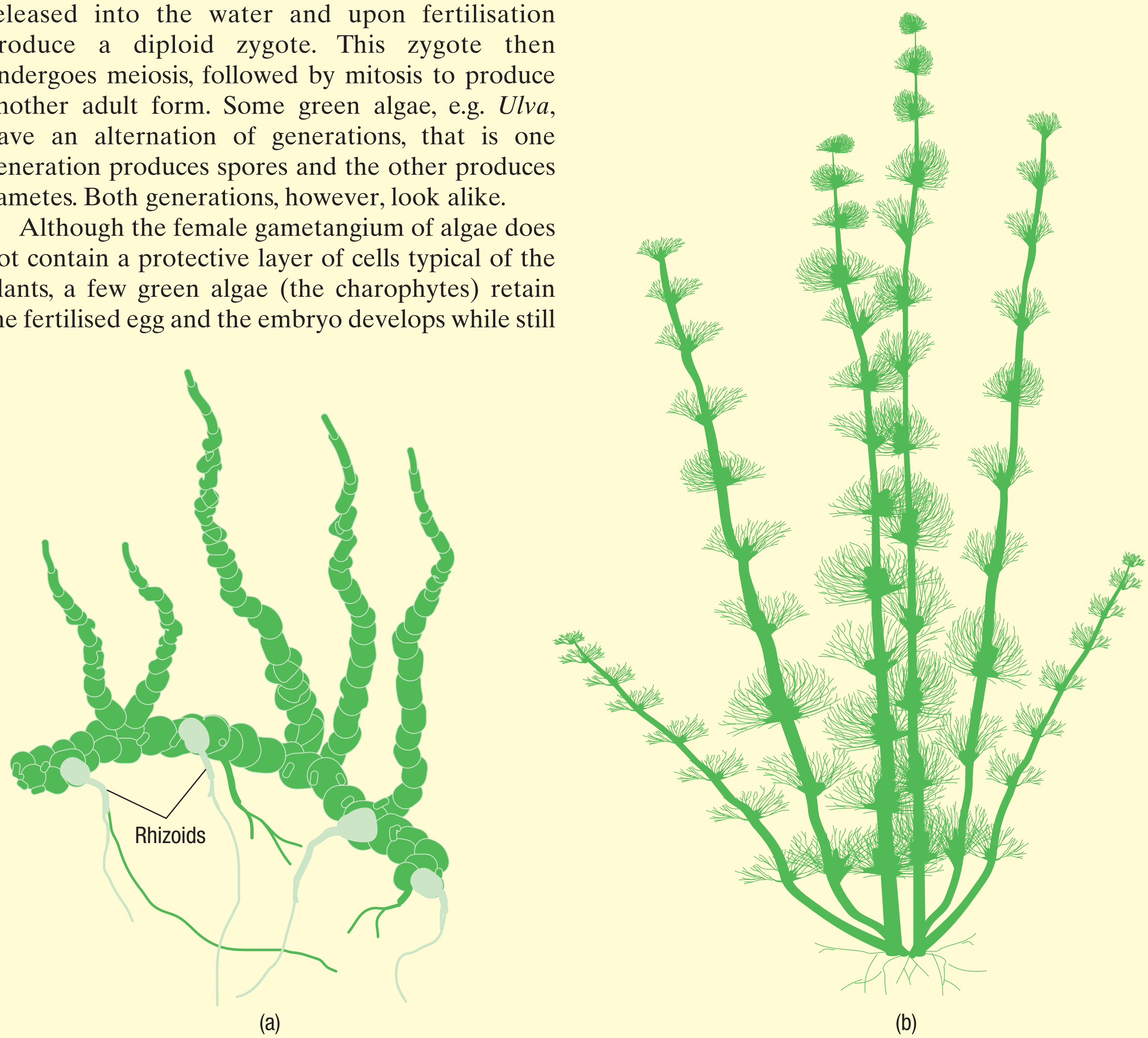


Figure 4.44 (a) *Fritschella* (b) *Nitella*

walls as plants

- both charophytes and plants have a similar mechanism of cell division; after replication of the nuclear material, microtubules are involved in the formation of a plate of cellulose that separates the two nuclei and the cytoplasm to form two cells
- nuclear genes and RNA are similar between charophytes and plants.

Right from the outset, two different plant forms were evident. One divergence of the ancestral group resulted in the gametophyte becoming the dominant generation. The sporophyte was retained and supported by the gametophyte. This group became the bryophytes (mosses, liverworts and hornworts).

The bryophytes are small terrestrial plants that lack vascular tissue and are most commonly found in damp, shady places. They do not have roots. Short rhizoids anchor them to the soil but are not involved in absorption of water and dissolved minerals. Water is conducted up the outside of the plant by capillarity, with the spaces between the leaves and the stem acting like a wick. Capillarity is the movement of water resulting from forces of attraction between individual water molecules, and between water molecules and the plant cell walls. The plant cells act like a sponge, absorbing water and the mineral nutrients that dissolve in it from dust. Some bryophytes have central strands of elongated cells that help in the transport of water through the plant, but these do not have the properties of true vascular tissues. As a result, the bryophytes have remained small in size, the largest attaining a height of only about 40 cm.

They have a free-living photosynthetic gametophyte (the dominant generation) and a simple 'parasitic' sporophyte generation which remains attached to, and derives its nourishment from, the gametophyte. The gametophyte of the mosses has a short 'stem' with small, photosynthetic leaf-like structures attached to it. These structures are only a few cells thick and lack the specialised cells of the true leaves of vascular plants. Although many are similar in structure to mosses, most liverworts and hornworts (*wort* = herb) are not leafy but thalloid: the body is a 'sheet' of photosynthetic cells called a thallus, lying flat on the ground.

In mosses, gametangia develop at the top of the plant. Flagellated sperm are released from the antheridia and swim in a film of water to the female plant. Fertilisation occurs in the archegonium, and the sporophyte develops in and grows from this structure. The sporophyte has a simple structure, consisting of a single sporangium, the capsule, usually at the top of a slender stalk or seta. It is embedded in the gametophyte by a foot which has cells specialised to transfer nutrients from the gametophyte. Spores released from the capsule germinate to form a thread-like structure, the protonema, from which a new gametophyte generation develops.

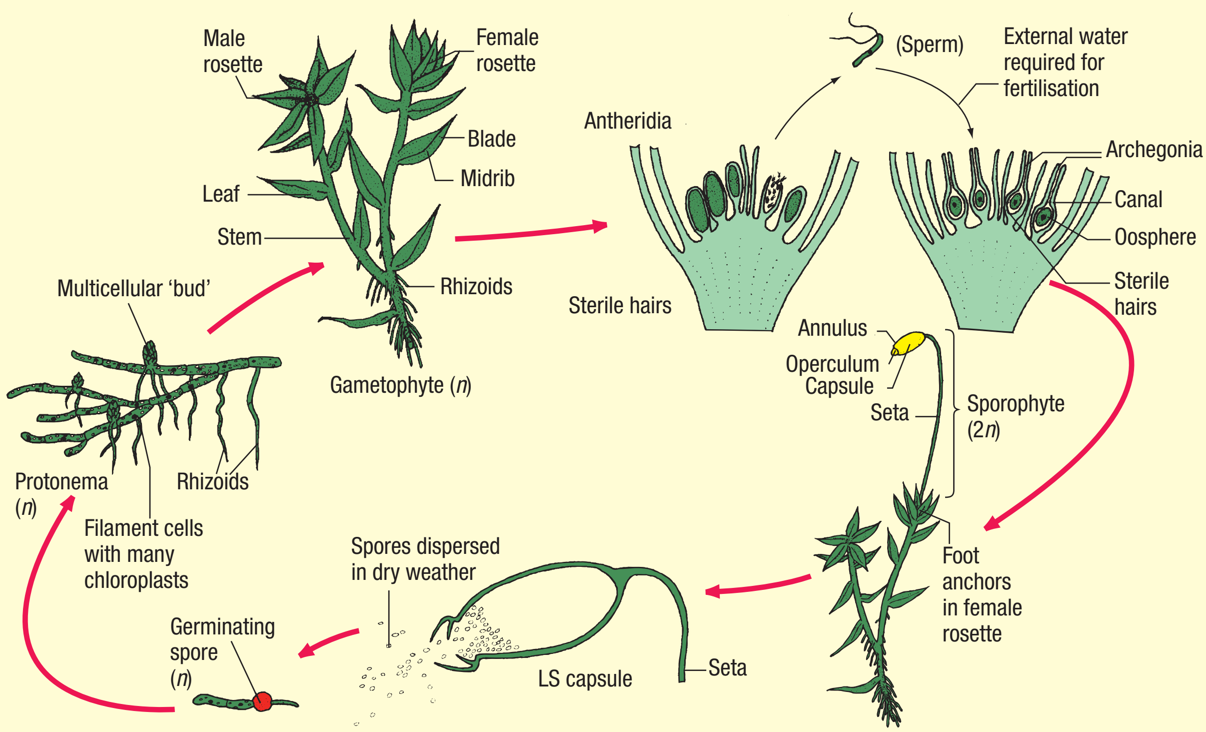


Figure 4.45 The life cycle of a moss

In addition to spore formation, there is another kind of asexual reproduction that can take place. Small pieces of the gametophyte break off and form a new plant. In the liverworts special cells called gemmae (singular *gemma*), usually in cup-shaped structures, can grow on the upper surface of the thallus. Each gemma is attached to the surface by a thin thread which breaks when the gemma is mature, allowing it to be dispersed by raindrops.

The other divergence from the ancestral form developed a reduced gametophyte generation relative to the sporophyte which had primitive conducting tissue. These were the fern allies that ultimately resulted in the ferns and seed plants.

In ferns and fern-like plants, the sporophyte is the dominant generation and the gametophyte is reduced to a small, simple heart-shaped structure called the prothallus. The ferns are fairly advanced plants with a vascular system and true roots, stems and leaves. In a few ferns (e.g. tree ferns) the stem is upright, forming a trunk, but in most the stems run horizontally along the ground or in the soil (rhizome) and the fronds or large leaves are the only part normally seen. Sometimes branches from the main stem break away and form new plants (vegetative reproduction). The fronds consist of a central stem or rachis bearing pinnae, which are usually subdivided into toothed pinnules.

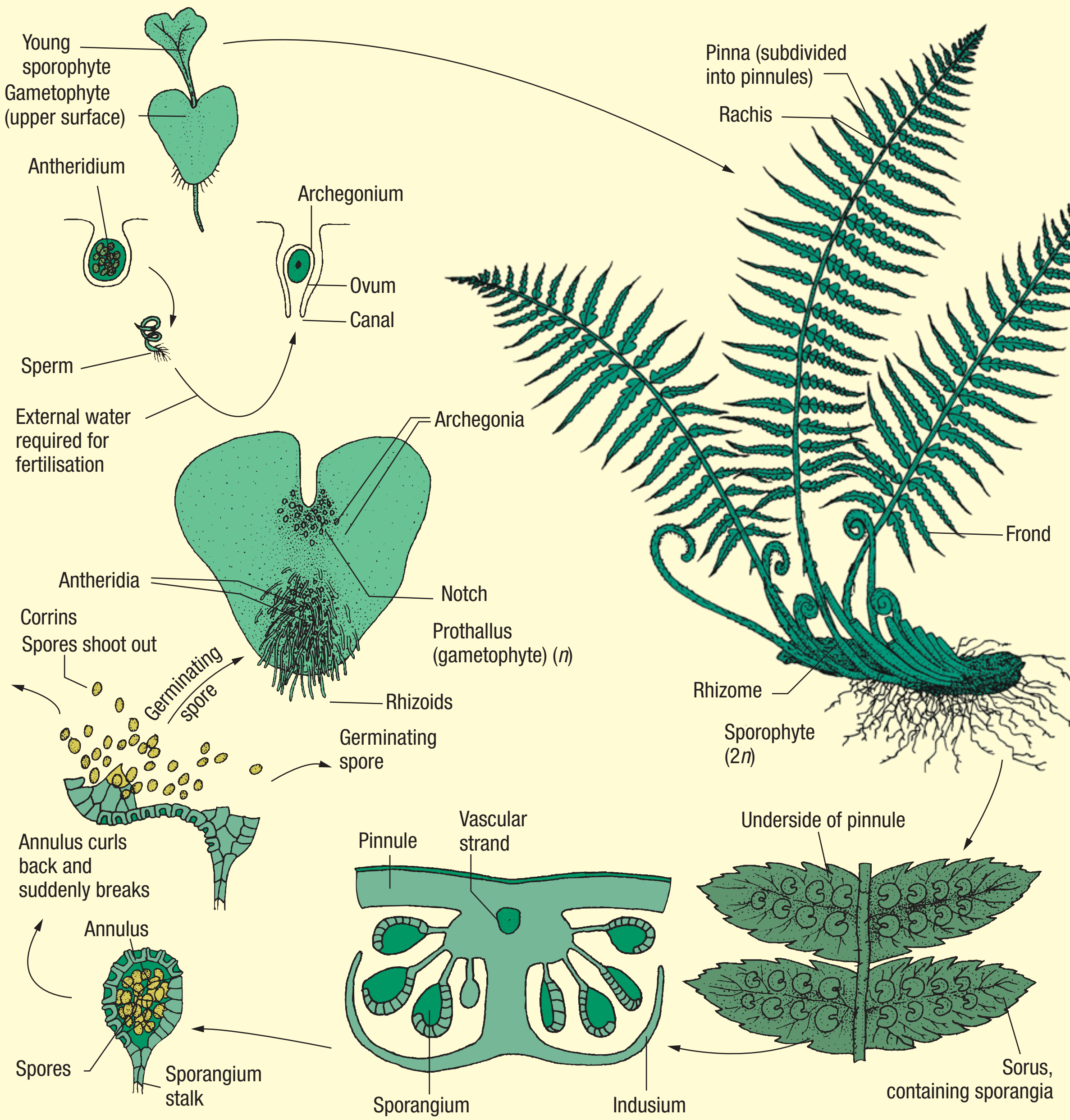


Figure 4.46 The life cycle of a fern

Sporangia are located in clusters called sori on the underside of the fronds. The shape and arrangement of the sori are important features in the identification of ferns. Spores, produced in the sporangia, are released when mature and are spread by the wind to new areas. On germination they develop into the prothallus. This tiny, delicate structure produces gametes in sex organs found on the undersurface. As in the bryophytes, the flagellated sperm swim in a film of water to fertilise the egg. The zygote develops into a new sporophyte, obtaining its nourishment from the prothallus until roots and leaves have developed. The gametophyte then withers and dies.

SUMMARY

The similarities between green algae and plants suggest that they are closely related. One group of green algae, the charophytes, has so many similarities with plants that it is probable that a charophyte, or its precursor, is the ancestral plant form.

Bryophytes—the mosses, liverworts and hornworts—are non-vascular plants. The gametophyte generation is the dominant phase of the life cycle. In liverworts and hornworts this phase is usually thalloid (although some liverworts are leafy). In mosses it is usually a leafy structure.

The plant is anchored to the ground by fine threads called rhizoids, but these are not involved in absorption of water. Water moves from the soil to the plant by capillary action along the outside of the plant.

Gametes are produced in gametangia on the upper surface. Flagellated sperm swim to the female gametangium in a thin film of water. Fertilisation takes place within this structure and the resulting sporophyte generation remains as a 'parasite', deriving its nourishment from the female plant.

The moss sporophyte consists of a capsule carried on a seta which is embedded in the female tissues by a foot. Spores produced in the capsule are released. If suitable conditions are present the spores will germinate to form a protonema which grows into the next gametophyte phase.

Because they lack vascular tissue, and their sperm need to swim to the female plant, bryophytes have remained small and can grow actively only in damp conditions.

The dominant phase of the fern life cycle is the sporophyte. This is a vascular, photosynthetic plant with true roots, stem and leaves. The stem is usually a horizontal, underground rhizome. The leaves are relatively large and called fronds. Sporangia are borne in clusters, called sori, on the undersurface of the frond. Spores germinate to form a small non-vascular gametophyte called a prothallus. Water is needed for the sperm cells to swim to the female gametangium, thus the habitat of most ferns is limited.

Review questions

4.47 List three reasons why green algae are the probable ancestors of plants.

4.48 What feature(s) of the charophytes make them the most likely algal ancestor of plants?

4.49 What is delayed meiosis? Why was this a significant evolutionary development?

4.50 Carpets of green moss plants are regularly found in damp, shady places. The presence of capsules on stalks is not so common. Explain this observation.

4.51 Compare and contrast the gametophyte generation of a moss with that of a fern.

4.7.5 Diversification of vascular plants

In early Paleozoic times the landscape was barren. Although some algae and lichen were probably found around the edges of waterways, there were no mossy banks with ferns, fields of grasses or forests. Upright plants are first seen in the fossil deposits of the Silurian Period. They were basically horizontal, stabilising sections with simple vertical stems that had no vascular tissue or leaves. These pioneers probably lived near water or may have been semi-aquatic marsh plants.

Even before the development of leaves, the vascular system, composed of primitive xylem and phloem, was the next major step in the advance of the plant kingdom. Fossils from the late Silurian

Figure 4.47 *Psilotum nudum*, a Queensland skeleton fern

Period show an array of different simple plants, some with either a single or clusters of bulbous spore producing organ(s) on top of upright stalks or arranged along the length of the stalk. These fossils are very similar in appearance to the fork or skeleton ferns (phylum Pteridophyta, class Psilopsida) of today. These plants do not have any roots; simple elongated cells (rhizoids) from a horizontal stem (rhizome) attach the fern to either rocks or another plant such as a tree fern. The upright stems have small scales or simple leaves. The spore-producing organs are found in the axis of the scales or leaves.

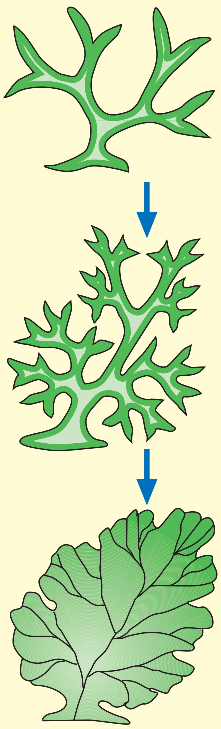


Figure 4.48 The possible evolution of the leaf

The development of the vascular system which allowed the rapid transport of water and dissolved minerals throughout the plant and food from the photosynthetic areas was a great physiological breakthrough for land plants. The very simple early vascular systems were the basis for further modifications that resulted in more efficient conduction of materials as well as mechanical strength. Along with improvement in these tissues, came roots for support and effective uptake of water and nutrients, and leaves for capturing large quantities of solar energy arose. Like the skeleton fern, the early land plants had branched stems but no leaves. This limits the amount of photosynthesis that can occur since the stems do not present a large surface area to trap sunlight. Increased branching of the flattened, terminal stems most exposed to sunlight occurred. It is thought that genetic changes allowing these small branches to coalesce to form a large single plate of tissue produced the typical leaf. By the middle Devonian times, the dominant plants were the lycopods (phylum Pteridophyta, class Lycopoda) which include the clubmosses of the modern world.

Figure 4.49 *Selaginella sp.*, a modern lycopod

Although modern specimens are relatively small plants, during the late Paleozoic Era many lycopods grew as large as trees. These plants, like the modern ferns, were limited in their ability to spread too far from water. The dominant phase of their life cycle was the sporophyte generation which produced spores that could survive when conditions were dry. The tiny gametophyte, however, needed wet conditions for fertilisation of their gametes to occur. The released sperm had to have a film of water in which to swim to the female gametangium in order to fertilise the egg.

In at least one of the lycopod species the ability to produce two kinds of spores—one that would produce a female gamete-bearing plant and the other a male gamete-bearing plant—arose. Prior to this development individual gametophytes could produce both male and female gametes, as occurs in modern ferns. Fossil plants from the late Devonian developed two different sized spores and it is assumed that these germinated into gametophytes of different gender.

The next step in the evolution of plants, the production of a seed, occurred soon afterwards. The seed is a complex structure in which the young embryo sporophyte and a nutrient supply are contained within a protective outer coating or seed coat. The seed coat protects the embryo while it lies dormant, sometimes for years, until conditions are favourable for its germination.

In seed-producing plants both the male and female spores germinate within the tissues of the sporophyte plant. The female gametophyte develops into an embryo sac, inside of which the female egg cell is produced. The male gametophyte becomes the pollen grain. The pollen has a waxy protective coating and is resistant to environmental stresses such as dehydration and temperature change as it is transferred by wind to the same or a different plant. A pollen tube penetrates the female tissue, transferring the male nucleus to the egg in the embryo sac. The only fluid required is that of the plant itself. Thus these plants have a far greater capacity to tolerate dry environments. The seed that is formed by fertilisation is small enough to be transported by air, water or an animal to a favorable place for germination. These plants are able to spread further from water since they are no longer dependent on an external water supply for fertilisation.

For the first time, in the late Devonian, dry land was invaded on a large scale. The roots of these seed-producing plants gripped the soil, stabilising it against erosion. This event changed the flow of water courses and resulted in meandering rivers that deposit their sediments in seasonal cycles.

The Carboniferous Period was a time of great expansion in the plant world—both onto dry land and in evolutionary 'experimentation'. In swampy areas the lycopods continued to thrive, with some species growing more than 30 metres tall. Present-day coal beds were formed from these plants. The undergrowth of these forests consisted mainly of ferns and fern-like plants. Included among these plants were the seed ferns—plants that were fern-like in appearance but reproduced by seeds. Many seed ferns were small bushy plants, but others reached tree size. *Glossopteris*, a common fossil found in coal beds in Australia, was a seed fern.

At this time the dry land was inhabited by seed ferns and horsetails, a fern ally. Although modern horsetails are quite small, some of the ancient forms were tree size. By the late Carboninerous Period forests of tall seed trees (cordiates) occupied the high grounds. These were the first gymnosperms (naked seed plants) that produced seeds at the bases of specialised leaves that formed a cone.

Over a period of 40 million years, between the late Carboniferous and late Permian Periods, these plants declined. Few tree-sized lycopods or horsetails remained and all the cordiates had disappeared. They were taken over by other gymnosperms, which were the dominant flora right

(a) Whole plant (b) Male cones (c) Female cones

(d) Naked seeds (e) Ginkgo

Figure 4.50 Modern survivors of the Mesozoic Era: (a)–(d) cycad; (e) ginkgo

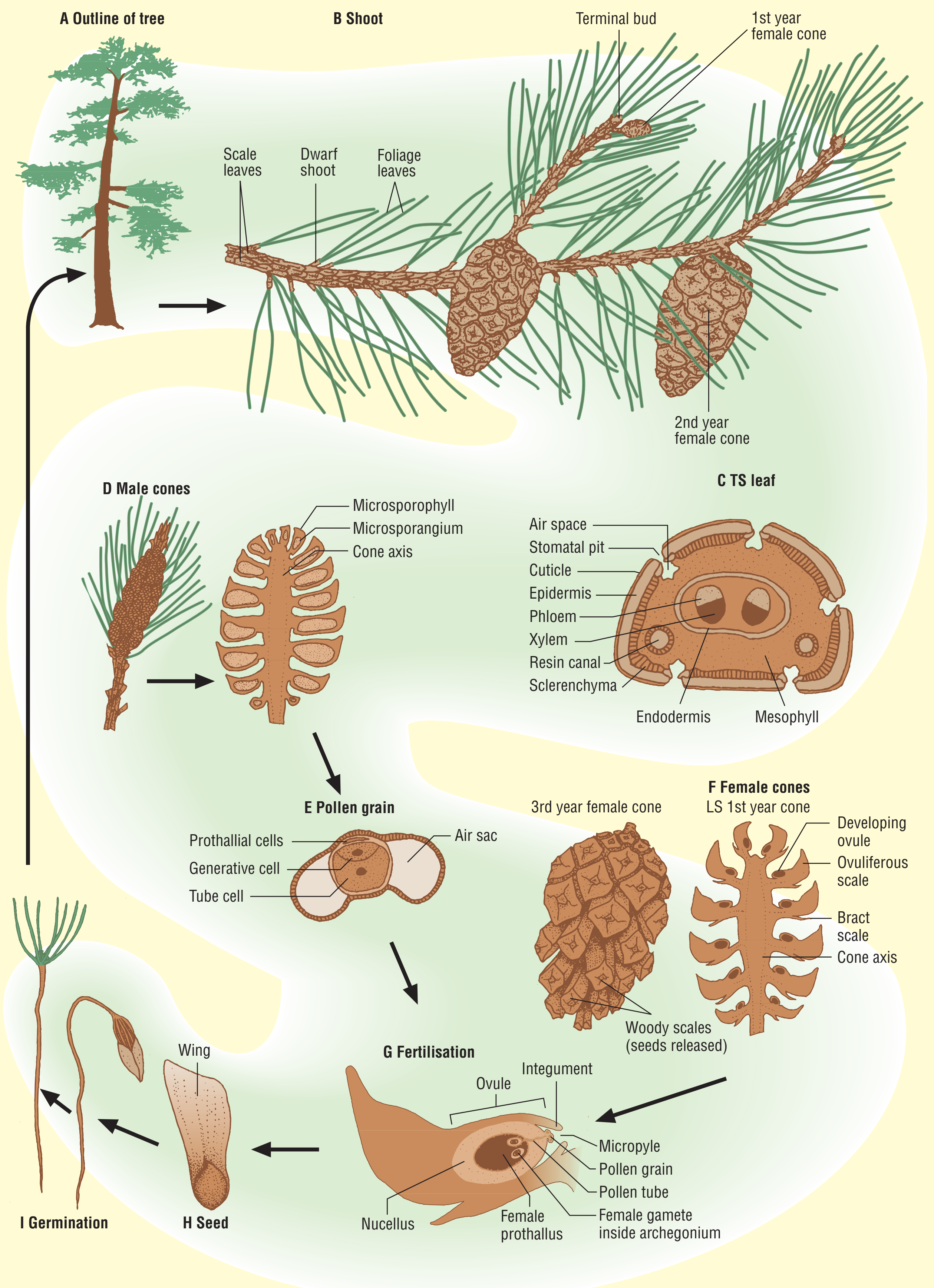


Figure 4.51 Life cycle of a gymnosperm

through to early Cretaceous times. The most diverse plants of this division were the cycads, the conifers and the ginkgos. All three groups survive in modern times although the cycads are rare and there is only one living species of ginkgo (*Ginkgo biloba* which is indigenous to China).

The gymnosperms (and many angiosperms) have special tissue (vascular cambium) between the xylem and phloem which produces new xylem on the inside of the stem and new phloem on the outside. The functional xylem and phloem tissues are grouped together into units called vascular bundles. Old phloem cells become part of the bark which is periodically shed. Xylem is retained in the stem and results in an increase in the girth of the plant. This type of growth is called secondary growth. The new xylem cells become impregnated with lignin (which provides support for the cells), die and increase the water-carrying capacity of the plant. Older, inner xylem becomes non-functional and filled with waste products. These cells provide a rigid supporting skeleton, known as wood. The increased transport capacity and the provision of a hard woody 'skeleton' provided the means for these plants to grow to massive sizes.

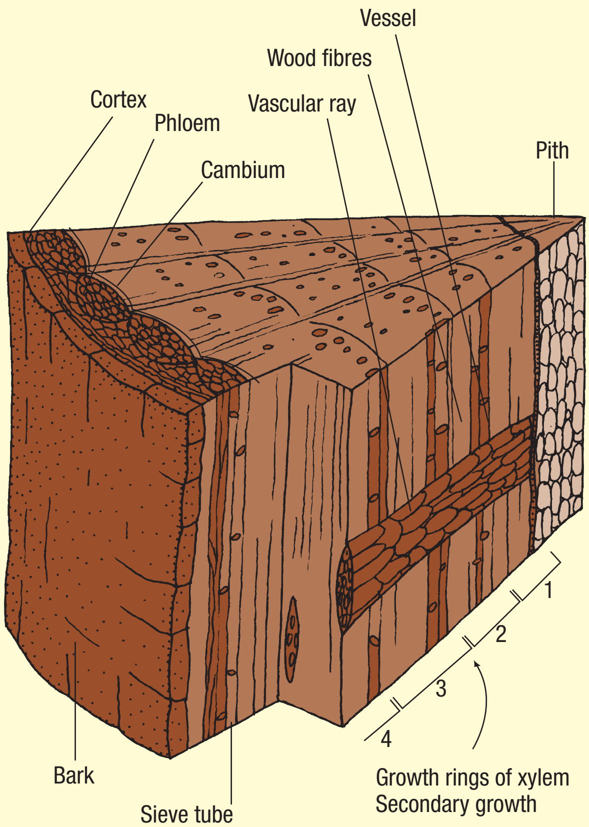


Figure 4.52 Secondary growth in seed plants

The cycads were the dominant plants of Jurassic forests and, along with their fern under-storey, were the major food source of the herbivorous dinosaurs. During the early Cretaceous Period, however, conifers became the most numerous species. This change in the forest landscape was short lived. About 100 million years ago, midway through the Cretaceous Period, the angiosperms began to diversify and within a short period of time became the dominant plant on earth.

The success of the flowering plants can be attributed to many major factors:

- Flowers replaced the cone and the embryo sac was enclosed within an ovary.
- Nutritional food is available for the seed. Double fertilisation occurs. One pollen nucleus results in the formation of the zygote while another pollen nucleus fuses with a diploid embryo sac nucleus, resulting in a rich food supply that can be used by the embryo during initial growth after germination.
- The stigma rejects pollen from other species, selecting only its own type.
- The proximity of the male and female parts within many flowers gives a high probability that an ovule will be fertilised.
- There are many agents of pollination—wind, water, insects, birds and mammals. Conifers rely almost totally on wind pollination.
- The development of fruit (ovary wall) has increased the means of seed dispersal.
- In conifers the xylem contains only tracheids. These cells have perforated end walls, which slow down water movement. The xylem in flowering plants also contains vessels which, not having end walls, conduct water much more rapidly. Flowering plants are therefore more likely than conifers to grow well in environments with hot, dry conditions.
- Flowering plants have evolved mechanisms to prevent foraging by animals; prime among these are toxic or noxious chemicals.

Just as the scales of the gymnosperm cone are modified leaves, so too are the parts of the flower. While it is easy to envisage the sepals and petals as elaborate leaves, considerable changes were required to form the ovary.

The gymnosperms also provide food for the seed embryo. This is supplied by the parent plant and takes a long time to produce. Gymnosperms usually have a reproductive cycle of at least 18 months. Due to double fertilisation, the angiosperms can rapidly produce a seed food supply. Many herbaceous plants can, for example, grow from a seed and then release seeds of their own in a few weeks. This rapid repro-

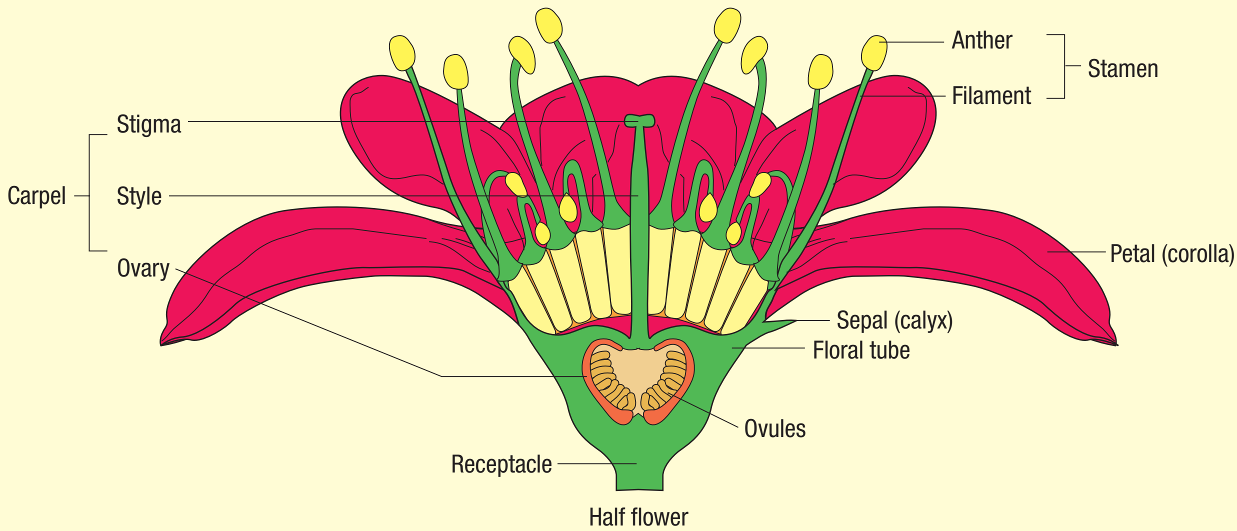


Figure 4.53 Section through a flower showing the whorls

ductive rate was a major reason for the flowering plants rapidly becoming the dominant plants on earth.

Flowering plants provide a source of food for insects and other small animals, such as honeyeaters and bats, that is lacking in the gymnosperms—the nectar and pollen. In return for food, they unwittingly act as pollinators. Some flowers have even evolved specific shapes, scents or colours that attract specific pollinators. As in all evolutionary processes, the chance mutation that provided a different flower that may attract a different kind of insect than the one that visited the parental stock, has an advantage, and will form many seeds. In time the differences between this type of plant and the original may become so great that a new species is formed. Similarly new types of plants create feeding opportunities for new kinds of insects. The massive diversity of both flowering plants and insects has been attributed to this type of reciprocity.

With the extinction of dinosaurs approximately 65 million years ago came the extinction of many of the plants. As discussed on page 81, this extinction was most likely the result of multiple asteroid collisions with earth. On impact the asteroid would have sent massive amounts of dust into the atmosphere. This would have blocked out much of the sun's rays for an extended period of time, some suggesting years. The effects of these impacts on the earth's crust could have triggered volcanic activity across the globe, further increasing the amount of

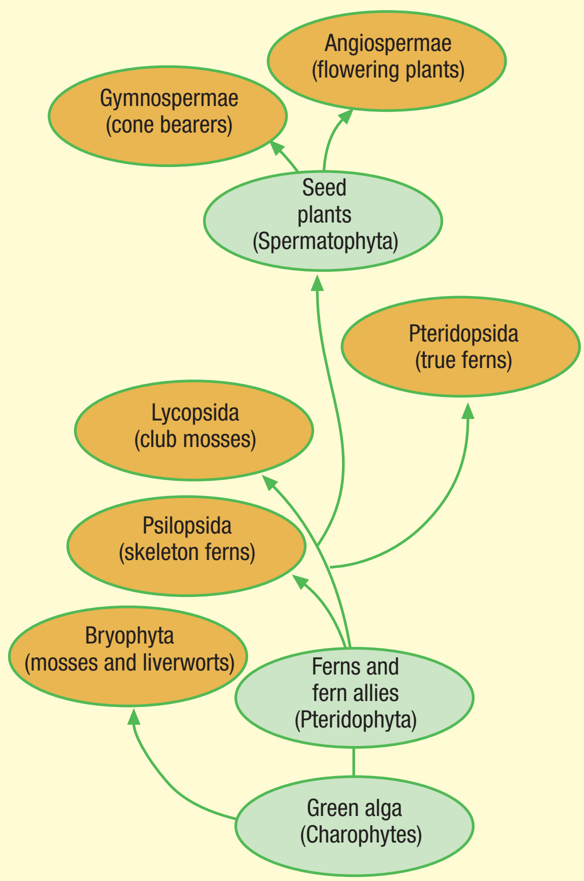


Figure 4.54 Possible evolutionary pathway of the plants

particulate matter in the atmosphere. Overall an impact winter of some duration resulted. This would result in greatly reduced photosynthesis. There would also be considerable cooling of the earth's surface. Both situations would have resulted in dramatic decreases in plant numbers.

Fossil plant records indicate that the plants that survived had leaves with jagged edges and were deciduous. These types of plants are typical of cold regions. Most broad-leafed evergreen plants do not become dormant during winter. It is from the remnant survivors of that time that modern plants came into existence.

SUMMARY

The first vascular plants were simple, with no roots or leaves. The dominant plant was a sporophyte, with spore-producing organs found at the tips of upright stems or along the stem. Further developments included:

- development of roots and leaves and a more efficient conducting system that also gave mechanical strength—ferns and their allies
- the formation of two different types of spores, one forming a female gametophyte and the other a male gametophyte
- retention of the female gametophyte within the sporophyte, formation of pollen
- seed formation—seed ferns
- vascular cambium and secondary growth, producing a woody skeleton
- seeds formed at the base of modified scale leaves of a cone—gymnosperms
- seeds formed within an ovary with double fertilisation within the embryo sac, resulting in the rapid production of a food supply for the embryo—angiosperms.

Review questions

4.52 Explain why it was necessary for 'male' and 'female' spore production to be present prior to the evolution of seeds.

4.53 Explain why seed production in plants allowed them to invade land well away from water.

4.54 What is meant by secondary growth?

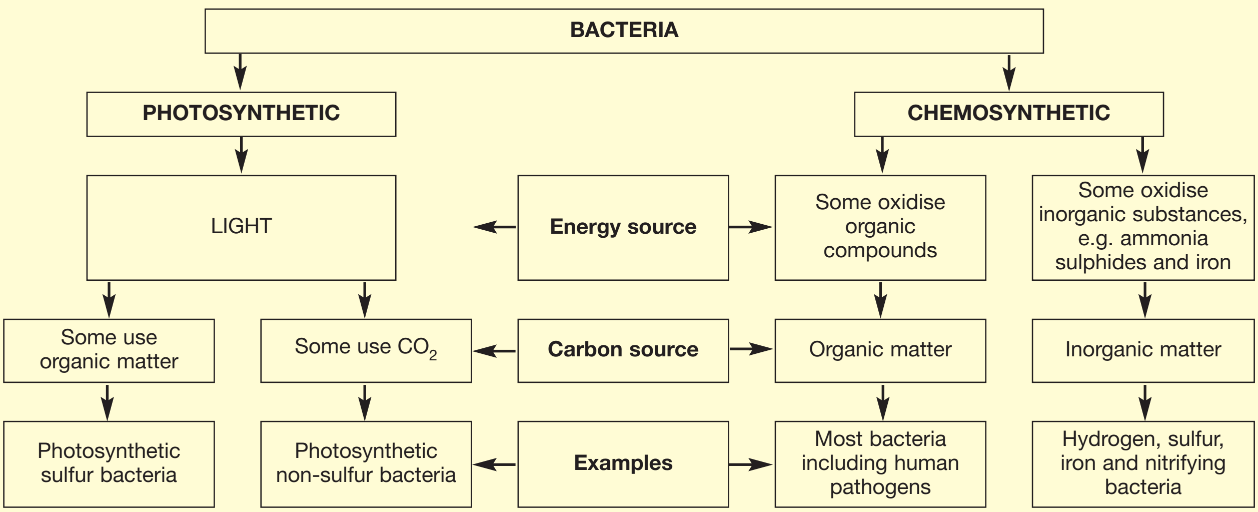
4.55 Why is secondary growth significant for the increased size of plants?

4.56 What are the significant differences between the gametophyte generation of ferns and that of seed plants?

4.57 Differentiate between pollen, seed and fruit.

EXTENDING YOUR IDEAS

1. In February 2001, it was announced that scientists working in space had discovered that cosmic dust formed complex organic molecules. When this dust was mixed with water, simple bacteria-like cells formed. Using your knowledge of previous experiments into the origins of life on earth:
   (a) Propose, with reasons, how organic molecules could form in space.
   (b) Suggest why actual living organisms, as we know them, are not found in space.
   (c) Proponents of the **Cosmozoan theory of evolution** claim that life could have arisen at various times in different parts of the universe. They favour the idea that life on



earth has an extraterrestrial origin.

Briefly discuss how these findings could support the Cosmozoan Theory and what further, more conclusive, evidence could be provided, given current expertise and facilities.

2. A summary of the various ways in which bacteria meet their energy needs is shown below.
   (a) A survey of certain hot springs that emitted strong sulfur dioxide fumes found that the only living matter in the springs was a single type of bacterium. Carbon dioxide levels in the water were measured and found to be stable over several weeks. To which major group of bacteria (photosynthetic or chemosynthetic) would the bacteria sample most likely be classified? Give reasons for your answer.
   (b) How would you classify bacteria that used light as an energy source?
   (c) *Salmonella* is a bacterium that causes food poisoning in humans. Describe the characteristics (such as energy, and carbon sources and so on) of this bacterium.
3. This table shows the levels of dependence on oxygen of four types of bacteria.

Bacteria type	Oxygen dependence
1	live only in the presence of oxygen
2	are killed by the presence of oxygen
3	are killed by normal oxygen levels but need a small amount of oxygen to live
4	live with or without oxygen

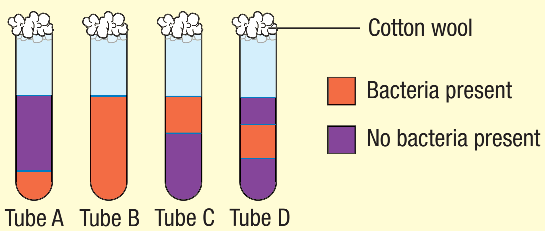


Figure 4.55

The diagram below shows the growth of four types of bacteria in nutrient broth. Some oxygen from the air dissolves in the nutrient broth. The amount of dissolved oxygen decreases as the distance from the surface increases.

In what order would you arrange the tubes of bacteria so that the first tube was representative of the earliest form of bacteria and the fourth the most recently evolved form?

Fully justify you answer from the data given and your knowledge.

4. Dr Elisabeth Sahtouris, an evolutionary biologist, has suggested that complex, multicellular organisms, such as humans, are simply giant taxies for communities of evolved bacteria to move around in safety. On what assumptions is her suggestion based?
5. Many sessile (fixed) and slow-moving animals are radially symmetrical. Unattached, fast-moving animals are usually bilaterally symmetrical. Propose, with reasons, a possible explanation for this.
6. Discuss how a triploblastic, coelomate, segmented animal would be more efficient at obtaining and processing food than a triploblastic, coelomate, unsegmented animal.
7. 'Banjo' rays are fishes somewhat intermediate between sharks and rays. They occur in modern oceans, including the waters off the Australian coast. These modern specimens are remarkably similar to the fossil representatives of this group found in rocks dating back 140 million years to the Jurassic Period. Suggest a hypothesis to explain why banjo rays have survived more or less unchanged over such a long period of time.
8. The structure of the moss is more complex than that of an alga. Discuss the proposition that mosses are more highly evolved than algae. Include in your answer a description of those features of the moss that contribute to its greater ability to colonise land than algae.
9. What trends in the evolution of the life cycle are evident from the bryophytes to the angiosperms? Discuss the implications of these changes in life cycle on the ability of plants to exploit the terrestrial environment.
10. A university lecturer was heard to make the statement: '*With regard to evolutionary development, members of the vascular plants are to the plant kingdom what the chordates are to the animal kingdom.*'

    Using specific examples, discuss the possible justification of this statement.
11. Tall, branched species of plants are more efficient at gathering light for photosynthesis because they can reach beyond the shadows of other plants. They must, however, bear the mechanical stresses associated with their height and have woody stems that increase in girth as the plant becomes taller. What factors might limit the distribution of

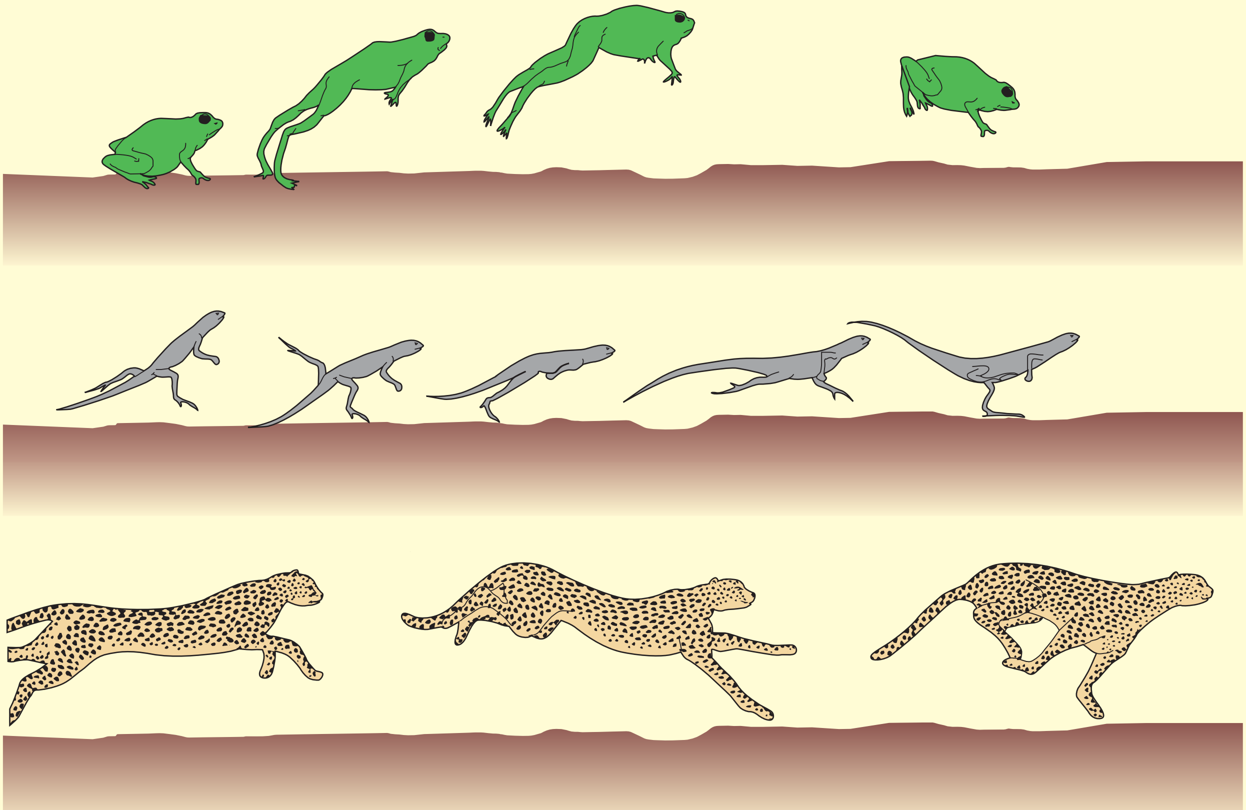


Figure 4.56 Locomotion in three tetrapods

the stems and leaves of plants, given the advantage of

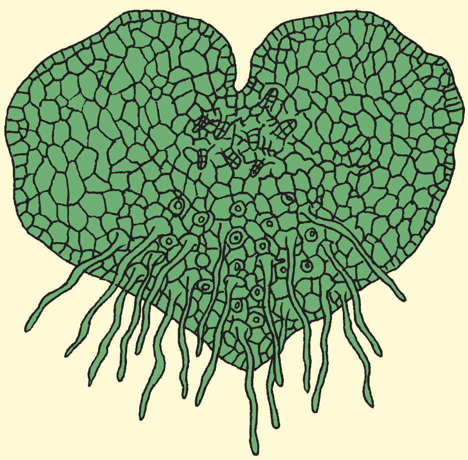


Figure 4.57 Stage in the life cycle of a plant

UB

height in competition for light?

12. The diagrams on page 99 show the pattern of locomotion in three different classes of vertebrates.

    From your knowledge of the evolution and structure of the tetrapod limb and its attachments, explain the differences in movement of the three organisms.

13. Figure 4. 57 shows one stage in the life cycle of a plant.

    Predict in which type of habitat you would find this structure, and discuss its role in the life cycle.

5 THE EFFECT OF ORGANISMS ON HUMANS

5.1 HUMAN REQUIREMENTS FOR SURVIVAL

The human species is totally dependent upon other organisms for its survival. Throughout their history humans developed an understanding of the plants and animals with which they share their environment. They learnt:

- the behaviours of certain animals to enable more effective hunting
- which plants could be safely eaten, were poisonous or could be used medicinally
- which animals or animal products were dangerous to eat
- how to use plant and animal products to make clothing and construction materials
- skills to avoid becoming food for other animals or being accidentally bitten.

Much of this knowledge has been lost by members of modern society who live in large urban areas and can purchase all of their requirements. The vagaries of climatic conditions and the effects of other organisms, other than those causing disease, do not impact directly on the survival of city dwellers of affluent societies.

Like all organisms, humans must perform a variety of functions to remain alive. They must:

- metabolise
- respire
- excrete metabolic wastes
- grow, develop, repair and maintain their body
- respond to stimuli
- move
- reproduce.

All of these actions depend upon maintaining an adequate energy supply and specific chemicals. Although energy cannot be created or destroyed, it can be changed from one form to another. Thus chemical bond energy stored in the glucose molecule can be converted to a more readily transferable form of chemical energy, **ATP**, in the process of respiration. This energy is then available to drive the cellular processes necessary to perform the life functions. With every energy conversion, however, heat energy is produced. Heat is unproductive energy that is lost from the body through conduction and radiation. A constant intake of energy is therefore required to counteract this loss.

Food is the source of this energy. Humans are heterotrophic omnivores. They eat a variety of different foods, including plants and animals and their products. Whatever they do eat, however, the ultimate source of energy is solar radiation. This is converted by plants to chemical bond energy in the process of photosynthesis and passed through the food web to the products we eat.

The food we eat is composed of large insoluble molecules that are inaccessible to the body cells. After ingestion they must be broken down into soluble molecules that are small enough to pass through the membranes of the cells lining the alimentary canal. This process is called **digestion**. The digested food then travels through the blood system directly to the cells that require their components or to the liver, where the small molecules are reassembled into the particles required. This is the process of **assimilation**.

Humans are mammals. Like other mammals, they are endotherms. They maintain their body temperature at a constant level irrespective of the environmental temperature. The enzymes that control the rate of metabolism within the body cells operate best at this constant temperature of 37.6°C. Endothermic animals can remain active in a wide variety of environmental conditions provided there is adequate food and water available.

Most mammals are adapted to living in particular temperature ranges. Thus mammals that live in very cold conditions decrease loss of heat through the body surface. This may involve:

- insulation such as a thick subcutaneous fat layer or thick fur
- reduction in the size of large surface area:volume ratio extremities such as ears
- transfer of heat from arteries to veins prior to reaching the extremities
- having a body size or structure that produces a small surface area:volume ratio.

Mammals living in very hot conditions have other adaptations that reduce uptake of environmental heat while increasing heat loss resulting from metabolic activities.

Humans are unusual mammals. They have a limited covering of hair. Thus they do not have an inbuilt protection from extreme cold or from the searing rays of the sun. In order to remain active in a wide range of environmental conditions, they need to provide their own protective coating—clothes. Until recent times the materials used in clothing were all derived from natural fibres from plants and animals or composites such as animal hides.

A great number of animals seek out or construct shelter. This shelter can provide a secure place in which to rest or produce young. It may be a burrow against adverse environmental factors such as the extreme heat during the day and cold at night in a desert. The shelter may form a duel function. An ant lion, the larva of a particular lacewing insect, constructs a small, conical crater in soft sand of sheltered areas. The larva conceals itself in the centre of the crater, with only its powerful jaws protruding from the sand. Small insects such as ants that stumble into the pit are immediately grasped and devoured. The ant lion's dwelling is both a protective shelter and a food trap.

Figure 5.1 Pits constructed by ant lion larvae

The shelters produced by humans are diverse, as are the materials from which they are constructed. From the time humans left the caves, plant and animal materials featured significantly in their buildings. Humans lack special adaptations for living in a particular environment. They are generalists who have the capacity to utilise whatever materials are available to make their environment livable. The plainspeople of Africa use grass cemented with a mud rendered from dirt and cattle dung to make their kraals. Eskimos construct their dwellings from blocks of ice. Being a generalist has allowed the human species to exploit most terrestrial environments on earth.

While getting adequate food is very important for human survival, so too is preventing becoming another organism's meal. Although people still die from shark attack, jellyfish stings and funnel web spider or tiger snake bites, these are more acts of defence on the part of the attacking animal than of predation. Like us they need some devices to capture food or prevent being eaten themselves. Most cases of man-eating animals, such as lions, are usually associated with a wounded or aged animal that no longer has the capacity to use its hunting techniques on a more preferred food source. The main danger to the human species is that of small invaders—parasites and pathogens—that have a vested interest in keeping their food supply alive for as long as possible.

It is easy to imagine animals fighting back to prevent becoming another organism's food. Plants also have evolved strategies of survival. While these adaptations have been against herbivores in general, they are equally deterrent to humans. Many plants, therefore, are unpleasant or unappetising to eat, while others have toxic chemicals.

SUMMARY

Humans have the same basic survival needs of all organisms. They are omnivorous mammals that lack specialised adaptations to any particular environment. Their generalised structure, coupled with their ability to change their environment, is responsible for their success.

Review questions

5.1 What is the ultimate source of energy for the human species?

5.2 Distinguish between digestion and assimilation.

5.3 List three ways in which heat loss can be reduced by mammals living in cold climates.

5.4 List two ways in which humans can be considered generalists.

5.2 Food

5.2.1 Nutritional requirements

The taking in of useful substances is called **nutrition**. A **nutrient** is any substance used by an organism.

Some nutrients can be synthesised by the organism from basic materials. Those nutrients that cannot be synthesised must be taken in from an outside source, and are termed **essential nutrients**.

Humans require water and oxygen as well as the following broad groups:

- carbohydrates
- proteins
- fats
- nucleic acids (found in all food)
- vitamins and minerals.

A diet containing all of these things in the correct amounts and proportions is called a **balanced diet**.

Carbohydrates, lipids (fats and oils) and proteins form the bulk of our diet. Vitamins and minerals are an important, if small, component. Vitamins are organic compounds which act as **coenzymes** or parts of coenzymes. They are loosely associated with an enzyme and act as carriers for transferring chemical groups or atoms from one enzyme to another. If a diet is deficient in one or more of over fifteen vitamins, it results in breakdown of normal bodily functions and symptoms of disease.

Carbohydrates contain the elements carbon, hydrogen and oxygen. Their chemistry is described in Chapter 12. The main forms of carbohydrate in the human diet are starch, sugar and cellulose derived from plant sources. Although humans do not have the enzymes that digest cellulose, it is the source of dietary fibre that prevents compaction of the faeces and thus constipation. Carbohydrates are a cheap and plentiful source of energy. The glucose produced by digestion of all forms of carbohydrate is used in cell respiration to provide energy for movement and essential chemical reactions. Excess glucose is stored as glycogen in the liver and muscles, or converted to fat where it is stored as deposits around organs or beneath the skin.

Proteins contain the elements carbon, hydrogen, oxygen, nitrogen and usually sulfur as described in Chapter 12. Proteins are formed from sub-units called **amino acids**. There are millions of different types of proteins but only twenty different amino acids. The particular protein formed depends on the specific combination of amino acids—the types of amino acids, their numbers and sequence. Plants are able to produce all amino acids they need from carbohydrates and nitrogen. Animals do not have this ability. They must obtain their amino acids from proteins that have been produced by plants or in the flesh of another animal. These proteins are digested and the resulting amino acids are reassembled in the cells to form the required proteins.

Several amino acids can be converted to a different type of amino acid in animal cells. In humans there are about ten amino acids that cannot be formed in this way but must be obtained in the diet. These are called the **essential amino acids**. They are found in meat and animal products such as milk, cheese and eggs. Most vegetable proteins lack one or more of these essential amino acids. Strict vegetarians, therefore, need to have vast quantities of mixed vegetables to ensure they obtain all of the necessary amino acids for healthy existence.

Apart from the formation of the musculature of the body, proteins play a significant role in all cells. The enzymes which control all chemical reactions are proteins. A large proportion of the membranes surrounding cells and forming strengthening filaments within all cells are proteins. The antibodies formed in immune responses and many hormones are protein, as are our hair and nails. It is very important, therefore, that there is an adequate supply of protein in the diet during periods of pregnancy and growth when new protoplasm, cells and tissues are being formed.

Amino acids that are not used directly in the formation of proteins are broken down. In the liver the nitrogen portion is removed and converted to urea, which is then excreted from the body by the kidney. The carbon, hydrogen and oxygen portions are rearranged to form carbohydrate. Since the amino acids cannot be stored, it is important that there is a regular intake of protein in the diet.

ala—gly—gly—leu—val—cyst—cyst—asp—leu—asp—glu—lys

part of a protein composed of 12 amino acids

↓ digestion

gly cyst asp gly leu ala val asp glu lys leu cyst

↓ absorption and assimilation

gly—leu—ala—val—cyst—lys—gly—asp—asp—glu—cyst—leu

part of a different protein assembled from the same amino acids by the cell

Figure 5.2 Digestion and assimilation of part of a protein

Lipids are also composed of the elements carbon, hydrogen and oxygen but in different proportions to carbohydrates. They are significant constituents of cell membranes and are important energy sources. Each type of fat is made up of two components—glycerol and fatty acids. Although some fatty acids can be formed from carbohydrates, some essential fatty acids must be provided in the diet. Animal fat is needed for the fat-soluble vitamins A, D, E and K which it contains.

Several **minerals** are needed in small amounts for the chemical activities of the body and for the construction of certain tissues. They are usually found in food, combined in the existing organic molecules. Sodium, magnesium, potassium and phosphate are normally present in adequate quantities in the diet. Salt (sodium chloride) is important in maintaining the correct water balance in blood, the carriage of carbon dioxide and the production of hydrochloric acid in the stomach. Potassium is present in most cells, particularly red blood cells and muscle, and is important in growth. Cereals are a high source of potassium and magnesium (a component of bone). Phosphates, found in protein, are needed in the formation of bone, nucleic acids, ATP, enzymes and cell membranes. Calcium, iron and iodine, however, are frequently in short supply.

It has long been known that the proper formation of bone requires adequate supplies of calcium during embryonic development and during early childhood. The fat soluble vitamin D (found in milk and its products, egg yolk and fish-liver oil) and bile salts are necessary for absorption of calcium from the alimentary canal. Vitamin D is also essential for the deposition of calcium in the bone. If either calcium or Vitamin D is deficient during early growth, the bones remain soft and become deformed by the child's weight, a condition known as rickets.

In recent years there has been an emphasis on maintaining good dietary levels of these substances throughout life. In Western societies the average age of individuals has increased and many afflictions associated with senility have become more prominent. One of these is osteoporosis—a condition where bones become brittle and breakages take a long time to heal. This condition is also obvious in young people, particularly those suffering anorexia or bulimia. In this situation, there is either inadequate calcium in the diet or the metabolism of calcium has been disrupted in some way.

Calcium also plays a part in clotting of blood, muscle contractions, the ability of nerves to conduct impulses, movement of materials in and out of cells and in the formation of the dentine of teeth. This important mineral is readily available in milk and its products as well as in plant matter such as beans, broccoli, almonds and figs.

Figure 5.3 Classic posture of an elderly person with osteoporosis

Although iron is conserved in the body, it is often deficient in the diet. Iron is present in a great variety of food sources combined with other chemicals. The way in which it is combined, however, determines how readily it is absorbed by the human body. Thus, although it is present in large amounts in spinach, not much of the iron present can be taken up because of its chemical composition. Readily available iron is found in red meats, eggs and parsley. Iron is essential for the formation of haemoglobin in the red blood cells (the pigment that carries oxygen from the lungs to the tissues). Shortage of this mineral in the diet leads to inadequate oxygen reaching the cells and thus lethargy, a condition known as iron-deficient anaemia.

Iodine is another mineral that may be lacking in the diet. It is essential in the formation of the hormone thyroxine in the thyroid gland. If iodine is absent, the precursors of this hormone build up in the thyroid gland, causing it to swell. Enlargement of the thyroid gland is known as goiter. Thyroxine controls the metabolic rate of cells. Low levels of thyroxine in developing children can lead to a condition known as cretinism with markedly retarded skeletal growth and mental retardation. In adults it can cause weight gain, lethargy and intolerance to cold. Although the small amounts of iodine needed in the diet can be found in most foods, its presence is determined by the amount of iodine in the soil in which food is produced. In some areas this is negligible. Seafoods are the best source of natural iodine.

Minute amounts of other elements (e.g. cobalt in vitamin B_{12} production, zinc in insulin, fluorides in teeth) are also required for proper bodily functions but these are usually in adequate supplies in most diets.

The amount of any particular nutrient that is necessary in a balanced diet depends on the age, sex and physical activity of the individual. An athlete, for example, requires higher carbohydrate and protein intake than an office worker who has minimal physical activity. For example, the energy requirements in kilojoules (kJ) for the average adult are:

- 8 hours asleep 2400
- 8 hours awake, relatively physically inactive 3000
- 8 hours physically active 6600

More nutrients of all types are required when the body is undergoing active growth than when it is in a maintenance phase.

A **deficiency disease** results when a particular nutrient is lacking, or there is an inadequate supply, in the diet. These diseases occur more frequently in developing countries or in tropical regions. About half the people in the world have an average daily intake of less than 9240 kJ. This amount of energy barely keeps a person alive and is inadequate for any sustained physical demands. Most of this energy is derived from a basic carbohydrate source, such as rice, yams and maize which are deficient in some essential nutrients.

Table 5.1 Human nutrient requirements

Nutrient	Function	Source	Deficiency disease
Carbohydrates	energy source	cereals	malnutrition
Proteins	formation of cell membrane, antibodies, enzymes, growth, energy source	meat, fish, milk, beans	kwashiorkor; degeneration of liver and pancreas
Fats	energy source, insulation	butter, oils, nuts	malnutrition
Vitamin A	pigment production in retina of eye, healthy cells lining respiratory tract	egg yolk, fish oil, carrot	night blindness; infections of respiratory lining
Vitamin B group (up to 12 vitamins)	involved in many chemical reactions e.g. respiration	whole grain, cereals, liver	beri-beri; muscular weakness and paralysis
Vitamin C	keeps tissues in good repair	citrus fruits, berries, raw vegetables, potato	scurvy; pains in joints and muscles; bleeding gums
Vitamin D	calcium and phosphorus deposition in bone and teeth	egg yolk, dairy products	rickets; soft and deformed bones
Vitamin K	blood clotting	green vegetables	haemorrhage
Calcium	bone and teeth formation, blood clotting, nerve conduction, muscle contraction	dairy products, bread, beans, almonds, some green vegetables	brittle bones and teeth
Phosphorus	bone and teeth formation	milk	brittle bones and teeth
Iodine	thyroxine production (hormone that controls metabolic rate)	seafood, sea salt or iodised salt	goiter (swelling in neck); slow metabolic rate; cretinism in infants
Iron	haemoglobin production	liver, egg yolks, some green vegetables	anaemia; not enough red blood cells; oxygen shortage
Sodium	osmotic balance, nerve conduction	most foods	muscle cramps
Potassium	muscle contraction, nerve conduction, osmotic balance	most foods	muscle cramps

In affluent societies there is generally no shortage of food and most people can afford a diet with adequate energy and protein content. Malnutrition is not usually a problem. Other nutritional diseases occur when there is too much of a particular nutrient present. An excess of carbohydrates and fats in the diet, for example, may cause obesity and this may result in coronary disease, high blood pressure and diabetes.

Even with the correct balance of nutrients in the diet, deficiencies can occur as a result of processing the food. Although cooking improves the taste and digestibility of food and destroys bacteria that may be present on the food, it also removes many vitamins from it. Water-soluble vitamins such as vitamins B and C are either destroyed by the heat or dissolve in the cooking water. Many minerals are also lost from the food when it is boiled.

SUMMARY

A balanced diet includes the correct proportions and amounts of carbohydrates, proteins, lipids, minerals and vitamins for the age and level of activity of the individual. Many nutrients can be converted from one type to another; for example, fats can be formed from carbohydrates. Essential nutrients are substances that an organism cannot synthesise from basic units and must therefore be ingested as a part of the diet. Lack of certain nutrients leads to deficiency diseases which affect the growth and development of the organism.

Review questions

5.5 Distinguish between a non-essential and essential nutrient.

5.6 Which elements are present in carbohydrates, proteins and lipids? In what ways is each of these nutrients different in its chemical composition?

5.7 Explain how the millions of different types of proteins can be formed from only twenty different types of amino acids.

5.8 Excess carbohydrates and fats in the diet can be stored, but not proteins. What happens to these proteins?

5.9 Describe how the body uses the minerals calcium, iron and iodine.

5.10 What is a deficiency disease?

5.11 Describe for *each* of the four nutrient groups:

(a) the main dietary source of the nutrient

(b) the function of the nutrient group in the human body

(c) a deficiency disease associated with an inadequate dietary intake of the nutrient.

5.12 Can an excess of food in the diet cause disease? Fully explain your answer.

5.2.2 Plants as food

Of all of the sources of human food, plants are the most significant. Some cultures depend entirely upon plants for their nutritional requirements. In other cultures they are eaten directly as well as being used as fodder to raise livestock for food.

Few ferns or their allies are used as food. The starchy pith of tree ferns is baked and eaten in Hawaii and was a valuable carbohydrate source for Australian Aboriginal people. Some South American ferns are used for extraction of sugar. In many parts of the world the very young fronds are used as a vegetable. Ferns are cultivated in Japan for this purpose. The small swamp fern (*Ceratopteris thalictroides*), widely distributed throughout tropical regions, is considered an excellent raw or cooked green vegetable. In Australia, the nardoo (*Marsilea*) was a valuable food for the early nomadic, Indigenous people. It is found in swampy areas and looks like a four-leafed clover. The spores are produced in capsules, called sporocarps, at the base of the plants. The sporocarps contain a gelatinous material and were ground up and used as food.

The seeds of several of the gymnosperms are eaten, but they are not a major source of food. In areas of scarce food resources, the ingenuity of indigenous people in using available plants is amazing. In Australia, for example, many of the open forests contain cycad plants (*Cycas* and macrozamias). These ancient plants were once the dominant land plant. They produce modified cones—a crown of short, overlapping seed-bearing leaves. Each of these leaves can produce up to four large seeds.

Although full of starch, these cycad seeds are highly poisonous, causing severe vomiting and purging. Aboriginal people, however, developed a method of preparing these seeds so that the poisonous qualities were destroyed. After roasting the seeds in a fire they soaked them for several days in water, either before or after grinding them up as flour.

Another significant gymnosperm food source for the Australian Aborigines was the bunya nut. The massive seed-bearing cones are borne on a large tree

(a)

(b)

Figure 5.4 (a) Nardoo (b) Cycad cone

(*Araucaria bidwillii*) that is found mainly between Gympie and the Bunya Mountains in southern Queensland. Aboriginal people used to eat bunya nuts either raw or roasted, and trees with notches in their trunks to assist climbers in obtaining the cones can still be seen at Bunya Mountains National Park. Individual trees were the responsibility of specific tribal members and the right to collect seed was passed from father to son. At meetings between different tribes, each would provide some food for the gathering. The bunya pines growing on Stradbroke Island were planted by mainlanders to ensure a food supply at future gatherings. The seeds of the black pine (*Podocarpus amarus*) of

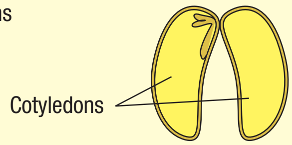
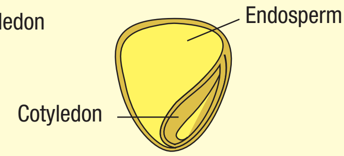
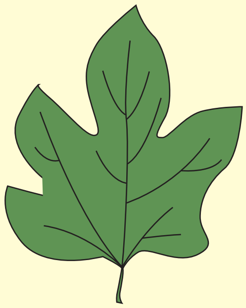
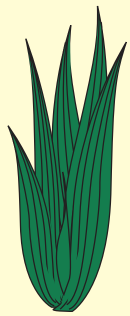
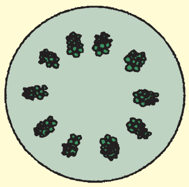
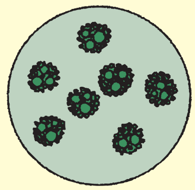
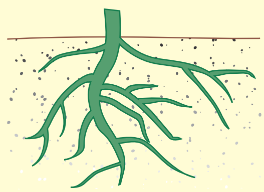
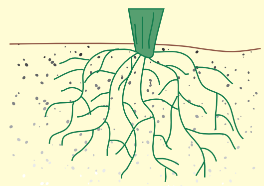
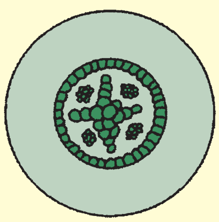
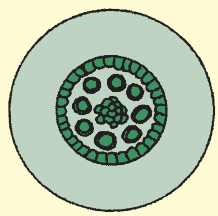
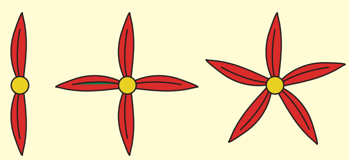
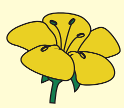
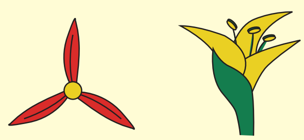
Figure 5.5 Bunya nut

Queensland rainforests were also roasted and eaten. The seeds of the brown pine (*P. elatus*) of the rainforests and the native plum (*P. spinulosus*) of sandy wallum areas, are borne on fleshy stalks. These 'fruits' were also eaten.

The flowering plants provide the greatest source of food for humans and their stock. These plants are divided into two subclasses, the Dicotyledonae and the Monocotyledonae, on the basis of four obvious differences:

- The monocots have only one seed leaf (cotyledon), while the dicots have two. Cotyledons are the simple leaves that appear first when the seed germinates. In some plants the cotyledon(s) remain inside the seed, while in others they are the main food supply for the embryonic plant.
- Monocots have leaves with parallel, un-branched veins, while in dicots the veins form a branched network.
- Although the form of the flower is highly variable in both groups, monocots generally have three or six of each flower component (e.g. petals and stamen), while dicots have four or five or multiples of these.
- None of the monocots show secondary thickening, while many of the dicots do. This is associated with the arrangement of vascular bundles in the stem. In the monocots the vascular bundles are scattered throughout the diameter of the stem. The vascular bundles of the dicots, on the other hand, are arranged around the circumference of the stem.

Table 5.2 Differences between monocotyledonous and dicotyledonous plants

Subclass Dicotyledonae	Subclass Monocotyledonae
Seed morphology: • Embryo has two cotyledons (seed leaves)  	• Embryo has one cotyledon 
Leaf morphology: • Reticulate (net-like) venation • Lamina and petiole • Dorsal and ventral sides differ 	• Parallel venation • Lanceolate • Identical dorsal and ventral surfaces 
Stem anatomy: • Rings of vascular bundles • Vascular cambium often present giving rise to secondary growth 	• Vascular bundles scattered • Vascular cambium usually absent • No secondary growth (except in palms) 
Root morphology: • Primary root a taproot that develops lateral secondary roots 	• Adventitious roots arise directly from the base of the stem, forming a fibrous root system 
Root anatomy: • 2–8 groups of xylem. Vascular cambium usually present 	• Many groups of xylem with vascular cambium usually absent 
Flowers: • Parts mainly in fours and fives or multiples of these (8, 10 etc.) • Calyx and corolla (= perianth) usually very different • Often insect-pollinated   2, 4 or 5 petals (sometimes 8 or 10)	• Parts mainly in threes or multiples (6, 9 etc.) • Perianth (calyx and corolla) not distinct, often the same • Often wind-pollinated  3 petals (or in muliples of 3)
Flowers: Melaleuca, eucalypts, everlasting daisy	Grasses, palms, orchids, lilies



Monocot flower and veins in leaf


Dicot flower and veins in leaf

Figure 5.6 Flower and leaf differences between monocotyledonous and dicotyledonous plants

The dicots vary immensely in form. They may be small herbaceous annual plants, shrubs or trees. These plants colonise all types of habitat except permanent ice and snow. Nearly all families of this group are used for food as root, stem, leaves, flowers, fruit or seeds. Some families, however, are particularly significant as food plants. These are illustrated in Table 5.3.

Although only about 20 per cent of the flowering plants are monocots, they are the most significant plant food source for humans. The monocots include the orchids (the pod and seeds of one species is vanilla), lilies (which include garlic, chives and onions), irises (saffron is composed of the stamen of a crocus), grasses, rushes and sedges. Grasses, either as cereal food or as forage for livestock, are the basic source of food for most of the world's population.

The cereals are cultivated members of the grass family. They have evolved through the deliberate selection of characteristics. Wheat species (*Triticum*) are among the earliest plants to be cultivated by humans. A species called Emmer wheat was found by archeologists to have been cultivated in Kurdistan around 5000 BC. It is thought to have

Table 5.3 Some dicotyledonous food plants

Family	Roots	Stem	Leaves	Fruit	Seed
Cruciferae	swedes, turnips		cabbage, brussel sprouts, kale, cauliflower, broccoli, watercress		rape, mustard, nasturtium
Solinaceae	potato			tomato, capsicum, chilli peppers, eggplant	
Compositae	jerusalem artichoke, chicory, salsify		globe artichoke, lettuce, chicory, endive, tarragon		sunflower
Rosaceae				apples, pears, plums, peaches, cherries, blackberries, raspberries, strawberries, rose hips	almonds
Leguminaceae	liquorice				peas, beans, peanut, lentils, fenugreek
Labiatae			mint, thyme, basil, sage, marjoram, rosemary		
Umbelliferae		celery, fennel	parsely, chervil, corander, dill		aniseed, caraway, coriander, cumin, dill
Myrtaceae				allspice, cloves (dried flower bud)	
Marantaceae	arrowroot				
Lauraceae		cinnamon (bark)	bay leaves		
Cucurbitaceae				cucumbers, zucchini, pumpkin, squash	
Tiliaceae				citrus	

(a) custard apple

(b) sapote

(c) coffee

(d) coconut

(e) pawpaw

Figure 5.7 Examples of dicotyledonous, tropical fruits originated from artificial crosses between two wild grass species. Since that time further crosses and selective breeding have resulted in different types of wheat. The most significant is the bread wheat, of which there are several varieties. Durum wheat has a higher proportion of gluten, the component of flour that makes it sticky and elastic when wetted. This wheat is grown specifically for pasta production. Other major cereals of temperate regions are barley, rye and oats.

(a) Wheat

(b) Oats

(c) Rice

(d) Corn

Figure 5.8 Cereal plants

In large parts of tropical and subtropical Asia and Africa the major food-producing grass is rice (*Oryza sativa*). It was first cultivated about 3000 BC. Because of its value as a food plant, within 1000 years its cultivation became widespread throughout China, India and South-East Asia. Sorghum, sugar cane and millet are other important tropical and subtropical cereals.

The third major cereal is maize (*Zea mays*). It is the only cereal to have originated in South America and was first cultivated between 4500 and 3500 BC. It is now a major crop in tropical and subtropical regions of the world. Some varieties are grown for the cob of seeds to be eaten fresh (sweet corn). Most maize is ground into a meal that is used in a similar manner to the flour produced from wheat and rye.

Bamboos are an unusual member of the grass family in that they have a woody stem. Although more significant in tropical regions for their use in buildings, the young growing tips of the plants are used in some Asian cooking.

Other significant families of tropical and subtropical monocots are the palms and screwpines (pandanus). Although both are trees, their growth is very different to that of the woody dicots. They only grow in height once the base of the trunk has reached a width sufficient to support the tree. Both the coconut and date palms are grown commercially for their fruit. Dates have been a staple food in North Africa and India for centuries. The bananas belong to another family of tree-like monocots. Each plant develops a terminal spike of flowers that bends over and hangs down. In wild species the male flowers are at the tip and the female flowers above them. In cultivated bananas the fruits develop from unfertilised female flowers and so are seedless. After fruiting the whole stem dies and a new one grows up to replace it. The tropical bromeliad family includes the commercially important pineapple.

SUMMARY

Plants form a significant, and for many cultures the sole, source of human nutrition. Ferns and the seeds of gymnosperms do not contribute to the diet to any great extent. The angiosperms, the major human food source, are divided into two groups (the Monocotyledonaea and Dicotyledonaea) on the basis of structural features. The roots, stems, leaves, fruit and seeds of various dicotyledonous plants are used. The seed is the most important food source of the monocotyledons.

(a) Flower

(b) Fruit

(c) Cross-section of stem

Figure 5.9 Banana: (a) Flower (b) Fruit (c) Cross-section of stem

? Review questions

5.13 How would you use the structure of the leaf to distinguish between a dicotyledonous and a monocotyledonous plant?

5.14 Give examples of food in the human diet from different types of plants, classifying each under root, stem, leaves, flowers, fruit or seeds.

5.15 Suggest why people in developing countries are more likely to live on cereal (e.g. rice, maize) than on an omnivorous diet.

5.2.3 Animals as food

While plant material may form the bulk of the human diet, meat or animal products are significant in maintaining a balance of nutrients. The lack of enzymes in the human system to break down cellulose means that many of the nutrients locked up in plant cells remains inaccessible. The human digestive system does not have the bacteria-filled chambers (either rumen stomach or large caecum) of herbivores that allow the digestion of cellulose. Even our back teeth lack the ridged grinding surfaces that would physically open up plant cells. The entire digestive system is that of a generalist that obtains its nutrients from a variety of sources. Careful selection of plant material can provide all of the essential nutrients for a balanced diet, but the majority of cultures that are strictly vegetarian do not have the luxury of such selection, and they tend to suffer from deficiency diseases.

Our forebears were hunter-gatherers. They ate what was available within their environment. It was not until well into human history, only 10 000 years ago, that certain animals were domesticated and husbanded for the sole purpose of providing food and other products. Modern domesticated animals are very different from the animals from which they have originated. Over thousands of years, humans have selectively bred those individuals in their herds that have produced better meat or milk, for example, for the particular area in which they lived. Thus many different breeds of each type of stock have been developed. The early herders would soon have recognised that it was not always necessary to kill the animals to get nourishment. Milk could be obtained from lactating cows, sheep, goats, llamas and yak. Not only was this a high source of protein and fat, it could be converted to butter and cheese. The latter could be kept for long periods of time and provide nutrients even when the female stock do not have young at foot and thus do not lactate. The Masai warriors of the Rift Valley of Kenya have even developed the ability to supplement their protein by taking blood from their cattle without killing them.

While Western cultures consider their basic protein as coming from cattle, sheep, pigs, poultry and fish, this is not the case for all cultures. Throughout human history, people have obtained their protein from whatever sources are available. Laboriously spearing individual termites from their mound might not be our idea of a pleasant meal, but to a nomadic tribe it could constitute a banquet. Frogs' legs and snails might not feature in our menu but to the first settlers of the marshlands of what is now Paris, these animals were bountiful. They were so significant in the diet that they are still an important part of French cuisine.

Obtaining food in any natural environment depends upon an intimate knowledge of the landscape. From the time of first Aboriginal settlement in Australia, there were great challenges for survival. Clans occupied specified areas. Although each group had detailed knowledge of the resources in that area, knowledge of other areas would have been limited. Thus the types of food eaten by a clan living in rainforest would be very different to those eaten by a desert group.

Coastal and riverine communities, as in contemporary Torres Strait island groups, depended to a large extent on fish for their protein. Turtles, dolphins and dugongs were harpooned from canoes in shallow waters. Turtle eggs were collected from their nests in the sand. Meat from beached whales was considered a real delicacy. They also relied upon a variety of other water life. The shells of oysters, pipis, mangrove worms and snails, yabbies and crabs are found in large rubbish dumps (middens) near camps along the coast, as a witness to their significance in the Aboriginal diet.

Figure 5.10 An old midden on Stradbroke Island (Queensland) that has been eroded by tidal wash over time

Although hunting land animals was also important to Aboriginal groups, this was not indiscriminate. Each animal, according to their culture, is descended from the creation ancestors and so are related to human beings. Each clan regarded particular animals as its relatives, or 'totems', and these were never hunted or eaten. Different clans had different 'totems'—goanna for one clan, koala for another and so on. The most commonly hunted animals were kangaroo, possum, bandicoot, echidna, flying fox and large birds like the emu and jabiru. In desert regions even the smallest of animals, like geckos and skinks, were eaten.

Many insects and their larvae also constituted a significant part of the Aboriginal diet. In central Australia honey ants build their nests under mulga (*Acacia*) trees. The worker ants gather honeydew and nectar from scale insects which they feed to special workers inside the colony. The abdomens of these ants become swollen with nectar to the size of large grapes. During periods of drought these ants not only have their own large food reserve, but on demand will feed other workers and so ensure the survival of the colony. These ants are considered a delicacy for desert tribes. So too are witchetty grubs.

There are several types of witchetty grubs, each being the caterpillar of a moth. One significant food grub is found in the roots of the mulga tree. A large, grey, nocutural moth lays its eggs on the ground. The larvae that hatch from the eggs burrow into the mulga, eating the root material as they tunnel through it for several years. Some grow as long and thick as a finger and provide the Aborigines with a nutritious, high-fat meal. The red gum moth also provides another highly sought after caterpillar that feeds on the roots of the river red gum. These trees grow along dry watercourses in arid country.

Figure 5.11 Wood-eating larva

In the mountains of southern New South Wales, huge numbers of bogong moths (*Agrostis infusa*) cluster in crevices of rocks and in caves during summer months to escape the dry heat of the lower plains. The larvae, known as cutworms, feed on the winter flowering annuals of the plains. During spring they pupate and the emerging moths migrate to the Australian Alps in millions. In the caves they go into a state of very slow metabolism, surviving the summer by using the fat stored in their bodies. The Aborigines found them highly nutritious.

SUMMARY

Protein in the human diet in Western cultures is mainly derived from domesticated animals (cattle, sheep, goats, pigs and poultry) as either meat, eggs or milk and its derivatives, or from fish. In other cultures, a wide variety of different animals are eaten, depending on their availability.

Review questions

5.16 It has been suggested that the Aboriginal peoples of Australia had to resort to eating worms etc. in order to survive in such an inhospitable land. Other authors have stated that, on the contrary, the peoples sought such food in preference to other more readily available supplies. Cite evidence for either of these views and give a reason for your answer.

5.17 Suggest reasons why domestication of animals is an advantage to the human species.

5.2.4 Other sources of food

Although plants and animals form the basis of human nutrition, other organisms are used directly for food, or are used in production of processed food.

Spirulina is a cyanobacterium that lives in brackish water. It is cultivated, particularly in Hawaii, dried and powdered to form a food supplement that has high levels of a large number of essential amino acids as well as most minerals required in the human diet.

The red algae are an important food source in many countries (e.g. Japanese nori) and extracts are used as stabilisers in confectionery, ice-cream, cosmetics and pet foods. The sea lettuce, *Ulva,* is common along rocky shores. As its common name suggests, the thallus is shaped like a lettuce. This is an edible species. One species of green alga, *Dunaliella salina*, grown in ponds with high salinity and light intensity, accumulates large amounts of a chemical called ß,ß-carotene. This is extracted and used as a colouring agent in margarine and other products, and as a vitamin supplement.

Many fungi, such as the field mushroom and truffle, are important sources of food and are rich in iron. Fermentation industries use the respiratory processes of heterotrophic fungi. In the production of alcoholic beverages (beer, wines, cider) yeasts are selected for their ability to convert sugars, during anaerobic respiration, to ethyl alcohol and carbon dioxide. The alcohol produced eventually kills the yeast. The yeast sludge removed from brewed beer is used in the production of 'Vegemite'. Another strain of yeast, selected for high carbon dioxide production, is used in baking to make dough rise. Fungi are used in cheese making to give the characteristic flavours to cheeses such as roquefort (*Penicillium roqueforti*) and camembert (*P. camembertii*).

Case study 5.1: Industrial fermenters and fermentation

Large-scale industrial production of many substances produced by microorganisms involves the use of fermenters. Although the term 'fermentation' strictly refers to anaerobic respiration, it is also used in industry to apply to aerobic processes.

The basic design of a fermenter is a large stainless steel vessel surrounded with a jacket through which water at a particular temperature is circulated. A series of blades within the vessel stirs the mixture of nutrients and organisms. If the fermentation is aerobic, air is bubbled through the mixture. Various openings to the tank are provided for the introduction of nutrients and culture organisms, sampling the medium at stages throughout the process, and for removal of gases and any foam produced.

Once the optimum environment has been achieved in the fermenter, the culture is inoculated. Since the microorganisms change the conditions within the fermenter as they metabolise, the medium must be constantly analysed to maintain optimum conditions. pH and temperature are measured using probes which are built into the fermenter. Control of conditions in the fermenter is critical in ensuring the desired products.

Recovering the product may involve the separation of cells from the medium. This may be achieved by settlement, centrifugation or ultrafiltration:

- **Settlement:** When agitation stops, the cells usually settle to the bottom of the tank. This process may be speeded up by adding certain chemicals.
- **Centrifugation:** The contents are spun at high speed with the heavier cells settling at the bottom of the container.
- **Ultrafiltration:** The contents are forced through fine filters that allow only liquids to pass through.

  The desired products may be:
  - the cells themselves (they are washed, dried and compacted)
  - the cell contents (the cells must be ruptured and the product extracted)
  - in the liquid medium (the product is separated as above).

Industrial fermentation processes must be undertaken under sterile conditions in order to prevent contamination of the product by other microorganisms. This is of particular importance when food substances are produced by fermentation, to prevent accidental introduction of species of bacteria that cause food poisoning.

SUMMARY

Humans use particular members from all kingdoms as food or in the production of food. Fermentation processes use bacteria or yeasts to produce specific products.

? Review question

5.18 Describe ways in which non-plant or animal sources are used in human nutrition.

5.3 Shelter

The human species has been described as 'the naked ape'. As described in Chapter 23 , the human species evolved in Africa from a primate ancestor from which are descended chimpanzees, gorillas, a diverse range of human-like organisms and modern humans. Our progenitors gradually assumed the skeletal changes essential for an upright stance and other features characteristic of our species. One of these features was the loss of much of the dense body hair covering and the formation of sweat glands over the entire skin surface. While this feature is an advantage in a benign environment, allowing evaporative loss of excess body heat, it was a distinct disadvantage to those members of the species who migrated to all parts of the earth's terrestrial surface. The need for protection extended from finding a secure haven against predators, to providing a means of overcoming heat loss in cold conditions. Mutations favouring a thick matt of body hair in tribes living in cold climates might have been an answer. That this did not occur suggests that early humans developed the ability to overcome the cold and protect themselves from rain early in their evolutionary history. Both warm shelters and the ability to construct clothing were involved in this process.

5.3.1 Dwellings

Modern humans construct their buildings out of a wide variety of materials, many of these being from non-living materials such as stone, glass, cement and metals. The first human shelters were most likely caves and rocky outcrops. Not only did they afford protection from the elements, they ensured that predators could not easily attack them without warning.

Tribes living on, or migrating across, the plains, however, would not have had ready access to caves. They developed the ability to construct shelters from available materials. Leafy branches forming lean-to protection progressed into more substantial wooden huts in wooded areas. Roofs of thatched grasses or palm leaves were discovered to be waterproof. In those areas where trees were scarce, huts constructed of woven grasses or grass mixed with animal dung evolved.

The moss *Sphagnum* grows in acidic bogs. The low oxygen levels associated with these bogs decreases the rate at which bacteria and fungi can decompose the dead moss remains. As these accumulate they are compacted to form peat. This can be cut into blocks which can be used as either a fuel or a building material. It takes time to collect the materials and build permanent huts. Nomadic tribes, therefore, learnt how to stretch the hides of animals they killed, and to sew the pieces together. These were then used for covering poles as a tent. A portable hut came into being. Examples of all of these types of construction can be seen in various parts of the world today. The nomadic Arabs also used tents made of woven strips of sheep or camel hair and vegetable fibres sewn together.

Although modern technology has resulted in the development of a vast array of processed materials, wood is still a significant resource in the construction of both buildings and furniture. Wood is hardened plant tissue, usually in the stem. A chemical, called lignin, is deposited in the cell walls of water-conducting tissue, called xylem, usually in rings and spirals. This type of strengthening is found in all plants that grow into trees. It is seen in tree ferns, bamboos and palm trees. Although these stems are strong and light, they do not reach a very large diameter and so their usefulness as a construction material is limited. Tree fern stems are used by villagers in tropical regions in preference to other timbers because they are resistant to both decay and termite attack.

(a)

(b)

Figure 5.12 Different tribes in East Africa used different building materials depending on local availability. For example, the Fipa people constructed a timber tepee, coating the inside with clay and the outside with grasses (a), while the Wpogo tribes constructed huts from timber and packed the inside with stones embedded in clay (b).

Increase in height of plants, **terminal** or **primary growth**, occurs at the tips of the plant stem, branches and roots. Special tissues divide rapidly during growing periods. The new cells then elongate and start to differentiate into the various tissues.

The largest trees are members of the dicotyledons and the gymnosperms. In these two groups a process known as **secondary growth** occurs. In these plants the vascular bundles are arranged in a ring towards the outer surface. The water-conducting vessels, the xylem, is on the inside and the food-conducting vessels, the phloem, is on the outside of each vascular bundle. Between these two types of vessel is a layer of **cambium** that is continuous right around the circumference of the stem. Cambium is an undifferentiated tissue. As it divides it can develop into any type of plant tissue. Thus the dividing cambium cells next to the xylem form new xylem cells, while those next to the phloem form new phloem cells. Between the vascular bundles the dividing cambium forms new filling or parenchyma cells. This growth increases the girth of the stem. The old phloem cells are pushed to the outside and the new cells take over the function of food transport. This results in the old tissues sloughing off as shed bark. The new xylem cells also take over the function of water transport. This is termed the sap wood. The old xylem, in the centre of the stem, is called the heartwood. It becomes the plant's rubbish dump, storing tannins and other metabolic waste products. (See Figure 4.52, page 95.)

The trunks of huge trees may be several metres in diameter but only have a surface layer of a few centimetres of living tissue. The outer coating of bark is a protective layer of dead impermeable cells. In some species this layer is very thick and rugged. The bark of the cork oak, *Quercus suber*, is so thick and impermeable that it is collected and cut into thin layers that can be used as a soft floor material or as insulation.

Secondary growth in temperate trees usually occurs in spring and summer. The xylem cells produced in spring are relatively large with thin walls. As the growing season progresses water availability decreases and the new cells are smaller with thicker walls. Over a number of years the wood comes to have a series of annual rings, each composed of a band of large cells and a band of small cells. In the tropics there are no pronounced seasons and the trees can grow continuously. These trees will have either no distinct rings, or rings indicative of periods of good and bad weather rather than years of age.

The heartwood formed by many trees is valuable to humans as building timber. This timber is classified as either softwood or hardwood. The division is based upon the type of xylem present and thus is related to the class of plants. The flowering plants produce hardwood, while the gymnosperms produce softwood which is more easily crafted.

Among the flowering plants, significant timber trees of tropical and subtropical regions are the mahogany, teak and ebony. In Australia the majority of the hardwoods belong to the myrtle family (Myrtaceae), which includes the eucalypts, brushbox and turpentine. The eucalypts are by far the most important of these forest trees. The timbers from different species display a considerable range of hardness, flexibility, strength, durability, colour and weight. As a result these timbers are put to a variety of uses—for heavy structural purposes such as bridge building and harbour pylons, general building timbers, cabinet making, plywood and paper pulping. The Western Australian jarrah (*Eucalyptus marginata*) and marri (*E. calophylla*) are of particular economic importance. Two other economically important hardwoods are the blackwood (*Acacia melanoxylon* of the family Leguminosae) and the karri oak (*Casuarina decussate*, family Casuarinaceae).

Many species of the conifers (class Gymnospermae), however, have such economic importance that they are grown in vast plantations, their timber being harvested for paper and chipboard production, furniture or building materials.

Although the conifers are important trees in the Northern Hemisphere, in number of species they are poorly represented in Australia. Many Australian species have a very restricted range. For example, the bunya pine (*Araucaria bidwillii*) is found mainly between Gympie and the Bunya Mountains in southern Queensland. Other significant Queensland species include the hoop pine (*Araucaria cunninghamii*), cypress pine (*Callitris glauca*) and the kauri pine (*Agathis robusta*). The timber of cypress pine is unsurpassed for resisting termite attack and is used extensively for flooring, house stumps and poles. The huon pine of Tasmania is particularly durable for a softwood and is used for constructions that require curved shapes and boat building.

5.3.2 Clothing

The first clothing used by early humans was probably animal hides. The skin of most mammals comes away easily from the carcass. These skins would have been dried and stretched and most likely used as a wrap around the body or a blanket. Over time people developed the skill of scraping excess tissues from the inside of the skin and applying solutions made from ground-up bark to the skin to preserve and soften it (the process of tanning). They also made needles from bone and used the tendons from their prey to sew pieces of hide together to make fitted clothing. The thicker parts were most likely used to make footwear, a practice still followed today using cattle hides. It is likely that the discovery of tanning was a significant step in human progress towards civilisation. Certainly there is evidence that it was a common occurrence in Europe in 10 000 BC.

How the process originated is lost in antiquity. It has been suggested that water dripping off the bark roof of a hut onto animal skins may have resulted in the leather being improved. This may have led to the observant owner deliberately soaking leather in a water and bark mixture. Regardless of the original observations that leather soaked with bark led to increased durability, water resistance and flexibility, the process was discovered and used independently by different peoples across the world. It is now known that the tannins in the bark are responsible for this process—thus the name tanning for the process. Tannin is the name given to a complex group of substances produced by the plant. It has been long thought that tannin is a waste product of the plant's metabolism although there is some suggestion that it is involved in cork production as well as that of red and blue pigments. Certainly it has been found that the presence of tannins in the soil inhibits fungal growth, and thus production of tannin by the plant may give it some protection from fungal attack. Although tannins are present in most flowering plants and conifers, some, like the wattles, tea trees, gum trees and mangroves of Australia, are particularly rich.

Wool from sheep and goats was twisted together to form long strands. This can be achieved by rubbing the fibres between the hands. Over time special devices were constructed to spin the fibres which could then be used to weave cloth. Until recent years, woollen clothing was the major textile of cold areas. The development of synthetic materials (acrylics and polyesters) has meant that a cheaper alternative is now available. The Chinese developed the ability to unwind the silk forming the cocoons of the mulberry-eating silk worms. A large industry developed around the controlled growth of these worms in silk production.

Plant fibres have also been significant throughout the ages in the production of clothing. Several different types of plants are used, depending on the properties of the cellulose fibres and the locality. The cotton plant produces soft white fibres surrounding the seeds in the ovary. When the ovary dries and splits open, the wind catches these fine fibres in the 'boll' and carries the seeds large distances from the parent plant. It is these fibres that are spun and woven to form cotton cloth. Other significant plants used in the production of material are flax (linen) and hemp (burlap). The cellulose fibres from the stems of these plants are extracted.

One of the earliest forms of cloth produced in most of the Asian region, Indonesia, Melanesia, Africa and South America was made from bark. The inner bark (bast) of trees such as the paper mulberry and fig were soaked in water and then pounded on stone with a wooden beater. This is a similar process by which felt (from wool) is made. The thickness to which the bast was beaten depended upon its use. In Indonesia, for example, some pieces were particularly fine for the use of head-cloths, while others were thicker and used to make jackets and ponchos.

(a)

(b)

Figure 5.13 Cotton: (a) unripe and (b) ripe cotton boll

Dyes were produced from both plants and animals to decorate the textiles produced. Over fourteen different plants, each producing a different coloured dye, are used to decorate the tapa (bark) cloths of Hawaii. Although it is not known exactly when coloured pigments were first used to decorate clothing, archeological evidence shows that it was not only common in Egypt, India and Mesopotamia by 3000 BC but used very complex processes to ensure the depth and durability of the colour. The colour indigo was derived from a plant of the same name, while alizarin (red) came from the madder plant. Blue and green were obtained from the woad plant. Shellfish were the source for tyrian purple. Most dyes are now synthetically manufactured although crafts people still extract pigments from a wide variety of plants to colour their textiles.

SUMMARY

Unlike other mammals, the human species is poorly endowed with protective body hair. The ability to construct protective shelters and make clothing was significant in the migration of humans from Africa throughout the rest of the world. Throughout human history, plants have played a significant role in both building and clothing.

Review questions

5.19 Distinguish between softwoods and hardwoods.

5.20 Explain the terms 'primary growth' and 'secondary growth'.

5.21 What is the basic component of plants that is used in the production of cloth?

5.22 Tanning is the name given to the treatment of leather. From where does the term 'tanning' come?

5.4 ORGANISMS THAT BITE, STING AND IRRITATE

Many different types of organisms have a negative impact on humans either by direct contact, attack on their domestic animals or cultivated plants, or by destroying their materials. For example, although some species of fungi are good sources of food and are very important decomposers, they can also wreak havoc.

Many fungi cause deterioration of food and materials. Certain fungi destroy paint by growing under it and causing it to flake. Some can grow on rubber and electrical insulators, on leather and other natural fabrics. Although few are human parasites (thrush, athlete's foot and ringworm are caused by fungal parasites), fungal infections of plants have huge ecological and economic effects. Almost every plant crop is subject to some form of fungal infection such as mildews, smuts and rusts. One fungus forms purple structures called ergot on the seeds of wheat, rye and other grasses. If diseased grain is eaten by pregnant cattle, the poisons produced by the ergot may cause them to abort. These same poisons, similar to LSD in composition, if present in flour products eaten by humans, can cause gangrene, nervous spasms, hallucinations and temporary insanity. A common mould of stale peanuts is *Aspergillus flavus*. It produces substances which are converted in animal livers to extremely potent carcinogens (cancer-inducing chemicals). The levels of this fungus in peanut production are therefore carefully monitored.

Several toxic species of mushroom occur in Australia, the most potent belonging to the genus *Amanita*. Members of this group are characterised by a swollen base located in a cup-shaped structure, the 'death cup'. They are usually large mushrooms with a whitish cap and white gills (both of which turn darker with age). Two toxic mushrooms which can be confused with field mushrooms are the iodoform mushroom and the green-spored parasol mushroom. The iodoform mushroom has a distinct ring, and a yellow stain appears if the stem is cut. It has an odour of iodine which becomes more pronounced with cooking. The green-spored parasol mushroom has a relatively tough ring on the stem which can be moved up and down, and the stem may become brown with handling.

Figure 5.14 'Death cup' fungus (*Amanita*)

The delicate inkcap mushrooms, found on lawns in Brisbane after rains, can be eaten by some people without ill effect. However, if alcohol is drunk at the same time, severe nausea can occur. The gold top mushroom (*Psilocybe cubensis*) is a known hallucinogen when very small amounts are eaten and can induce severe nausea when taken in larger amounts. In Queensland it is illegal to have possession of this mushroom.

As seen from this description of fungi, the adverse effects of some organisms on humans can be as parasites, irritants and poisons. Parasites, particularly those that cause disease, will be described in Section 5.5.

Adaptations of a living thing may include the ability to:

- protect itself against predation
- ensure successful competition for resources
- capture prey.

Thus many organisms have mechanisms that act as deterrents to, or ensure capture of, other organisms. Many of these also act on humans.

Some of these adaptations inadvertently create superficial harm to humans. Thus the thorns of the rose bush can tear the flesh of unwary gardeners. The cut itself may be superficial, but it does expose the underlying skin tissues to the possibility of bacterial infection.

Figure 5.15 Thorns of the rose bush

The main negative effects, apart from parasitism, of organisms on humans come about as a result of:

- lesions that can then become infected by other organisms such as bacteria
- irritants
- allergens
- poisons.

5.4.1 Irritants

Many organisms produce fine hairs or bristles on their surface that are readily released on contact. The hairs can cause rashes on the skin, eye irritations and inflammation of breathing passages to the unsuspecting 'attacker'. Many caterpillars use this defensive strategy. In Australia the bagmoth caterpillar (*Teara contraria*) and the caterpillars of the mistletoe browntail moth (*Euproctis edwardsi*) are responsible for seasonal itchy rashes that may persist for many days. Their bristles, which are shed as they pupate and may also be woven into cocoons, are heavily barbed and may penetrate deeply into the skin. Both caterpillars feed in gumtrees and the shed bristles are often found in large numbers around the bases of these trees. Wind may then carry the bristles large distances. Bristles may fall and lodge in clothes on washing lines near gum trees. Thus a person does not have to have direct contact with the caterpillar to experience the itchy rashes produced by the hairs.

Figure 5.16 Hairy caterpillar

5.4.2 Allergens

An allergic reaction occurs when the body's immune system overreacts to particular chemicals (**allergens**) produced by other organisms. These reactions are typically very rapid and are extremely sensitive to small amounts of the allergen. The reaction can occur in a variety of tissues—the nasal passages and bronchi, the intestines and the skin being common. Special mast cells in tissue attach to the allergens.

This binding results in the mast cell releasing a large amount of the chemical histamine. Histamine causes small blood vessels to enlarge and blood to leak into the surrounding tissues. The area becomes swollen and red. The increased blood cells in the area allow destruction of the allergen. The symptoms of an allergy include sneezing, nasal irritation, itchiness of the skin or tearing of the eyes.

In some cases the reaction is so severe that **anaphylaxis** occurs. Such large amounts of histamine are released that the dilation of the blood vessels in the affected area is extreme. The body blood pressure falls to a level that can result in a potentially fatal shock reaction. This can occur in people who are hypersensitive to particular chemicals such as that found in bee stings.

The sensitivity to environmental chemicals varies from person to person. The most common allergens include chemicals found on animal hairs, in wasp and bee stings, in certain seafoods such as prawns, in plant saps and on pollen. Some people are extremely sensitive to chemicals in dust mite faeces and develop asthma in their presence.

Many people suffer hayfever and asthma during spring in Australia. Although a variety of plant pollens have been attributed to these reactions, it has been found that the most common cause is grass pollen. A study in Melbourne demonstrated that the most common grass species causing an allergic response is rye-grass (*Lolium perenne*) and that weather conditions influence the severity of the reaction. Two allergens are associated with this pollen—one on the surface and another on the starch granules within the pollen grain.

In dry weather only the surface allergen operates. The pollen is blown into the eyes and nostrils. The histamine released by the mast cells that bind to the allergens causes production of both tears and nasal mucous. The classical hayfever response occurs.

In wet weather the pollen ruptures in the rain and hundreds of starch granules are released from each pollen grain. These tiny particles, with their allergen, are breathed in and pass into the bronchi. The reaction of people sensitive to this allergen is large-scale constriction of the bronchi and production of thick mucous (phlegm). Both result in narrowing of the lung airways and difficulty in breathing i.e. an asthma attack.

In addition to grasses, the pollens of other common plants are known to bring about either hayfever or asthma in sensitive people. These include casuarina (she-oak), clover, cosmos, fennel, Paterson's curse, pine trees, plantain, wattle and white cedar.

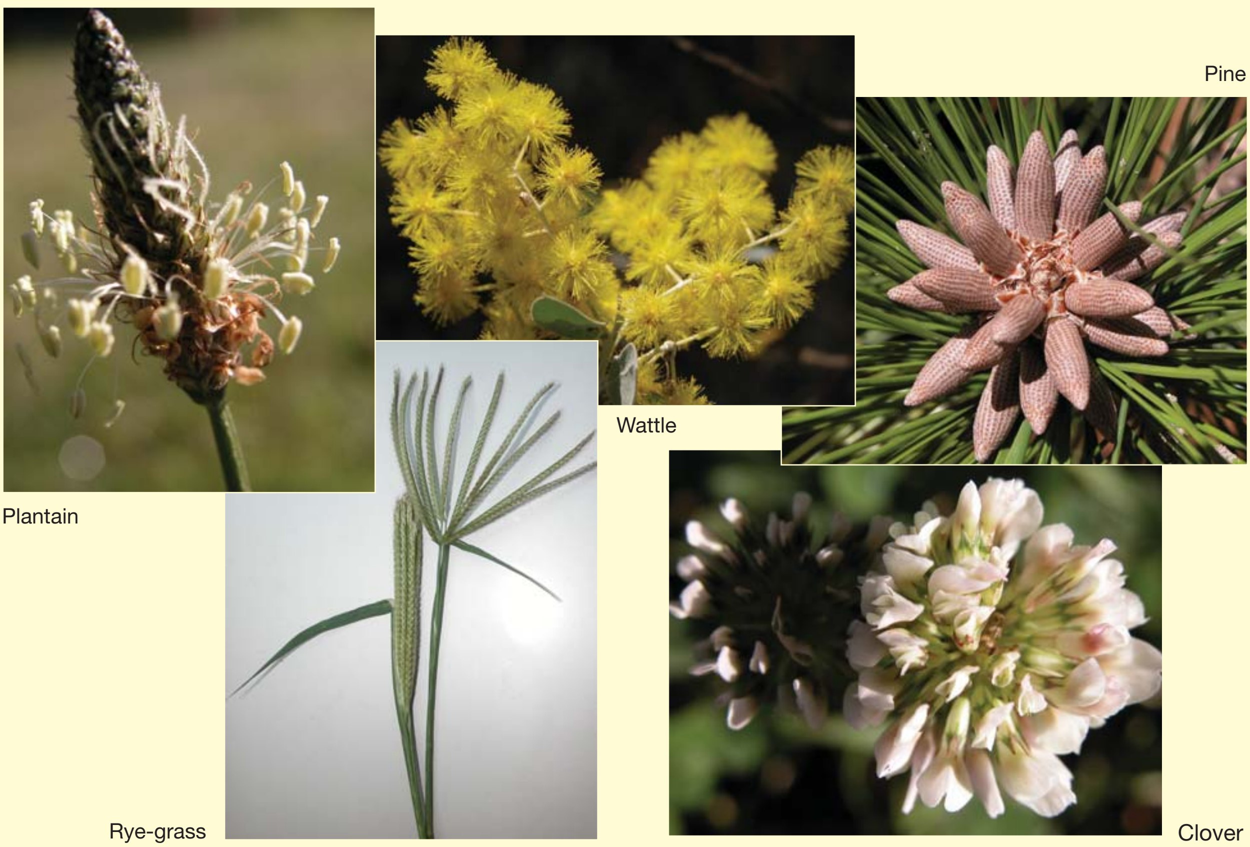


Figure 5.17 Common plants whose pollens may result in allergic hayfever or asthma

Tomato

Lantana

Frangipani (sap exuding from broken stem)

Figure 5.18 Some plants that may result in allergic contact dermatitis

Some people are also sensitive to touching parts of plants and develop the allergy called contact dermatitis, a large itchy rash that can swell and develop blisters. A large proportion of people display this reaction to poison ivy. Other plants known to produce this effect in some people include carrot, celery, chrysanthemum, fig, geranium, onion, primula and tomato.

5.4.3 Poisons

Poisons are chemicals that cause injury or death when introduced into, or absorbed by, a living organism. Some poisons are inherent in the tissues of organisms. Oleander plants, for example, contain poisons in all tissues. Drinking water can be contaminated if leaves or flowers fall into it. It has been reported that 300 soldiers were severely poisoned, with some even dying, when they used oleander sticks as skewers to cook meat.

Other poisons are classified as **toxins**. These are chemicals secreted by an organism and are often a metabolic waste product. Many bacteria produce toxins. **Venoms** are poisons secreted and actively injected into another organism. Classical examples are snake and spider venom.

Production of poisons may be an adaptation for competitive superiority. Some fungi, for example, release chemicals into their substrate that act on bacteria that utilise the same food source. Many of these chemicals (**antibiotics**) have been extracted and used to treat bacterial infections in humans and their livestock. Others are an adaptation to avoid being eaten. Many plant poisons originate in this manner. Thus the sap of the milkweed (*Ascelpias*) contains chemicals that affect the heart of vertebrates but does not directly affect the caterpillars of the wanderer butterfly (*Danaus plexippus*). The poison is not broken down by, but accumulates in the tissues of the caterpillar. Not only does the plant have a defence against being eaten by vertebrate herbivores but confers its protection to the wanderer butterfly and caterpillar.

Candlenut

Oleander

Cunjevoi

Figure 5.19 Some poisonous plants

Several other examples of recycling poisons have been documented. Members of the phylum Cnidaria (e.g. jellyfish) produce stinging cells (nematocysts) that are released to capture their prey. Some nematocysts immobilise the prey by adherent action, while others penetrate the skin and release toxins that can have various effects such as paralysis, breakdown of red blood cells (haemolysis) or cardiovascular collapse. Some animals are known to recycle the undischarged nemotocysts.

The sea lizard, *Glaucus atlanticus*, is a carnivorous, marine gastropod that has lost its mantle, shell and gills. This small, delicate creature drifts on surface waters with the ocean currents. It attaches itself to any jellyfish it encounters and starts to devour it. Any undischarged nematocysts ingested migrate through the intestinal wall to the tips of its tentacles. When under threat, the nematocysts are activated as a defence mechanism. The potency of the mechanism is determined by the type of jellyfish eaten and thus the type of nematocyst present.

The small octopus *Tremoctupus violaceus* also uses jellyfish nematocysts. It is, however, more specific in that it picks up fragments of the Portuguese man-of-war. It uses these fragments in both offence and defence.

Some marine animals are poisonous because they have accumulated toxins produced by other organisms. This is an example of biological magnification which will be discussed further in Chapter 10. 'Red tides' are caused by a population explosion of oceanic dinoflagellates in certain conditions of high temperature and nutrient supply. Many of these red tides are caused by harmless dinoflagellates but others can bring about oxygen depletion of the water and thus death of fish and invertebrates in shallow bay areas. There are some species, however (particularly *Gambierdiscus toxicus*, *Gymnodinium* and *Alexandria*), that produce a potent toxin called phytotoxin which can pass through the food chain from shellfish and fish to humans and produce a condition known as ciguatera poisoning. Paralytic shellfish poisoning (PSP) of humans in the Pacific region (but not recorded in Australia) has resulted from eating mussels and clams that have accumulated these toxins. In Australia ciguatera poisoning more commonly occurs after eating large reef fish such as reef cod, coral trout and Spanish mackerel.

A large number of plants that produce contact poisons only affect sensitive people. Some, however, have a universal effect. Stinging nettles and the giant stinging tree of the Australian rainforest come into this category. Given the number of poisons that plants produce, there are relatively few severe illnesses or deaths from ingestion. Most plants with poisonous qualities have a bitter or unpleasant taste. Adults trying a new food invariably only take a very small amount and rapidly spit out anything that has an unpleasant taste. Their body mass is large compared to the amount of poison they might ingest and thus they suffer few if any effects. Children, on the other hand, are natural explorers. They are much more likely to swallow small berries without even chewing them. Due to their smaller mass, the effect of the poison is more potent. It is not surprising, therefore, that most plant poisonings involve young children.

Figure 5.20 Stinging nettle

Table 5.4 Common Australian poisonous plants. Those plants marked with an asterisk (*) are known to cause death.

Family	Plant	Part of plant	Symptoms
Family Anacaridaceae	Poison ivy Mango Scarlet rhus Broad-leafed pepper tree Pepperina	Sap	Contact dermatitis
Family Apocybaceae	Oleander* Yellow oleander*	Whole	Vomiting, abdominal pains, diarrhoea, dizziness, irregular heartbeat
	Allamanda	Fruit and sap	Fruit—diarrhoea and vomiting Sap—contact dermatitis
	Pink periwinkle	Whole	Laxative effect, irregular heartbeat, hallucinations, loss of hair, skin tingling
	Frangipani	Sap	Contact dermatitis Ingestion—gastrointestinal irritation, increased urination
Family Araceae	Arum lily*	Yellow flower spike	Swelling of the throat and tongue, acute gastroenteritis and diarrhoea
	Diffenbachia (dumb cane) Cunjevoi Elephant's ears Philodendron	Whole	Burning sensation as chewed; swelling lips, mouth, tongue and throat
	Syngonium*	Flowers	
	Anthurium	Whole	Skin and eye irritations
Family Araliaceae	English ivy	Whole	Contact dermatitis Ingested—diarrhoea, nervousness, convulsions, coma
Family Asclepiadaceae	Balloon cotton bush* Red-head cotton bush (milkweed)*	Sap	Salivation, nausea, muscle paralysis (including heart)
Families Cycadaceae and Zamiaceae	All species	Seeds and rhizomes	Severe gastrointestinal irritation with vomiting and nausea

Family	Plant	Part of plant	Symptoms
Family Euphorbiaceae	Castor oil plant*	Seeds	Vomiting, diarrhoea, rapid and weak pulse, drowsiness, thirst, cramps, delerium
	Coral plant (physic nut)	Fruit	Vomiting, diarrhoea, numbness and paralysis of arms and legs
	Candle nut	Fruit	Severe vomiting and diarrhoea
	Chinese tallow tree	Sap, seeds	Purgative
	Zig zag plant	Sap	Contact dermatitis, swollen joints and rheumatism Ingested—vomiting and diarrhoea
	Naked lady	Sap	Corrosive contact dermatitis, temporary blindness
	Poinsettia	Sap	Contact dermatitis
Family Fabaceae	Gidee gidee (crab's eyes)*	Seeds	Intestinal irritation, vomiting, inability to stand, circulatory response, haemolysis, uraemia
	Cassia	Seeds and pods	Purgative
	Broad bean	Seeds in some people	Headache, dizziness, fever
	Japanese wisteria	Seeds and pods	Gastroenteritis and repeated vomiting
	Sweet pea	Seeds	Paralysis, convulsions
	Coral tree	Seeds	Diarrhoea and vomiting, hallucinations
	Black bean (Moreton Bay chestnut)	Seeds	Vomiting, diarrhoea, dizziness
Family Meliaceae	White cedar*	Fruit	Vomiting, diarrhoea, severe thirst, cold sweats, convulsions
Family Myrtaceae	Finger cherry	Fruit	Permanent blindness
Family Ranunculaceae	Delphinium Larkspur	Young plants, seeds	Burning of mouth, tingling skin, nausea, abdominal pain, weak pulse, laboured respiration
	Celery buttercup*	Whole	Severe gastrointestinal irritation
Family Solanaceae	Nightshade (black and Brazilian)	Green parts and fruit	Gastrointestinal irritation
	Golden cup (chalice vine)	Whole	Dilation of pupils, lack of coordination, excitability, numbness of extremities, delirium
	Gooseberries	All except ripe fruit	Gastrointestinal irritation
	Cestrum	Whole	Elevated temperature, rapid heartbeat, excess salivation, gastritis
	Datura (including angel's trumpet)*	Whole	Intense thirst, hallucinations, delirium, dilation of pupils, convulsions, coma
Family Umbelliferae	Hemlock*	Whole	Nervousness, trembling, dilation of pupils, paralysis, respiratory failure
Family Verbenaceae	Duranta (golden dewdrop)*	Berries	Intestinal irritation, sleepiness, high temperature and pulse, swelling lips and eyelids, convulsions
	Lantana	Fruit * Leaves	Vomiting, lethargy, laboured respiration, circulatory collapse Contact dermatitis
	Vitex	Sap	Asthma, dizziness, headache, nausea

Although the phylum Cnidaria all produce nematocyts to use in the capture of prey, and some of these contain potent neurotoxins that cause paralysis, most marine poisons are used in defence rather than offence. A large number of organisms—for example, the pretty, little, blue sponge (*Neofibularia mordens*) of South Australia—release spicules coated in toxin when touched. Several fish (including the butterfly cod, *Pterois volitans*, and stonefish, *Synanceia*) have a similar mechanism. Venom-producing tissues enclose sharp spines on the dorsal fin. Mechanical pressure associated with the spine penetrating the flesh of an attacking organism (or inadvertent contact by a person) releases the venom which causes extreme local pain, muscle dysfunction and even paralysis.

Other marine animals have poisons distributed throughout their body. Most of the puffer fish (family Tetrodontidae) have flesh that contains the highly potent tetrodotoxin, one of the most toxic naturally occurring poisons that attacks the nervous system. Death can occur within 20 minutes of ingesting the flesh. Tetrodotoxin is tasteless and is not destroyed by heat. In spite of documentation of its effects, puffer fish flesh is highly sought after in Japan, where it is prepared as *fugu*. The concentration of the toxin in the fish muscle varies seasonally and between the different species. Specialist chefs are trained to select flesh of low toxicity whose only effect is to produce a pleasant tingling sensation. The methods are not, however, infallible and approximately 75 Japanese people die each year of poisoning from eating *fugu*.

Several crabs of the family Xanthidae ('black-fingered' crabs) found from Japan to northern Australia are also lethal if either the flesh, or the fluid in which they are cooked, is ingested. Along with tetrodotoxin, they contain two other toxins that also affect the nervous and muscular systems.

Thirty-two species of sea snakes are found in Australian waters, particularly in tropical waters. All of these snakes use venom to capture and immobilise prey. Although potent, the amount of venom injected in a strike is usually very low and the fangs of most species are very short so that they cannot penetrate deeply into the flesh. The toxins act on the skeletal muscles and death is associated with respiratory failure. Most sea snakes prefer to avoid people but become aggressive if interfered with. Thus fishermen clearing trawl nets and over-curious scuba divers are the most likely to be bitten. The most dangerous is the beaked sea snake (*Enhydrina schistosa*) that is found along the north coast of Australia to Rockhamptom. The potency of its venom is comparable to that of a tiger snake and it is able to release a large volume in a single strike.

Most people consider that their greatest danger in the sea is that of shark attack. Although not poisonous, sharks are highly adapted carnivores. Human attacks by the largest species (e.g. white pointer and grey nurse sharks) are sensationalised in the press. The reality, however, is that there are relatively few attacks and even fewer result in death. Over a ten-year study period there were only eleven fatal shark attacks while over 3000 people drowned and approximately 33 000 people died in road-related accidents in Australia.

(a)

(b)

Figure 5.21 Examples of poisonous marine organisms: (a) cone shell; (b) butterfly cod

Table 5.5 Some dangerous marine organisms in Australia

Phylum	Examples	Locality	Effects
Phylum Porifera (sponges)	*Neofibularia mordens* *Lissodendoryx*	St Vincent's Gulf Victoria	Intense dermatitis caused when silica spicules coated in toxins are released on contact.
Phylum Cnidaria **Class Hydrozoa (hydroids)**	Seaweed-like colonies of *Aglaophenia* (stinging 'seaweed') and *Lytocarpus* (fireweed) Millipora (fire coral)	Tropical coasts as far south as Moreton Bay Coastal Australia	Contact results in release of nematocyst containing toxins that cause a stinging sensation followed by swelling, pain and small pustules. The rash may last for up to a week.
	Physalia utriculus (blue bottle) and *P. physalis* (Portuguese man-of war)	Tropical coastal waters	Nematocysts in the trailing tentacles contain toxins that cause haemolysis, muscle cramps and respiratory difficulties. May be lethal.
Class Scyphozoa (jellyfish)	*Chironex fleckeri* (box jellyfish)	Tropical coastal waters	Tentacular nematocysts contain toxins that cause rapid death of skin cells, haemolysis and cardiovascular collapse.
	Carukia barnesi (irukandji jellyfish)		Nematocyst toxins result in pain, cramping of muscles, high blood pressure, vomiting and nausea.
Class Anthozoa (sea anemones and corals)	Solitary sea anemones of order Actinaria	Tropical and subtropical waters	Nematocyst toxins have been known to produce severe rash and blistering; eating uncooked flesh of some species can cause poisoning.
	Species of stony corals (*Acropora, Fungia* and *Scolymia*)	Tropical reefs Temperate waters	Mild stings on contact.
Phylum Mollusca	Cone shells, particularly *Conus geographus, C. striata* and *C. textile*	Shallow reef waters	Barb-like teeth are coated with toxins and used like a hypodermic syringe to inject venom into prey. Affects neuromuscular systems. Death can occur within 5 hours.
	Hapalochlaena maculosa (blue-ringed octopus)	Subtropical and temperate shallow waters and rock pools	Toxin enters wounds made by the beak-like jaws with saliva. It produces gradual numbness, followed by lack of coordination and paralysis. May be fatal.
Phylum Echindermata **Class Asteroidea (starfish)**	*Acanthaster planci* (crown of thorns)	Coral reefs	Spines are coated with toxin-producing tissues. The toxins are released when the spines rupture skin to produce a painful rash and temporary paralysis.
Class Echinoidea (sea urchins)	*Diadema setosum, Toxopneustes pileolus*	Tropical and subtropical rocky shores and reefs	Grasping organs between the spines secrete venom into wounds made by spine penetration. Intense pain and localised paralysis. Venom from *Toxopneustes* can be lethal.
Class Holothuria (sea cucumbers)	Many species	Coral reefs and estuarine sea meadows	Holothurin toxin may be present on the body surfaces or concentrated in tubules that can be ejected through the anus when the animal is irritated. Causes a violent inflammatory reaction and neural blockages. Can cause blindness if the secretions enter the eyes.

Phylum	Examples	Locality	Effects
Phylum Arthropoda Class Crustacea	Mostly crab members of the family Xanthidae (black finger crabs)	Tropical reefs	Numbness, nausea, vomiting, paralysis that may lead to respiratory arrest and death when the flesh or water in which crab is cooked is ingested.
	Prawns/lobsters/crabs	All areas	Some people have an allergic reaction to a variety of crustaceans. Reactions may vary from rashes to asthma and rarely anaphylactic shock.
Subphylum Vertebrata			
Class Chrondrichthyes (sharks and rays)	Stingrays	Coastal Australia	Penetration by defensive stinging spines attached to the tail release venom from surrounding tissues into the wound. Although the venom is a neurotoxin, the main symptom is intense pain.
	Port Jackson shark (*Heterodontus portus jacksonii*)	Temperate parts of Australia	Penetration by venomous spines at the front of each dorsal fin causes intense pain and local swelling.
	Large carnivorous sharks	Coastal Australia—the white pointer is particularly abundant in the Great Australian Bight.	Shark attack injuries are usually severe as the structure of the shark's teeth result in tearing rather than biting. Haemorrhage is usually massive and is often the cause of death.
Class Osteichthyes (bony fish)	Reef and pelagic fish such as mackerel	Coastal Australia	Ciguatera poisoning can result from accumulated toxin that has passed down the food chain from dinoflagellates. Results in tingling, numbness, joint and muscle pain and a rash.
	Puffer fish	Coastal Australia	The tetrodotoxin is in all parts of the body and can cause death if the fish are eaten.
	Stinging fish include butterfly cod (*Pterois volitans*), catfish, stonefish (*Synanceia trachynis*), bearded ghoul (*Inimicus caledonius*), flathead (*Platycephalidae fuscus*), zebra fish (*Enoplosus armatus*) and surgeon fish (*Acanthirodea*)	Coastal Australia	Spines, associated with the dorsal fin, and sometimes pectoral fins, are envenomed by surrounding poison-producing tissues. Penetration of the skin by the spines releases the poisons into the wounds, producing intense pain, swelling and delirium. Only the sting of the butterfly cod has been known to be lethal.
Class Reptilia	Sea snakes	Subtropical and tropical coasts	Venom from the fixed fangs contains neurotoxins that affect the skeletal muscles. May be fatal.
	Turtles	Tropical and subtropical waters	Poisoning, demonstrated by nausea, vomiting and diarrhoea, is sporadic and suggests that the poison may be passed along the food chain and accumulate in the turtle's flesh.

In Australia there is a tendency to limit dangerous terrestrial animals to spiders and snakes. While bites from these certainly account for many severe side effects and may result in death as a result of their venom, a larger array of terrestrial animals can have a negative impact on people. As with plants and shellfish reactions, only some people are affected by a few of these organisms. They have a specific reaction to the allergens associated with the organism. For most, a bee sting is a temporarily uncomfortable irritation and yet is life threatening for those who have an allergic reaction to the bee venom. In the majority of reactions to animals, a poison is involved. However, a real danger exists from physical damage inflicted by attack from saltwater crocodiles, magpies, cassowaries and dingoes.

Of over 140 types of snake in Australia, only fifteen contain venoms considered dangerous to humans. In order of decreasing danger, the extremely venomous terrestrial snakes are the fierce (small-scaled) snake, brown snake, taipan, death adder, tiger snake, king brown (mulga) snake, rough-scaled (Clarence River) snake, copperhead and the red-bellied black snake. Their distributions are shown in Figure 5.22.

These snakes have a venom gland in each upper jaw, connected by ducts to the hollow front fangs. As the snake bites, venom is pumped though the fang deep into the victim's skin. The chemicals in the venom can bring about a variety of responses including breakdown of red blood cells, prevention of blood clotting, muscle breakdown and interference with nerve conduction which can lead to skeletal muscle paralysis. The severity of snake bite inflicted by any particular species depends upon the length of the fang, the potency of the venom and the amount of venom produced.

Most snakes avoid humans and only strike if cornered or attacked. The death adder, however, is a night hunter and is fairly sluggish during the day. Even hunting is done with relative inactivity. It partially buries itself in leaf litter or sand with the head curled near the tail. The snake slowly flicks the end of the tail to attract rodents and lizards which it then rapidly strikes. This habit of remaining inactive, and only striking if touched, has resulted in many human bites. Because the fangs are long and can be rotated forward in the jaw, the death adder is able to inject large amounts of venom into its victim.

Although a large number of spiders produce venom only a few are known to be fatal. The most dangerous spider in the world is the Sydney funnel web (*Atrax robustus*), found from Newcastle to Nowra and west to Lithgow in New South Wales.

Figure 5.22 Distribution of extremely dangerous terrestrial snakes in Australia

This large, dark spider has massive parallel fangs they can drive into the victim with a large force. The female spider spends most of her long life (about 10 years) in the burrow and as a consequence is little threat to humans. If disturbed, she can inject venom that is considered dangerous. The male, however, is usually found migrating searching for females. It is an aggressive spider that attacks any creature that approaches it. The venom of the male is five times more potent than female venom. Even though only a small amount of venom is produced it may kill a human. One child died within 15 minutes of being bitten. The main chemical in the venom is called robustoxin. This produces a range of bizarre actions resulting from erratic nerve impulses throughout the body.

In Queensland two funnel web spiders (*Hadronchye infesta* of Toowomba and *H. formidablis* of the forests between the Hunter River and the Bunya Mountains) have potent venoms.

(a)

(b)

(c)

Figure 5.23 Spiders: (a) burrow entrance of the funnel web spider *Hadronchye formidablis*; (b) trapdoor spider entrance; (c) redback spiders

Table 5.6 Some dangerous terrestrial animals in Australia

Phylum	Example	Effects
Phylum Annelida	Leech	Loss of blood and irritation. Development of allergic responses may occur after repeated contact.
Phylum Arthropoda Class Diplopoda	Millipede	Lateral glands on each segment produce toxins that are used as defensive secretions. These can cause chemical burns on human skin.
Class Chilopoda	Centipede	The legs of the first segment are modified to form venom fangs. The venom has cardiotoxic effects, although in all but the larger Australian species the main effects are of severe swelling and pain.

Phylum	Example	Effects
Class Insecta	Fleas	The direct effect is inflammation in response to the flea's saliva which may develop into a rash. Since fleas are the intermediate host for the dog tapeworm and a vector in bubonic plague, it is important to prevent flea bites.
	Honey bees and wasps	The stinging apparatus for both groups is found at the end of the abdomen and associated with a venom gland. Although the venom usually causes pain and swelling, the proteins in the venom are extremely potent allergens and may be life threatening for sensitive individuals.
	March fly	The saliva introduced into the person when bitten causes an inflammation reaction which in sensitised individuals can lead to a severe allergic response.
	Culicoide midges	Intense itching results in lesions that may become secondarily infected. Allergic response can develop.
	Hairy caterpillars	The caterpillars of a variety of moths have spines and hairs projecting from their surface that contain venom. Irritations can occur when the hairs make contact with skin, and can develop into a severe dermatitis.
Class Arachnida	Paralysis tick (*Ixodes holocyclus*)	The saliva of this blood-sucking animal contains toxins which act on the nervous system and result in paralysis and possible death. Sensitivity and allergic responses can develop from repeated exposure.
	Mites—of a huge number, few affect humans, e.g. human hair mites, scabies mite, Queensland scrub itch mite	Mostly lesions to the skin which can become secondarily infected due to scratching. Some may be vectors for other organisms, e.g. Q fever rickettsias. Chemicals in dust mite faeces are allergens for some people, causing asthma. It has been suggested that these allergens may also be a causative agent in sudden infant death syndrome.
	Spiders	Most species have venom but only a few are considered dangerous to humans—Sydney funnel web spider, redback spider and mouse spider. Bites from others, such as the black house spider and white-tailed spider, can produce nausea, muscular pains, and sweating and necrotic wounds.
Phylum Chordata **Subphylum Vertebrata** **Class Amphibia**	Toads and frogs	Skin glands in a large number of species secrete toxins when the animal is handled. The greatest danger is if the secretion gets into the eye, causing severe irritation, or into scratches.
Class Reptilia	Saltwater crocodile (tropical estuaries and rivers)	Most attacks occur at dusk or night in shallow water. Severe lacerations can be secondarily infected. Most deaths result from transection of the torso or decapitation.
	Snakes	Discussed in text.
Class Aves	Magpies	These birds are extremely territorial during the breeding season. The most serious injuries inflicted on people are attacks on the eyes which could lead to traumatic cataracts.
	Cassowary	If the bird is threatened it leaps off the ground and kicks out with both feet. The inner two toes have long dagger-like claws that can eviscerate a person.
Class Mammalia	Platypus	The male is the only mammal in the world with a functioning venom apparatus. This is attached to two spurs, one on each inner hind ankle. Envenomation results in long-lasting, severe pain.
	Dingo	Attacks, and some deaths, have occurred in tourist areas where population numbers and reduced fear of people have increased due to feeding.

SUMMARY

Adaptive survival strategies of a large number of organisms can have a negative effect on humans. Many of these adaptations are defence mechanisms such as production of spines, irritating hairs or poisons. Other mechanisms are also used in offence. These include strong jaws, teeth and claws in many vertebrates as well as venom-injecting structures. Some people are very sensitive to chemicals produced by a broad variety of plants and animals. These allergens can produce effects that range from mild to life threatening.

Review questions

5.23 What is an allergen?

5.24 How is anaphylaxis different from a mild response to an allergen?

5.25 Distinguish between a toxin and a venom.

5.26 Give an example of how a plant and an animal poison is recyled by another organism as either a defensive or offensive mechanism.

5.27 Large reef fish such as coral trout do not produce poisons. Sometimes, however, eating these fish can result in ciguatera poisoning. Explain how this is thought to occur.

5.28 Tetrodotoxin is the most potent naturally produced poison. It is found in a number of organisms. What are the characteristics of this poison?

5.29 More people are bitten by death adders than any other snake. With reference to its distribution and behaviour, explain this observation.

5.5 Parasites and pathogens

Organisms that live on or in another organism are called **parasites**. They obtain their nutrients from their host and in doing so invariably cause some form of damage. Parasites that live on the outside of their host are called **ectoparasites**. Fleas are an example of this type of parasite. They are insects that have a piercing mouthpart that can penetrate the skin and enter the blood capillaries. They feed on their host's blood. Parasites that live within the body of the host are called **endoparasites**. A tapeworm living in the alimentary canal is an example of an endoparasite. Regardless of whether the parasite lives inside or on the outside of the host, it is usually an advantage to keep its host alive. If the host dies, it is highly likely that the parasite will also die unless it, its eggs or larvae have some means of moving to another host.

Parasites are found among all of the kingdoms of life. There is also a large array of host organisms. Some parasites even use another parasite to move from one host to another. The organism used in this transfer is called a **vector**. This vector may be a secondary host in the parasite's life cycle, and thus essential for its survival, or may be an inadvertent means of transport. It is very common for endoparasites to have a secondary host in their life cycle.

Being an endoparasite has some great advantages. There is a constant food supply in a well-protected environment. Among the animal kingdom many endoparasites have special adaptations for their mode of life. These may include one or more of the following features:

- *Attachment devices*. The tapeworm, for example, which lives in the gut of its host, uses hooks and suckers to prevent it being washed out of its host with undigested food.
- *Thickened cuticle.* A thickened outer layer, the cuticle, is resistant to digestive enzymes, acids and alkalis produced by the host.
- *Reduction of feeding organs.* Many endoparasites do not have their own digestive system since their host provides all their nutrients in a form that can simply be absorbed by the parasite's cells.
- *Reduction of locomotory powers.* Locomotion is unnecessary for most endoparasites.
- *Hermaphroditism*. The chance of encountering another member of their own species within a host is slight, so in some species each individual has a set of both male and female reproductive organs and reproduces by self-fertilisation.
- *An excess of fertilised eggs*. Endoparasites produce large numbers of fertilised eggs which are released into the outside environment. These eggs depend upon chance dispersal to the correct host organism, and so many are lost.

Parasites that cause a disease in their host are termed **pathogens**. A disease results from the dysfunction of the body or part of the body. Not all diseases are caused by pathogens. As seen earlier in this chapter, a variety of diseases occur as a result of nutritional deficiencies. Diseases are usually classified as **infectious** (i.e. can be passed from one individual to another either directly or indirectly) or

Table 5.7 Some different types of human disease

Type of disease		Example
Infectious		
Diseases caused by microorganisms:	bacteria	Cholera, tuberculosis
	viruses	Measles, rabies
	protozoa	Malaria, trypanosomiasis
	fungi	Ringworm, athlete's foot
Diseases caused by larger organisms:	roundworms	Ascarisis, onchocerciasis
	flatworms	Schistosomiasis, tapeworm
Non-infectious		
Nutritional deficiency diseases		Beri-beri, pellagra; kwashiorkor
Metabolic disorders		Diabetes, phenylketonuria
Degenerative diseases		Coronary heart disease, arthritis
Cancer		Skin cancer, breast cancer
Inherited diseases		Sickle cell anaemia
Occupational or industrial diseases		Silicosis
Mental disorders		Depression, alcoholism

non-infectious (cannot be spread from one individual to another). An infectious disease that passes directly between people (e.g. the influenza virus) is termed **contagious**. Some examples of human diseases are given in Table 5.7.

Disease in humans, their crops and domestic animals is caused by a diverse array of living agents. It has been assumed that the agents for these diseases were organisms that were capable of either causing their host cells to make more of them (e.g. viruses) or reproducing within the host. These organisms could, in some way, be passed from one host to another. In the vast majority of infectious diseases, organisms have been identified as the agents of the infection.

Prions—non-organism transmission of infectious disease

Recent investigations into the cause and transmission of bovine spongiform encephalitis (BSE) or 'mad cow disease' have resulted in heated debate in biological circles. Between 1986 and 2000 large numbers of cattle in the United Kingdom and certain European countries were infected with this disease—a fatal brain disorder that causes brain cells to die. This results in very strange behaviour in the cattle before they eventually die. A similar disease is found in sheep (scrapies) in Europe and deer in Canada.

Two similar diseases occur in humans. Creutzfeldt-Jakob disease (CJD) is an uncommon, degenerative disease that occurs in middle-aged people. Those that contract the disease show increasing signs of memory loss, have difficulty in controlling movement and become comatose. They usually die within 3 to 6 months. Kuru is a disease that was common in a tribe from New Guinea that practised ritualistic cannibalism. They eat the bodies of their own dead in the belief that this will immortalise the deceased person. Only the women and children eat the brains and only they are affected by kuru, which has similar symptoms to CJD. Although a living agent for these diseases has long been investigated, none has been found.

High protein feed has been developed to supplement grass for cattle in developed parts of the world. This cattle feed invariably includes ground meat and offal from sheep. During the 1980s the method of production of this feed was altered and it is thought that this somehow allowed the scrapie disease agent to survive and contaminate the cattle. At the time neither scrapie nor BSE were thought to affect humans. Brain tissue from BSE-infected cattle therefore made its way into the human food supply, particularly as sausages and hamburger meat. In the 1990s at the height of the BSE infection, several young people died of a new variation of CJD (nvCJD).

This prompted an increased search for the causative agent and particularly the relationship between BSE, CJD and the new variety of CJD. The link between all of these degenerative brain diseases was found to be an abnormal protein. The brain cells produce a protein called a **prion**. Abnormal forms of this prion are common in infected animals. Proteins cannot reproduce themselves under normal circumstances. New proteins can only be formed when the DNA of a cell's nucleus directs its production. A gene (a particular segment of the DNA molecule) is able to code for the production of one specific type of protein. Prions are unusual in that they are proteins capable of producing more of themselves when they are inside brain tissue, apparently without intervention by a nucleic acid.

It has been suggested that abnormal prions have a similar amino acid sequence to the prions normally found in the brain. They differ from these normal proteins in the way that the polypeptide chain is folded. When abnormal prions infect the brain cells, they convert the normal into abnormal prions. The proteins accumulate in the brain cell, eventually causing it to die and so release the abnormal prions. These then enter new cells and the process continues. Gaps occur in the brain where cells have died, giving it the classical spongy appearance.

Thus a person ingests abnormally shaped prions from contaminated food containing brain tissue. The abnormal prions are absorbed into the bloodstream, where they pass into nervous tissue. In some cases these proteins can remain dormant for several years. Once they are activated they start changing normal into abnormal forms of prion. It appears that the cell tries to get rid of these abnormal proteins by clumping them into a digestive sac (the lysosome) within the cell. No protein-digesting enzymes are present in the lysosomes capable of breaking down the abnormal prions. They therefore accumulate in the lysosomes, eventually killing the cell and releasing the abnormal prions to attack new cells. Within a year the brain tissue has been so badly destroyed that death occurs.

Control of nvCJD and BSE in the United Kingdom has been achieved by:

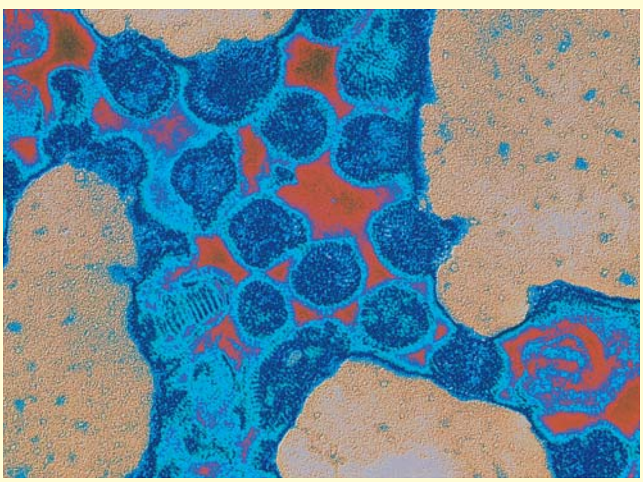
- testing all cattle for BSE
- killing and burning the carcasses of all BSE-infected cattle
- avoidance of all sheep nervous tissue in the production of cattle feed
- rigid laws controlling human food production (e.g. sausages and hamburger meat) to avoid contamination by any tissues that could contain abnormal prions.

Viral infections

Basically a virus is a large molecule of protein surrounding a nucleic acid (either DNA or RNA). It cannot perform any of the metabolic activities characteristic of living things but inside the cell of another organism it can direct the host cell's nucleic acid to produce more virus particles. Ultimately so many virus particles are present that the cell ruptures and releases the viruses to infect new cells. The process is described more fully in Case study 1.2. When not in a host cell the virus, which is a tiny 30 to 300 nanometres in size, forms a crystal that can survive extreme conditions for many years.

Different types of virus can only infect particular types of cells of specific organisms. Thus a virus that infects dogs is unlikely to infect a person. Similarly the virus that causes cold sores in people (*Herpes simplex* type 1) does not result in chicken pox, another viral infection of the skin caused by *Herpes varicella-zoster*. Viral nucleic acid can, however, undergo mutations. When this occurs, a disease that was found only in one type of organism can pass to another type of organism. Mutation also results in a variety of related infections such as influenza.

(a)



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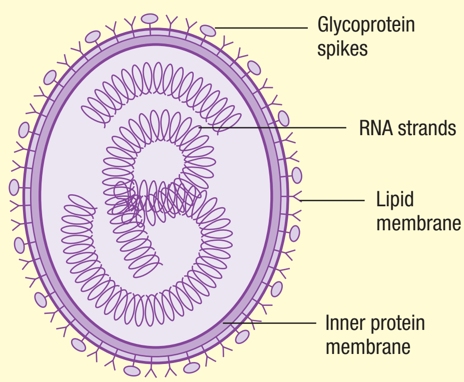


Figure 5. 24 Influenza virus: (a) an electronmicrograph; (b) structure of the virus

Prior to the development of farming, humans were hunter-gatherers who travelled large areas in search of game and other food in small bands. Although a particular band may be infected by a virus, the disease did not spread to other groups due to their isolation. About 10 000 years ago some bands took up growing crops and domesticating certain animals. Thus the people settled in one place and the population of an area started to increase. Records in fossil bones indicate that these people were far more susceptible to disease than their hunting relatives. The close association between humans and their animal stock resulted in transfer of animal viruses to humans. The animals had, over time, developed immunity to these viruses and so did not exhibit diseases. The human population, however, did not have this resistance and the subsequent diseases were able to rapidly decimate large numbers of people. The viruses responsible for measles, tuberculosis and smallpox were transferred from cattle. Influenza and whooping cough viruses came from domesticated pigs and ducks.

Outbreaks of new viral strains originating from domestic ducks in Asian countries continue to occur. Travel between countries is now a regular occurrence. Since many influenza viruses have an **incubation period** (the time for the viral numbers to build up sufficiently to produce the symptoms of disease) of up to 14 days, an infected person can contract the disease in one country and travel to several other countries before becoming aware of the disease. This person could, in their daily contact with others, infect thousands of people all of whom could take the infection to another part of the world. They in turn will be in contact with new individuals, many of whom could also become infected. In the first 6 months of 2003 an estimated 8500 people became infected with the pneumonia-like SARS (severe acute respiratory syndrome), of whom almost 800 died. It is believed that this virus is a mutated form of a similar virus found in wild civets which are captured and sold for food in the Chinese village in which the disease originated.

Case study 5.2: Flying foxes spread viral disease

In October 1994 a Brisbane horse trainer achieved fame as the first known human to die from the virus equine morbillivirus (EMV). Fourteen of the victim's racehorses also succumbed to the disease. The stables were immediately quarantined and no further incidences were reported. But 12 months later a Mackay horse breeder also died of the same cause.

The genetic composition of the virus was such that scientists knew it was not horse-specific and that its natural host was probably a native animal. The only possible hosts found in the Brisbane area were rats, mice and bandicoots, none of which showed a positive test for the morbillivirus. Combined efforts in January 1996 by scientists from the Queensland Department of Primary Industries, Queensland University, the Australian Quarantine and Inspection Services and the Queensland Department of Environment and Heritage isolated the possible host as the migratory flying fox. Three of the four large species had antibodies to this virus in their blood, indicating that although they did not have symptoms of the disease, they had been infected at some stage.

Since the human deaths occurred at a time when both horses and flying foxes were pregnant, the scientists hypothesised that there was an association between viral activity and pregnancy. Tests of flying fox uterine fluids and fetal material indicated that this was the case. Analyses of the morbillivirus in both flying foxes and horses show, from shape characteristics and the gene sequences tested, that they are probably identical viruses.

Later in 1996 the black flying fox and the little red flying fox (and probably also the grey-headed and spectacled flying foxes) were found to be vectors of another virus, a form of lyssavirus which belongs to the group that includes rabies. This virus lasts for only two hours outside the host body and cannot be transmitted from washed fruit (which the flying foxes eat). Experiments show that the rabies vaccine protects mice from lyssavirus. Australian health authorities are identifying people at risk (fruit pickers, vets and wildlife handlers) for vaccination after the death of a Rockhampton wildlife carer in November 1996 from encephalitis induced by the virus.

Although neither of these viruses is at present epidemic, the migratory pattern of their flying fox hosts extends from Victoria along the eastern and northern coasts to Western Australia. The potential for spread of lyssavirus between colonies is great. Care should be taken, therefore, when handling flying foxes to avoid being scratched or bitten.

All wildlife are potential carriers of disease. In spite of the negative publicity given to flying foxes, they are a vital part of Australia's environment, helping to maintain the forests through pollination and seed dispersal.

Viral infections cause a variety of symptoms, many of which aid their dispersal. Thus the coughing and sneezing caused by the common cold virus carries these parasitic particles to further hosts. In mosquito-borne viruses, the human host often has an increased temperature and carbon dioxide output, both of which attract mosquitoes and thus result in further spread of the virus.

AIDS (acquired immune deficiency syndrome) is caused by the human immunodeficiency virus (HIV). This virus is carried in body fluids (blood, semen, vaginal secretions, urine and saliva). The virus is very fragile and able to survive only for a matter of hours away from tissue fluids. It is transmitted during all forms of sexual intercourse that involve the exchange of body fluids, and by direct transfer of blood. There is no evidence to suggest that HIV is spread through the air, by touch, or from toilet seats. Inside the body the virus attacks cells (the T-lymphocytes) which are vital for normal functioning of the immune system. The virus may remain dormant for many years but usually its activity will be triggered when the T-lymphocytes start to divide in response to a bacterial infection.

Many AIDS patients have been known to suffer from one or both of two rare diseases:

- Kaposi's sarcoma—a form of cancer mainly of the skin, but known to affect other organs
- *Pneumocystis carinii* pneumonia—a very serious infection of the lungs.

Illnesses which the normal healthy body would be able to fight off readily become serious or fatal in those afflicted with AIDS. Although certain drugs can slow the progress and alleviate the symptoms, to date AIDS is always fatal.

AIDS diagnosis requires both medical examination and repeated blood tests. As with all viruses, its identification and study is difficult because it can be cultured only **in vitro** (inside living host cells, e.g. chicken eggs). The growth of this disease is of great concern worldwide. Since no successful vaccine has been discovered, nor effective preventive measures involving radical changes in social practices achieved, it has rapidly become **pandemic** (a disease prevalent all over the world).

A very few people who contract the HIV virus remain healthy for long periods of time (some have not developed AIDS after over a decade of carrying HIV). A few others are known to have had sexual contact with AIDS patients and not developed HIV. Researchers in America have studied these people in detail and believe that they may have HIV-resistant genes.

Bacteria

Many bacteria have been found to be harmful to humans, their domesticated animals and to cultivated plants. Pathogenic bacteria may spread in many ways (see Table 5.9). When they enter the body they may cause disease by producing poisonous chemicals (toxins), by changing the host's metabolism, or by damaging tissues. Some *Clostridium* species, for example, cause food poisoning by releasing a toxin into the food. If this food is then eaten, the toxins affect the nervous system causing problems in vision, paralysis and often death (botulism).

Many bacteria, like viruses, only affect particular parts of the body. The bacterium that causes bacterial dysentery produces a powerful toxin that affects the cells of the large intestine. This results in loss of blood with the faeces as well as diarrhoea. Other bacteria can affect many different tissues. The bacterium *Trepoloma pallidum* that causes syphilis initially causes inflammation of the penis (or vulva of the female) but can travel to, and affect, all parts of the body.

Table 5.8 Some common viruses and the symptoms of the disease they cause in humans

Virus	Host (primary /secondary)	Symptoms in humans
Influenza	human	headache, sore throat, fever
Measles	human	cough, fever, rash or spots
Poliomyelitis	human	affects muscles, nerves; paralysis of limbs
Rubella	human	similar to measles
Smallpox	human	fever, headache, rash, vomiting
Ross River fever	human/mosquito	fever, joint enlargement, headache
Mumps	human	cough, swelling of the salivary glands and testes
Yellow fever	human/mosquito	swelling of the liver
Encephalitis	human/horse	inflammation of the brain, headache, fever

Table 5.9 Some common bacterial diseases of humans

Disease	Symptoms	How transmitted
Cholera	profuse diarrhoea	water, faecal contamination; often transmitted by the body louse
Diphtheria	infection of the nose and throat	airborne, water droplets in breath
Pneumonia	fluid in lungs, fever, pain	water droplets in breath
Tetanus	muscular spasms	wound infection
Tuberculosis	lung disease	airborne, contaminated food or water
Typhoid	fever, muscular pain, diarrhoea	contaminated food or water
Syphilis	infection of reproductive organs, eyes, joints and central nervous system	sexual contact

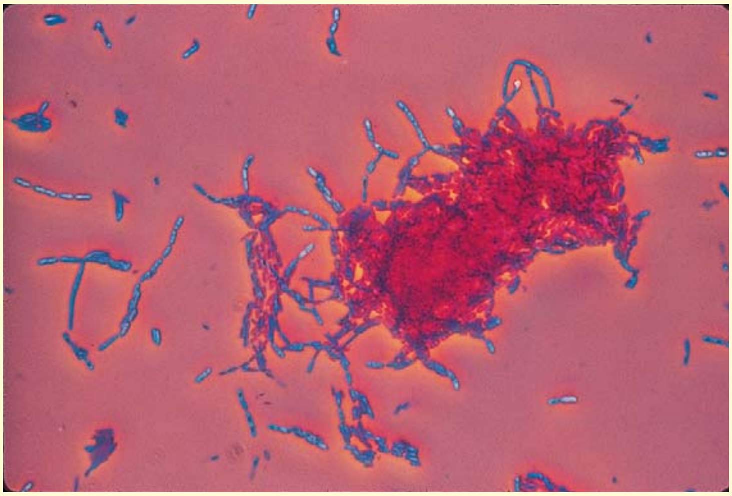


Figure 5.25 Chains of *Anthrax* bacilli with red and white blood cells

Protozoans

The amoebas and flagellates include some important human parasites. *Entamoeba gingivalis* lives in the human mouth, feeding on bits of food caught in the gums and teeth. As their numbers rise, by-products of their metabolism bring about tooth decay and gum disease. They are transmitted by kissing.

Entamoeba histolytica, which causes amoebic dysentery in humans, is spread via contaminated food or drinking water. The flagellate *Giardia lamblia* also causes human dysentery. Another flagellate, *Trypanosoma gambiensis*, transmitted by the tsetse fly, is a human blood parasite causing African sleeping sickness. *Trypanosoma cruzi* is transmitted by blood-sucking bugs and affects muscle, particularly that of the heart. It causes the fatal Chaga's disease.

The Apicomplexa, all of them parasites of animals, have complex life cycles involving both sexual and asexual stages. Many Apicomplexa require a different host for each phase of the life cycle. Thus *Plasmodium*, the parasite that causes malaria, undergoes sexual reproduction in the digestive tract of the *Anopheles* mosquito, and asexual reproduction in both the human liver and blood cells. Toxoplasmosis, a human brain disease, is caused by *Toxoplasma*. This organism has the domestic cat as one of its hosts. It leaves the cat as spores in the faeces. These spores may remain on the cat's fur and then be transferred to the human host.

Large-scale insecticide spraying of the watery breeding grounds of the *Anopheles* mosquito during the 1960s successfully eradicated this vector of

Plasmodium from many parts of Europe. The sprays used, however, were found to have such a devastatingly adverse effect on the environment that their use was discontinued. These effects will be studied in detail in later chapters. Malaria, therefore, continues to be endemic in many Mediterranean and tropical regions of the world. Between 200 and 400 million people have malaria, 80 per cent occurring in Africa. Every year 2.5 million people die of the disease, while the survivors usually are subject to a wide range of other infections due to their weakened resistance.

Four different species of *Plasmodium,* generally from different parts of the world, produce malaria in people. The life cycle is similar in each. Infection occurs when a person is bitten by a female mosquito that is carrying the parasite. One stage in the *Plasmodium* life cycle, the **sporozoite**, is injected into the human blood stream with saliva when the mosquito feeds. The sporozoites travel to the liver cells, where they multiply by binary fission. This takes about a week. Some remain in the liver and continue to divide while others move back into the blood stream. The parasites invade red blood cells, where they again undergo rapid asexual division to form a stage called the **merozoites**. The red blood cells rupture, releasing the merozoites to infect more red blood cells as well as their metabolic waste products. Amazingly, the rupture of the red blood cells by the merozoites appears to be synchronised.

It appears that the number of merozoites in the blood must be very high (an estimate of 150 million has been suggested) before the infected person shows the classic symptoms of malaria. These occur approximately 14 days after infection and are initiated by a cold stage that lasts approximately an hour, coinciding with the rupture of the red blood cells. As the parasites enter new cells and as a result of the waste materials, the body temperature rises. This is usually accompanied by a very rapid pulse rate, rapid breathing and headache and may last for 3 to 4 hours. The following 2 to 4 hours are characterised by profuse sweating and decrease in body temperature. This cycle occurs every 2 to 3 days.

Some of the cells produced within the red blood cell may develop into gamete-forming cells or **gametocytes**. This is the only stage that can develop further within the stomach of the female mosquito. The female and male gametocytes develop into gametes which fuse to form a zygote. Repeated division of the zygote results in the formation of the sporozoites that migrate to the mosquito's salivary glands.

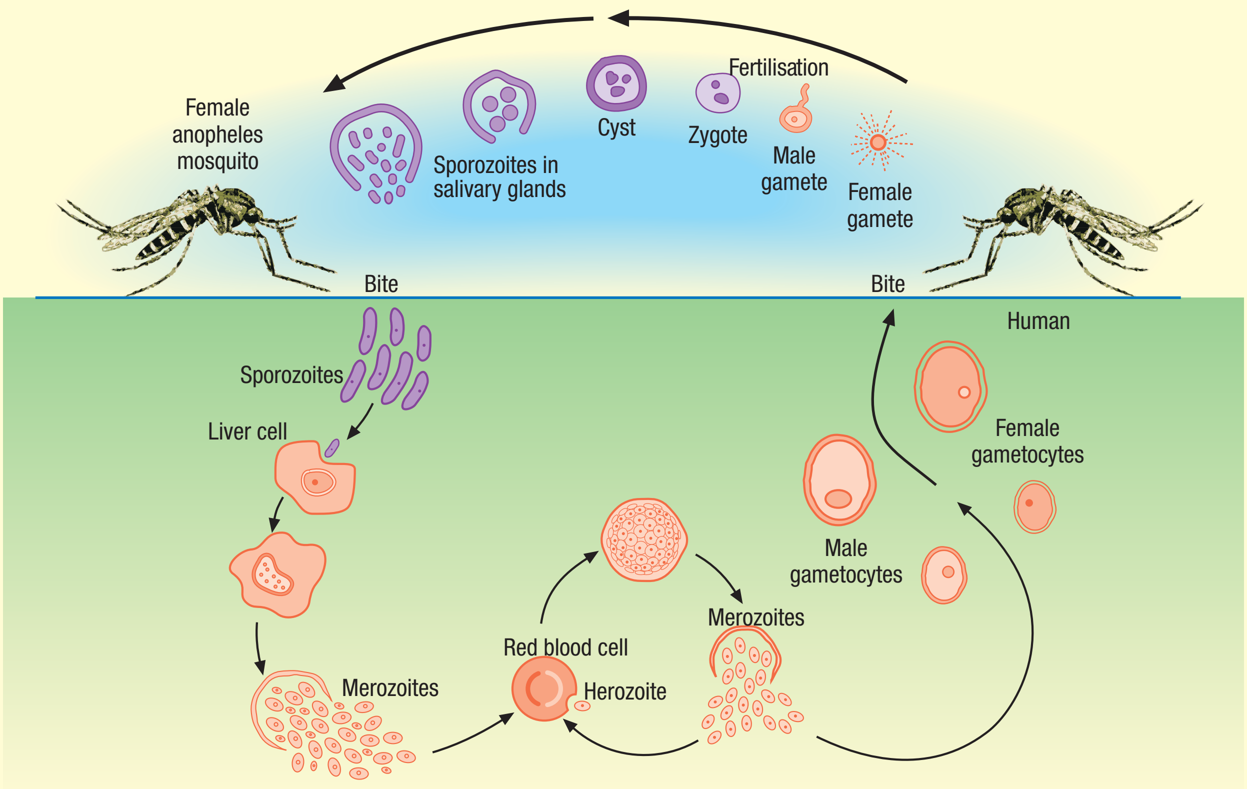


Figure 5.26 The life cycle of *Plasmodium*

Table 5.10 Some common protozoan diseases of humans

Disease	Symptoms	How transmitted
African sleeping sickness	headache, fever, enlargement of lymph nodes, drowsiness leading to coma	The tsetse fly takes up *Trypanosoma* from blood of an infected person. The parasite multiplies in the fly's salivary glands. They are injected into another person as the fly feeds on human blood.
Giardiasis	diarrhoea, bloating, flatulence, vomiting	Food or water contaminated with *Giardia lamblia*.
Vaginitis	inflammation and irritation of the vagina in women and urethra in men	Usually sexual intercourse, although the disease-causing flagellate, *Trichomonas vaginalis*, can survive for several days in moisture in towels or in droplets on toilet seats.
Amoebic dysentery	fever, nausea, vomiting, diarrhoea	Food or water contaminated with *Entamoeba histolytica*.
Malaria	anaemia; fever alternating with shivering	The *Anopheles* mosquito is the secondary host of *Plasmodium*

Fungi

The main body of a fungus is a mass of thin threads, called hyphae. Some of these hyphae secrete enzymes into the material on which they are growing. These enzymes digest the matter that can then be absorbed by the hyphae. Only a few types of fungi are parasitic on humans. The most common fungal infections are:

- Ringworm: Usually a single fungal spore from *Trichophyton* or *Epidermophyton* germinates on the skin and hyphae spread out, digesting and absorbing the nutrients from skin cells. This causes inflammation of the skin which may become very itchy or sore and which is seen as an increasing circle of red tissue as the growth of the fungus proceeds. As fruiting bodies are formed, spores may be transferred directly to another person or via towels or clothing.
- Athlete's foot: The fungus *Taenia pedis* primarily grows on the skin between the toes, although it may spread to other parts of the foot. It is common in people who wear shoes and socks that do not allow perspiration from the feet to evaporate. Thus athletes who spend hours training are particularly susceptible to infection. Since they invariably share change rooms and showers, the fungus can spread rapidly from person to person.
- Thrush, *Candida albicans*: Thrush is a yeast that infects the mouth, throat and vagina, where it grows as a white patch on the moist tissues. It can be kept in check by bacteria that normally inhabit these regions and thus a person may not be aware that they are harboring the fungus. If these bacteria are killed by antibiotics, or the person's resistance is lowered due to other illness or malnutrition, the fungus can grow rapidly and cause disease. In the vagina the symptoms are intense itchiness and the discharge of unpleasant pus. Vaginal thrush can be transferred from mother to baby during birth. Care should be taken not to share towels, since this could result in transmission from one person to another. Females should also use underwear (pants and stockings) that allows removal of heat and moisture from the vaginal area, since thrush thrives in humid conditions.

Figure 5.27 Tinea

Macroparasites

Most macroscopic endoparasites of humans are either flatworms or roundworms. The flatworms (phylum Platyhelminthes) are dorso-ventrally flattened animals that include both free-living and parasitic forms. The main human parasites are the flukes (class Trematoda) and tapeworms (class Cestoda). Both have a very complex life cycle involving a vertebrate and an invertebrate host. The flukes have a leaf-like body and two suckers and are generally quite small. The tapeworms have an elongated body, some reaching up to 10 metres in length, and a highly modified head which serves to attach the body to the host's gut wall by suckers and a series of hooks.

A widespread disease of tropical regions is caused by the blood fluke, *Schistosoma*. The three common species that infect people are *S. haematobium* and *S. mansoni* in the Nile Valley and Africa and *S. japonicum* in China, Japan and the Philippines. Since the secondary host is a water snail, this disease is more common in areas where canal irrigation of farmland is practised. The adults of *S. haematobium* are found in the blood vessels of the bladder, while the adults of the other two species are found in the blood vessels of the intestines.

The association between the male and female blood flukes is unusual. The larger male permanently carries the female in a groove in the body surface. The eggs, each of which has a spine, are laid in the small blood vessels. The embryo vibrates as it develops and this movement pushes the spine against the wall of the blood vessel, resulting in a puncture hole large enough for the eggs to escape. Depending on the species, the eggs are released from their primary, human host with either the faeces or urine.

Transmission to another human host requires the eggs to hatch in freshwater and the larvae to penetrate the body of a suitable species of freshwater snail within a day. If these conditions are met, after feeding on the snail's tissues the larvae reproduce asexually. A second type of larva (cercaria) forms that leaves the snail. It has a tail which assists in swimming in search of a new human host, someone walking or bathing in the water. This tiny larva has a sucker which is used to burrow through human skin as well as special enzymes that assist in the penetration. The tail is shed as soon as the larva enters the host. Again timing is critical for these larvae can only survive for a couple of days in the water. The larvae can also enter through the intestinal wall if contaminated water is drunk.

Once inside the body, the larvae are taken up by the lymphatic vessels and so enter the blood system as the lymph empties into the major veins entering the heart. They travel in the blood to the liver, where they mature into the adult worms. The worms re-enter the blood supply, where they establish themselves in the appropriate blood vessel for the species approximately a month after initial infection.

Although itching is felt as the larvae enter, the main symptoms do not occur until the adults start to reproduce about a month after infection. Blood- and mucous-stained diarrhoea are the initial signs of infection by *S. mansoni* and *S. japonica*. Build-up of eggs can result in them being carried through the blood stream, where they can block the small vessels in the brain and spinal cord. This will ultimately result in death. Infections of *S. haematobium* result in blood-stained urine, obstruction and scarring of the ureter and kidney damage.

A similar life cycle is seen in the liver fluke, *Fasciola hepatica*. Although this species of fluke is most common in sheep, it can also occur in humans. In both primary hosts the adult fluke, which is a hermaphrodite, lives in the liver and bile ducts. The eggs are released with the bile into the intestines and pass out with the faeces. If the eggs land on moist grass and are eaten by the appropriate type of water snail, the cycle continues. The eggs hatch and the larvae feed on the snail tissues before undergoing asexual reproduction. Again a cercarian larva leaves the snail's body. This larva, however, swims to a stalk of grass, climbs above water level and forms a protective cyst. When sheep graze, or humans eat watercress, they may ingest the cysts. Inside the intestine the cyst coating breaks down to release the larva which burrows through the intestinal wall into the blood vessels.

Adult *Taenia* tapeworms are the largest endoparasites of humans, growing to several metres in length. Although their waste products can be absorbed into the human blood stream causing illness, their main effects are host malnutrition and obstruction of the bowel.

Most of the organs of the tapeworm have degenerated and the body consists of a series of sections (proglottids) effectively filled with reproductive organs. This is not true segmentation, since the proglottids are formed from the head end (scolex) continuously throughout the life of the tapeworm. These new proglottids are pushed back as still more are formed. The scolex is an attachment organ, firmly fixed to the intestinal wall with suckers and, in some species, hooks. A thick, mucous-covered cuticle covers the entire body, preventing digestion by the host's enzymes while still absorbing the digested food in which it is bathed.

Each proglottid contains both male and female reproductive organs. After fertilisation, the testes are absorbed and the eggs grow and develop so that they effectively take up the whole space of the proglottid. Mature proglottids, furtherest from the scolex, containing fertilised eggs break off and pass out with the host's faeces for dispersal to the secondary host, a cow or pig. Grass infected with tapeworm eggs may be eaten by the secondary host. Digestive enzymes release the larvae from the eggs.

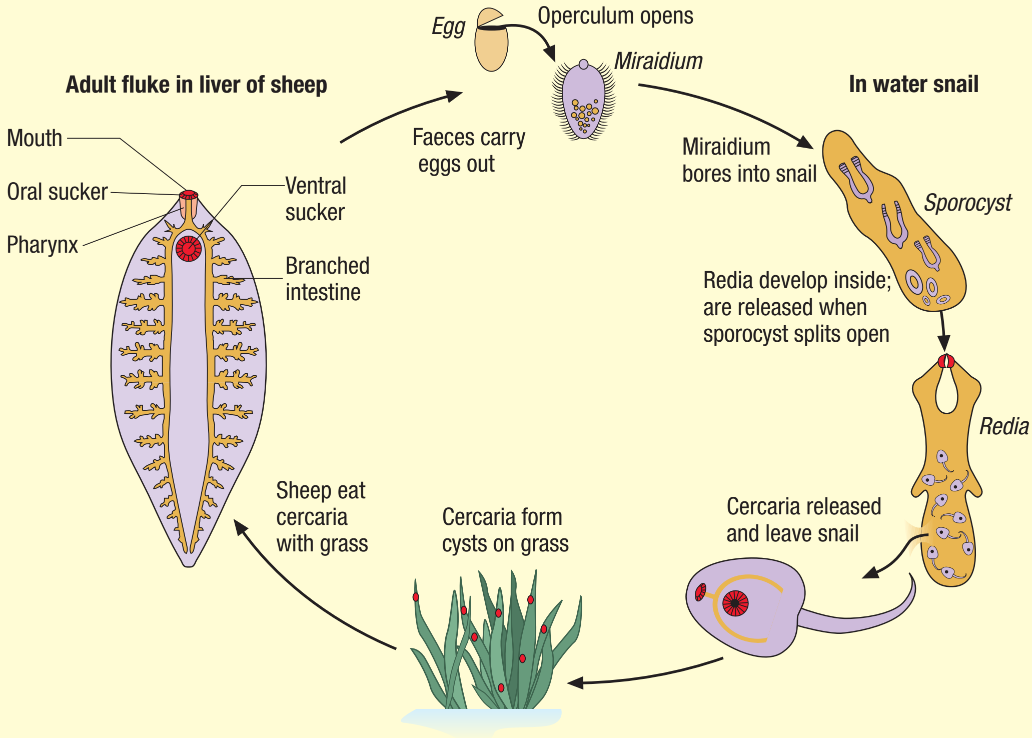


Figure 5.28 Life cycle of *Fasciola hepatica*

The hooked larvae burrow through the intestinal wall into the bloodstream, where they are carried to muscle tissue. In the muscles the larvae develop into a small fluid-filled bladder surrounding a scolex. If a person eats undercooked, infected meat, they then start the cycle again.

The larvae of the dog tapeworm, *Echinococcus gransulosa*, will only develop into a sexually mature adult within the dog's intestine. Sometimes faeces containing eggs become attached to the dog's hair. These eggs can be transferred to people playing with or patting a dog. The larvae then hatch in the person's intestine, burrow into a blood vessel and pass into the liver, lungs or brain. There they form fluid-filled swellings called hydatid cysts. These organs are damaged by either pressure directly on their tissue or by blocking blood vessels supplying essential oxygen and nutrients.

Figure 5.29 *Taenia* scolex, immature proglottids and mature proglottids

The roundworms, phylum Nematoda, occur in enormous numbers in a great variety of habitats. Most are free-living in moist soil and decomposing organic matter on the bottom of lakes and oceans; others are parasites of plants and animals. Humans are hosts to about fifty species of roundworms. Few people have escaped contracting pinworms during their childhood. This infection has more annoyance than disease value. More serious diseases caused by roundworms occur in tropical and subtropical regions and include elephantiasis (with a mosquito vector), onchacercariasis (with a water-breeding fly as vector) and ascariasis and hookworm which are spread directly from person to person through faecal contamination of food or water.

One of the earliest recorded diseases was called the 'fiery serpent' (guinea worm). It is caused by the female roundworm, *Dracunculus medinensis*, commonly found in tropical Africa, Arabia, India and Indonesia. Infection occurs when a person drinks water containing tiny copepods (crustaceans) contaminated with the guinea worm larvae. The larvae penetrate the gut wall and migrate through the tissue to become lodged just below the skin. Growth and development of the worm may take up to a year. Little is known about the male worms which are thought to disintegrate after fertilisation. The female worms migrate to the skin of the lower leg. The worm secretes a chemical which causes a blister to form. Over a short time this blister bursts and leaves a shallow ulceration of the skin. When the person steps into water, the worm projects its uterus through the ulcer and releases a thick cloud of milky secretion containing hundreds of active larvae. The moment the host comes out of water, the exposed part of the uterus dries and shrivels to prevent further release of larvae. If the water-borne larvae are ingested by a copepod (*Cyclops*), they burrow through the intestinal wall and remain in the body cavity. The cycle is then repeated when these copepods are accidentally ingested in human drinking water.

One of the earliest methods to remove these worms was to place a small stick in the loop of the worm that penetrates from the ulcer. Each day a small portion of the worm would be rolled onto the stick until eventually the entire worm was removed. At that time the copepod vector was unknown. Of all the treatments for guinea worm infection trialed, the most effective has proven to be a more sterile version of the ancient method. Infection can easily be prevented by straining water through cloth prior to drinking.

Table 5.11 Some common macroparasitic diseases of humans

Disease/causative organism	Symptoms	How transmitted
Schistosomiasis/bilharzia Flatworm (*Schistosoma*)	Bloodstained urine/faeces Brain/kidney damage leading to death	Pollution of waterways by human faeces/urine; water snail secondary host
Beef/pig tapeworm Flatworm (*Taenia*)	Malnutrition, obstruction of bowel	Undercooked meat of secondary host (cattle/pig)
Hydatid cysts Flatworm (*Echinococcus*)	Swellings in brain, lungs, liver; poor circulation; change in behaviour	Eggs from dog faeces
Fish tapeworm Flatworm (*Diphyllobothrium*)	Malnutrition, obstruction of bowel	Mammal (including human) faeces with eggs contaminate freshwater; larvae hatch, eaten by freshwater copepod (*Cyclops*) which are eaten by fish. Humans eat undercooked fish.
Pinworm Roundworm (*Enterobius vermicularis*)	Nervous irritation, itchiness around anus	Ingestion of minute, airborne eggs that resist desiccation
Hookworm Roundworm (*Ancylostoma duodenale*)	Stunted growth, anaemia, lassitude, acute mental distress	Larvae hatch in soil and water contaminated with infected human faeces and burrow through feet of next human host
Ascariasis Roundworm (*Ascaris lumbricoides*)	Haemorrhage of lung tissue, obstruction of intestine, poisoning from toxic wastes	Ingestion of eggs in food/water contaminated with human faeces
Onchacerciasis/ river blindness Roundworm (*Onchocerca*)	Nodules in any connective tissue; may cause blindness	Vector is the blackfly *Simulium* which breeds in fast-flowing steams
Elephantiasis Roundworm (*Wucheria bancrofti*)	Blockage of the lymph nodes, resulting in accumulation of lymph and thus swelling of lower extremities	Female produces larvae which leave the lymph and enter the blood. These are transmitted by mosquitoes to a new host.
Guinea worm Roundworm (*Dracunculus medinensis*)	Ulcerations of ankles	Freshwater copepod

Quite a large number of arthropods are ectoparasites of humans. Although most do not themselves cause disease, many are vectors for pathogens. In addition to the diseases already described transmitted by mosquitoes and tsetse flies:

- deer tick have been shown to be the vectors of Lyme disease in America
- body lice are vectors for typhus
- rat and human fleas transmit bubonic plague
- assassin bugs in South America are vectors of Chaga's disease and
- flies and cockroaches can inadvertently transfer pathogens from, say, latrines to food.

Secondary infections resulting from lesions or irritations of ectoparasites can often occur. Thus the irritation from bedbug (*Cimex*) bites stimulates scratching responses. If this breaks the skin, pathogenic bacteria can enter the wound. Chiggers are a small group of fleas found in tropical regions. After mating the female flea burrows into human skin. As the eggs develop, her abdomen swells. This enlargement causes skin irritation and inflammation. The eggs are laid in this inflamed tissue, which then ulcerates and releases the eggs back into the environment. At the ulceration stage, the infected person is subject to secondary infections.

SUMMARY

Parasites are organisms that live in or on, and gain their nutrients from, another organism. Endoparasites usually have special adaptations associated with living in a host. Pathogens are organisms that cause disease, or dysfunction, in another organism. Not all parasites are pathogens but all pathogens are parasites. Diseases that can be spread from individual to individual as a result of pathogens are termed infectious diseases. There are many non-infectious diseases.

Pathogens may be microbes (viruses, bacteria, protozoans and fungi) or macroorganisms (such as flukes and worms). A great number of microbes and macroorganisms are pathogens of humans, their domesticated animals and cultivated plants. It appears that at least some diseases may result from abnormal prion proteins that can cause normal prions to become abnormal.

Some pathogens are spread from person to person directly. The disease is contagious. Other pathogens require a second host for part of their life cycle. This host acts as a vector between individual people in spreading the disease. Common vectors for many diseases are mosquitoes, flies, water organisms (fish, arthropods and molluscs) and other terrestrial vertebrates (domestic and game animals).

Review questions

5.30 Distinguish between an ectoparasite and an endoparasite.

5.31 Many endoparasites exhibit special adaptations for their mode of existence. Select two possible adaptations and explain their significance to the organism.

5.32 A fly may be a vector to a certain parasite but is not a host for that parasite. Other organisms may be both a vector and a host to the disease. Distinguish between the terms 'secondary host' and 'vector'.

5.33 All pathogens are parasites but not all parasites are pathogens. Explain this statement, giving examples.

5.34 The proposal that some diseases, such as spongiform encephalitis, are transmitted via an abnormal protein has been very controversial in the scientific world. Explain why this is the case.

5.35 How do viruses differ from bacteria?

5.36 Define the terms 'HIV' and 'AIDS'. Describe how the virus is transmitted and the symptoms of its host.

5.37 Explain why many viral infections rapidly become pandemic.

5.38 Is thrush caused by an ectoparasite or an endoparasite? Explain your answer.

5.39 The blood fluke, *Schistosoma*, is very common in areas where there is canal irrigation of farmland. Suggest two reasons why this is the case.

5.6 Controlling parasites and pathogens

In order to control parasites and pathogens an understanding of their life cycles is essential, as is knowledge of the ways and means by which they gain access to human tissues.

5.6.1 Entering the body

Pathogens may enter the body through natural openings or via wounds and breaks in the skin. Each of the natural openings leads to a tube lined with soft, moist membranes that are safe breeding havens for many pathogens. Thus:

- eyes: through contact and dust › conjunctivitis
- nose: airborne organisms › tuberculosis, cold, influenza, measles

- mouth: contaminated food, drink, utensils › cholera, bacillary dysentery, tapeworm, salmonella food poisoning
- urinary, reproductive and anal passages: contact › gonorrhoea, HIV, syphilis, candidiasis.

When there is no break present, the human skin has a remarkable protective ability against micro-organisms. The larvae of *Schistosoma,* hookworm and the fungi that produce tinea and ringworm are among the few pathogens that can enter unbroken human skin. As has been seen, many pathogens can enter from vectors that penetrate the skin. Contaminated needles used for injection can spread HIV and hepatitis. Many pathogens, such as bacteria-causing tetanus and septicaemia, enter the body via scratches and abrasions.

5.6.2 Prevention

Preventative measures can be taken to minimise the spread of disease. We are continually touching objects that have been previously touched by others—doors and seats of public toilets, money, pets, taps and so on. All have the potential to transfer pathogenic organisms to our bodies. Personal hygiene is therefore of utmost importance in decreasing the risk of contracting pathogens. Regular washing of hands with soap and water after using the toilet and before eating can significantly reduce transfer of bacteria. Many microorganisms stick to small droplets of oils released by skin glands. Water alone will not remove these. Soap affects the surface tension so that the area of contact between the oil and the skin is smaller and allows the oil to be washed away.

Both contagious and non-contagious diseases can result from contaminated food. Food poisoning often occurs because food is kept too long, or stored incorrectly. Some decomposing bacteria in the food release toxins which then affect the person eating the spoilt food. Several contagious diseases can be unwittingly transferred from people preparing food as they can be carriers of disease without displaying any of the symptoms. Strict laws govern cleanliness of commercial food preparation areas. All people involved in the industry must wear special protective clothing and disposable gloves. The actual premises must also be kept clear of all vermin such as cockroaches, flies and rats that may be vectors in disease. Similar controls should be implemented in all homes.

Meat bought in Australia and in most other Western countries is subject to strict meat inspection at the abattoirs for parasites. It is still important that meats, such as pork, are thoroughly cooked. The heat generated in the cooking process kills the larvae of tapeworms and other flatworm parasites that can be passed on to humans.

Many diseases are spread by water, either directly or via a vector. In Australia we take clean drinking water for granted. All major towns and cities have strict treatment and quality control of household water supplies. This is not the case in many parts of the world, particularly in developing countries, where people must use the local streams or wells for water. Contamination of these waters by human and domestic animal wastes frequently occurs. Moving water can swiftly transport micro-organisms over large distances. Even in places where there is sterilised, reticulated water, defects in pipes, flooding and other factors can result in recontamination of water supplies. In those areas where intestinal diseases are common, it is important that people are educated in methods of disposal of human wastes to prevent spread of disease.

Cholera is an intestinal disease, common in tropical Africa and Asia, caused by a bacterium. The bacterium enters the person in drinking water or from contaminated food. It produces toxins which result in both diarrhoea and vomiting. Even after all food contents have been voided, there is constant elimination of digestive juices. The fluid to produce these juices is withdrawn from other body tissues. The ensuing death is a result of dehydration and loss of potassium. In many places where cholera is endemic, human faeces are collected and used as manure for growing vegetables. Bacteria from an infected person are rapidly transferred via the vegetables to others. Flies move between the house and garden. They can pick up the bacteria now on the growing vegetables on their feet, and transfer them to other food. In other areas, privies are built over the banks of streams or rivers. The flowing water carries the wastes away. The cholera bacteria, however, reproduce in these warm waters. Thus water used further downstream for drinking or watering vegetables will be contaminated and result in further infections.

The control of many diseases can be achieved by minimising the effects of vector organisms. An understanding of the life cycle of the vector can provide different strategies for eradication. In the past, insecticides have been intensively used in an attempt to eliminate secondary hosts to a number of human pathogens. Similarly swamps have been drained to prevent mosquito and snail breeding areas. These strategies, however, have resulted in severe environmental damage since they target a whole range of organisms and so disrupt ecosystems. Years after their use many pesticides have been shown to have a direct negative impact on humans. Thus, in addition to a wide range of other effects, DDT has recently been shown to be a hormone mimic that can affect the development of the human fetus. A variety of strategies to control pests is discussed more fully in Chapter 10.

Avoiding contact with vectors of disease is the best means of control and include:

- Use personal insect repellants in places and times where vector insects are most likely to be active.
- Wear clothing that minimises being bitten by insects—long, loose trousers and shirts.
- Use insect screens in windows and doors of houses.
- Use a mosquito net to cover beds.
- Use building materials that do not harbour insect pests.
- Do not wade or swim in waters suspected of being contaminated by pathogens and/or their hosts.

Some of these measures may not always be practical all of the time or for all people. In many countries where diseases such as malaria and yellow fever are prevalent, the majority of the population lives at subsistence level and has little opportunities for education.

Internal medication may also be used to reduce and prevent the effects of infection. Thus anti-malarial tablets can be used prior to, during and for a period of time after possible exposure to *Plasmodium*. These drugs kill the organisms within the human.

The variety of methods used to control malaria indicates ways that other diseases might be controlled. Control of malaria can target either the *Plasmodium* or its mosquito vector as illustrated in Figure 5.30. Because most malaria exists in Africa, a country that continues to experience political upheaval and high levels of poverty, the actual control of the disease will be difficult to achieve.

Individuals who have a contagious disease should ideally be isolated from other people. Many bacteria and viruses pass from person to person in airborne droplets of water. Isolation reduces the chance of this occurring by mininising the number of people with whom the infected person comes in contact. The period of isolation depends upon the incubation period of the pathogen as well as the length of time of infection. Thus for chickenpox, the infected person must be kept isolated until all skin lesions have dried.

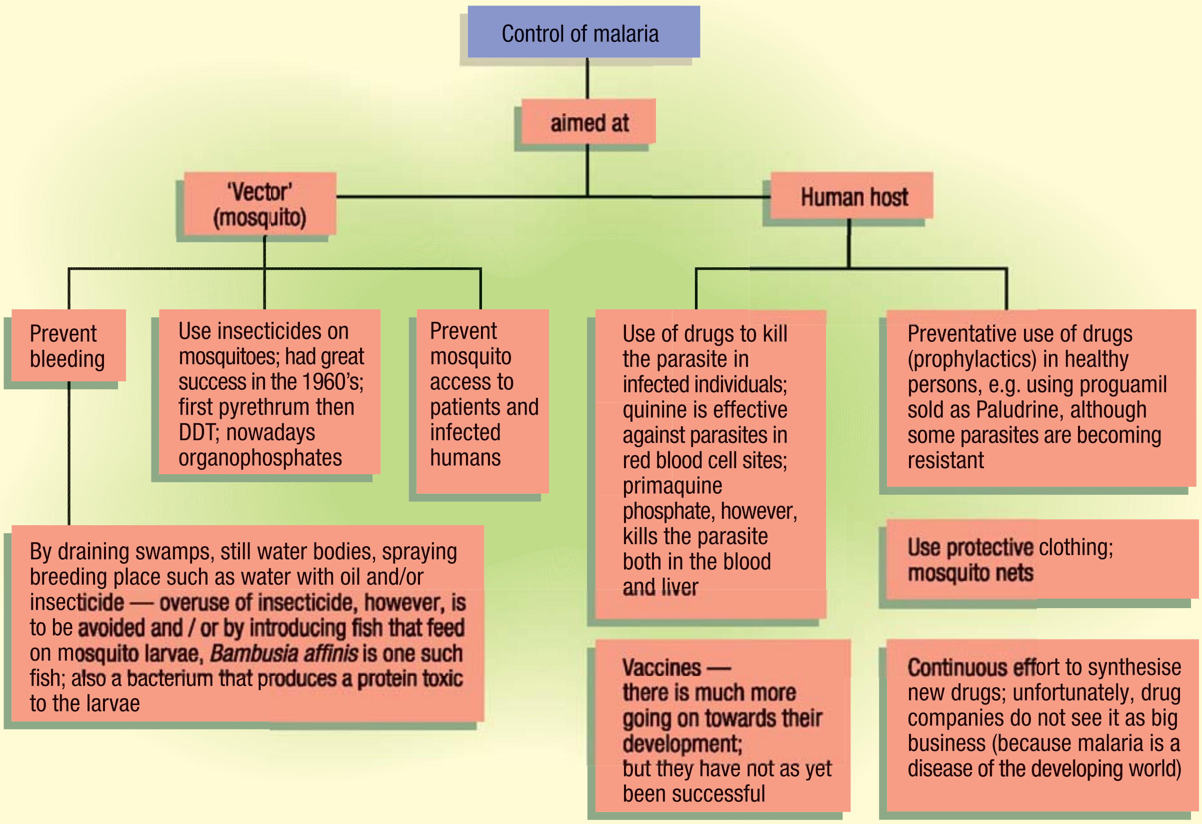


Figure 5.30 Mechanisms to control malaria

Five rules to reduce the spread of infectious disease are:

1. Do not get bitten.
2. Do not urinate or defecate in or near water supplies.
3. Do not use fresh human faeces as fertiliser in gardens.
4. Maintain good hygiene.
5. Isolate sources of infection.

5.6.3 The body's defence mechanisms

The body has many defences against disease. The skin, digestive, respiratory, urinary and reproductive systems form a first line of defence by decreasing the chance of entry of pathogens into the body. They may be physical (e.g. skin and hairs) or chemical (e.g. secretions of the vagina, respiratory tract or acid of the stomach). If a pathogen penetrates these defences, the immune response is activated.

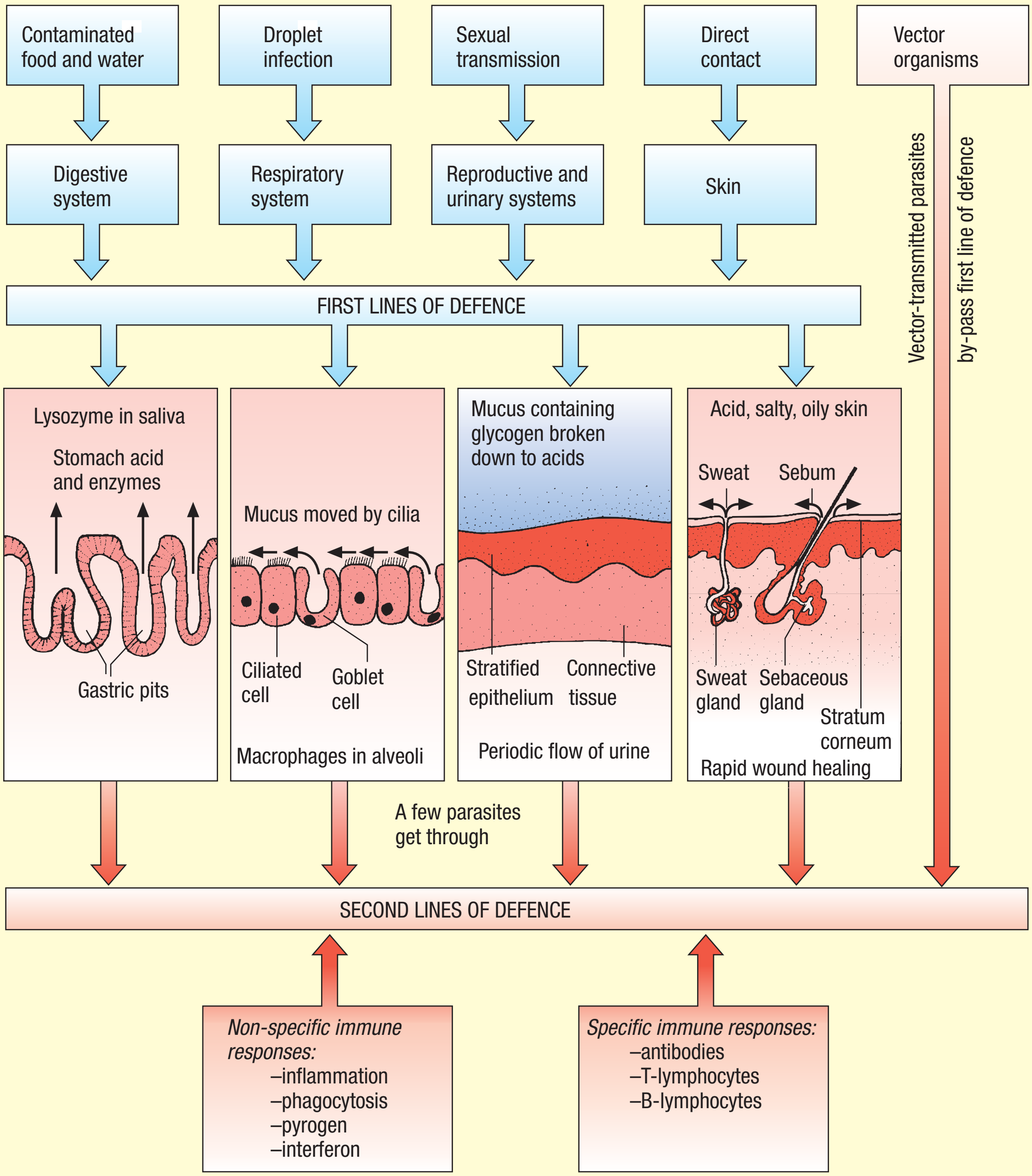


Figure 5.31 The body's defences against disease

The immune system

The immune system refers to those internal cells and structures that specifically combat infections within the body. White blood cells (**leucocytes**) play a very significant role in this process. They are found in the blood, tissue fluids surrounding cells and in the lymphatic system. All leucocytes are formed in the bone marrow and have a nucleus.

There are five different types of leucocytes. Each type either performs the same function in different parts of the body (e.g. in tissue fluids or lymphatic fluid) or different functions.

- **Neutrophils** and **monocytes** are phagocytes that ingest foreign matter. Monocytes pass through the capillary walls and enter tissue fluid where they mature into large phagocytic cells called **macrophages**. A sac of enzymes (a lysosome) within the phagocytic cell fuses with the engulfed pathogen, causing it to be digested. When neutrophils die, due to bacterial toxins, they form pus.
- **Basophils** are important in **inflammatory reactions**. When tissue is damaged and pathogens are able to overcome the body's first lines of defence, chemicals (chemokines) are released that stimulate the basophils to produce and release the chemical called **histamine**. This chemical redirects blood flow to the injured area. Increased numbers of phagocytes, therefore, flow into the area to destroy any pathogens. Because of the increase in the amount of blood present, the area becomes red and swollen. The basophils also secrete the chemical **heparin** that prevents the blood clotting. In more severe infections the inflammation can be more widespread and accompanied by a fever. The fever is brought about by chemicals called pyrogens. The increased temperature aids in the destruction of the pathogens. Also involved in the inflammatory response is another group of chemicals, **prostaglandins**. These are released from cells damaged by the pathogen and act with the histamine to redirect the flow of blood to the injured area.
- **Eosinophils** have two major functions. They can help in the destruction of macroparasites such as worms, by secreting digestive enzymes into them. Eosinophils also take part in allergic reactions.

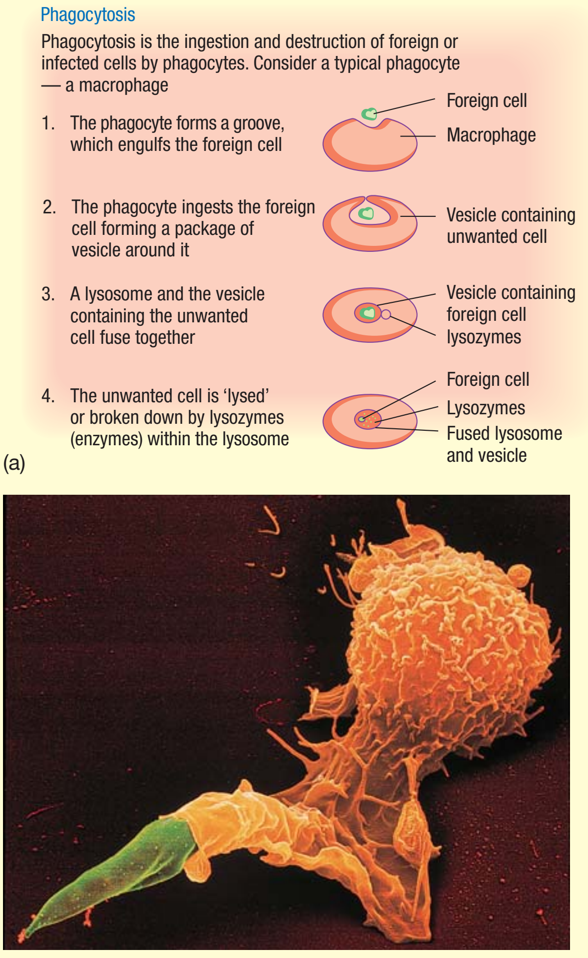


Figure 5.32 Phagocytosis: (a) the process (b) fibril-like pseudopodia of a macrophage attaching to rod-shaped bacterium which will be ingested and destroyed

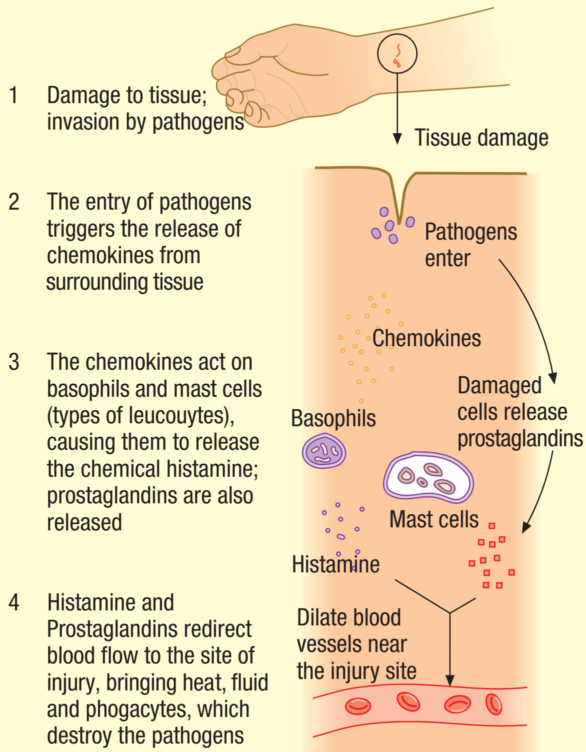


Figure 5.33 The inflammatory response

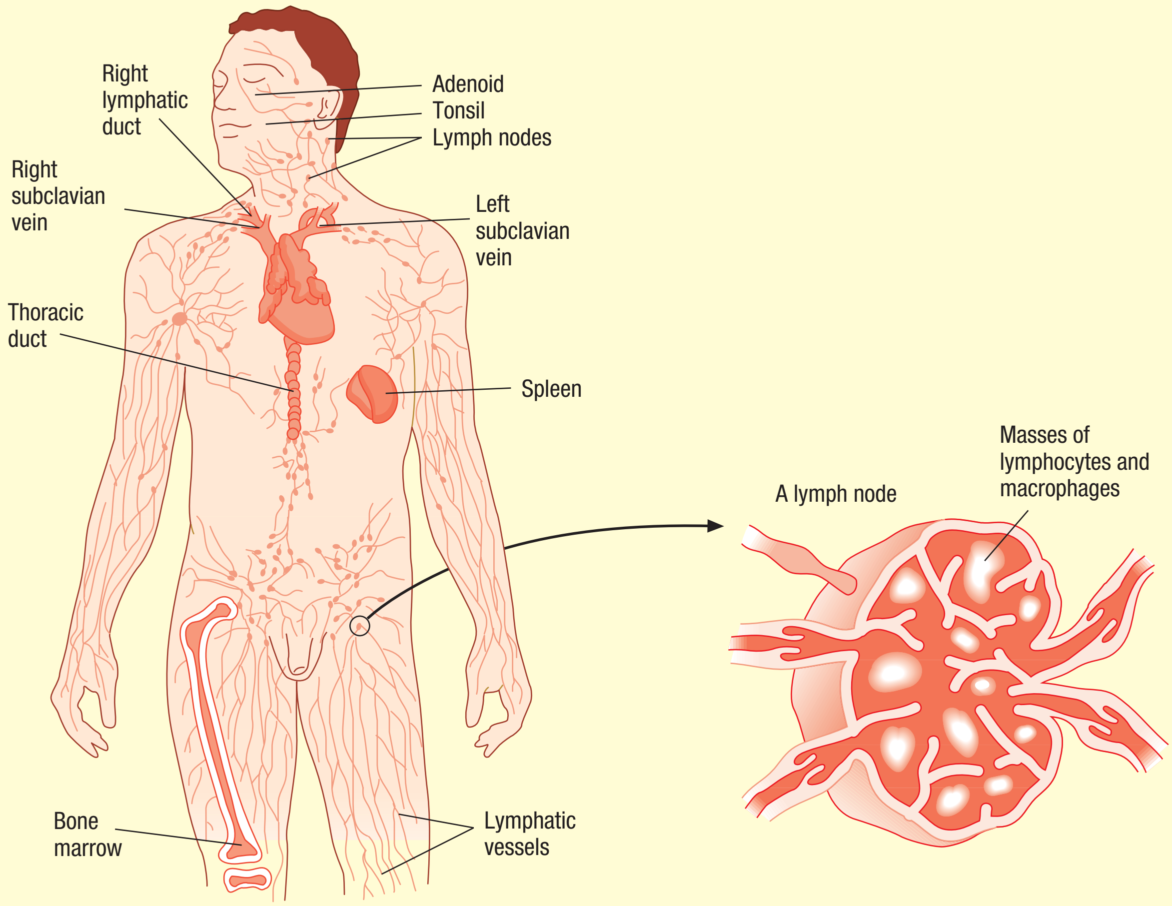


Figure 5.34 The human lymphatic system

- **Lymphocytes** are found in the lymphatic system and are responsible for the formation of antibodies, specific chemicals formed in response to the presence of particular chemicals on the surface of the pathogen, that are the last line of defence in overcoming disease-producing organisms. The lymphatic system is a series of vessels, intercepted by enlarged 'mazes' of canals called **nodes**, that return tissue fluid back to the blood circulatory system. Pathogens become trapped in the lymph nodes where they are systematically attacked by both lymphocytes and macrophages.

Antibody formation

The cells of each organism have a special protein molecule called MHC (major histocompatibility complex) on their outer membrane. It is a kind of identity tag. The immune system can therefore recognise 'self'. Cells not containing the specific MHC for the individual are not recognised and therefore attacked.

Pathogens such as viruses, parasites, fungi and bacteria do not contain the host identification tag. Any non-self tag is known as an **antigen** (Ag) to the host organism, and this initiates the immune response.

White blood cells called lymphocytes are produced in the bone marrow. They enter the bloodstream and follow one of two separate pathways as they mature. Those that pass through the thymus gland become sensitised and form T-cells. Lymphocytes which do not pass through the thymus are termed B-lymphocytes.

B-lymphocytes congregate in lymph nodes, the tonsils, spleen, appendix and in specialised areas (Peyer's patches) in the gut. When they encounter a particle with an antigen on its surface, the B-lymphocytes produce a gammaglobulin molecule. The gammaglobulins contain five classes of immunoglobulin or **antibodies**. These are designated IgG, IgA, IgM, IgD and IgE. They differ in the amino acid sequence of one part of the gammaglobulin molecule. The specific sequence is initiated by the B-lymphocyte in response to a particular antigen.

The presence of an antigen stimulates B-lymphocytes to divide rapidly and produce many identical cells. Some of these cells turn into **plasma cells**. The mature plasma cells produce and secrete antibodies which have combining sites specific to the particular antigen. Other cells become **memory cells**. They persist long after the original antigen has been removed or destroyed. If the individual is later reinfected by an organism containing that antigen, the memory cell is immediately activated.

An antibody has a complementary structure to the specific antigen. When it binds with the antigen, it may:

- block parts of the pathogen needed to survive (neutralisation)
- cause the foreign matter to agglutinate (stick together) to facilitate phagocytosis
- cause the foreign matter to break up and dissolve (precipitation)
- produce an antitoxin to the pathogen's toxins (complement activation).

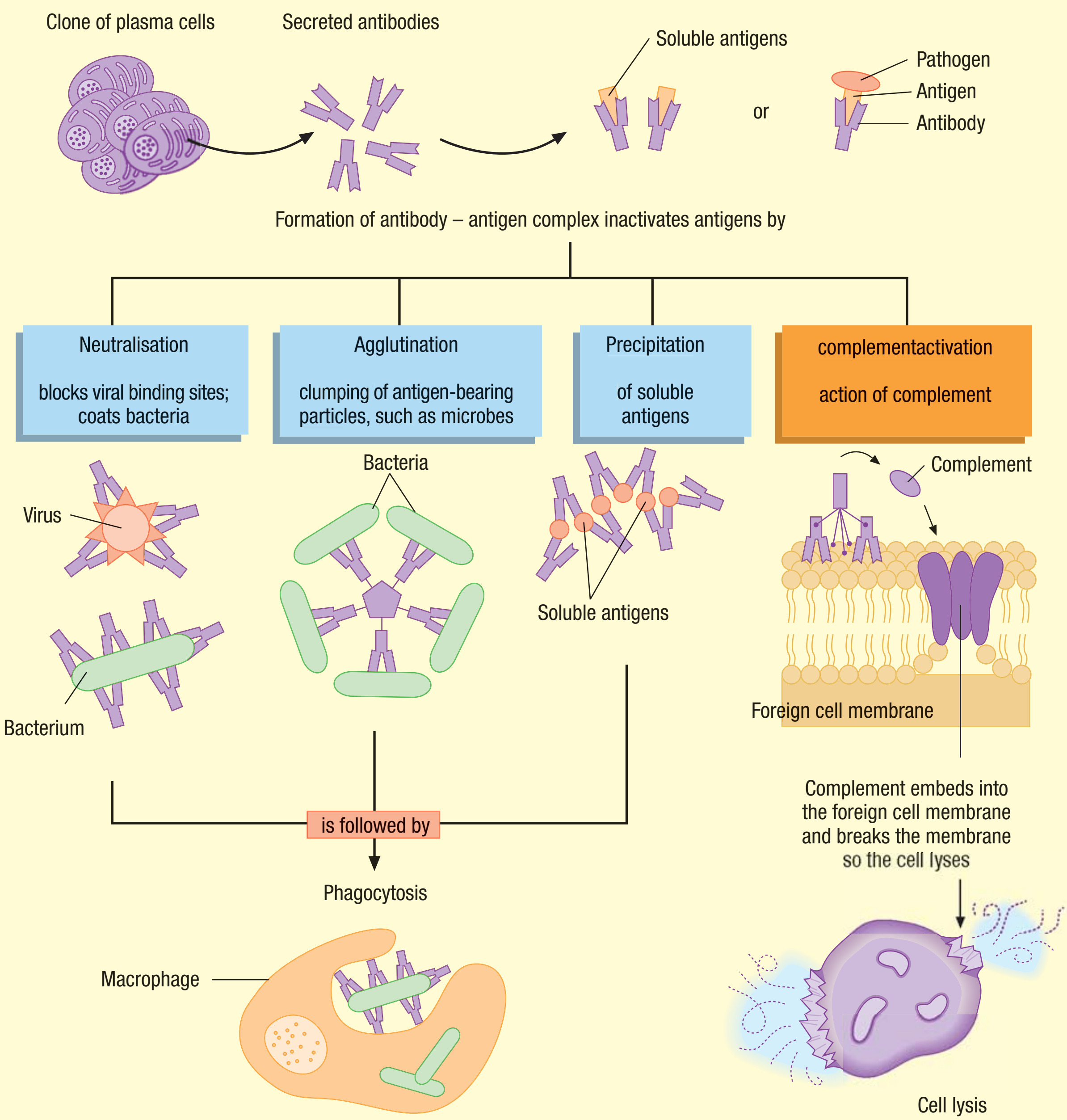


Figure 5.35 The action of B-cells in antibody production and the action of antibodies in destroying antigens and pathogens

Antigens also stimulate the production of T-cells in the thymus gland. On contact with the foreign matter, these sensitised cells release soluble proteins (lymphokines) into the body fluids. These proteins may:

- attract phagocytes to the foreign matter
- prevent the foreign matter from leaving a site
- activate monocytes and thus increase phagocytosis
- kill the foreign matter.

Some T-cells also become memory cells. T-cells are responsible for reactions such as graft rejections, delayed hypersensitivity and resistance to cancer.

Although T-cells and B-lymphocytes are capable of producing independent immune responses, they sometimes work together. Some T-cells have a 'helper' function, stimulating the production of antibodies. Other T-cells suppress antibody formation when helper T-cells and B-cells have carried out the immune response. Another type of T-cell (cytotoxic T-cell) induces toxicity in the cytoplasm of the pathogen which kills it.

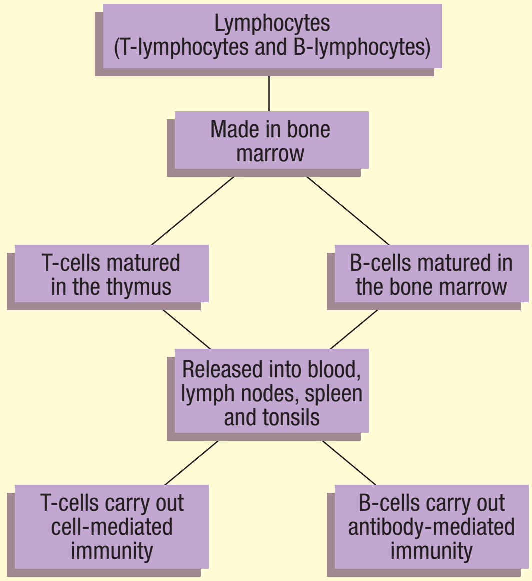
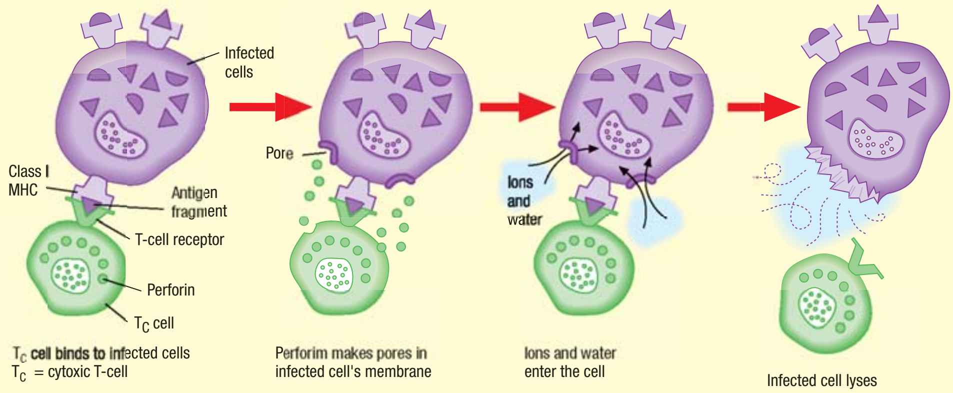


Figure 5.37 T-cells and B-cells

(a)



(b)

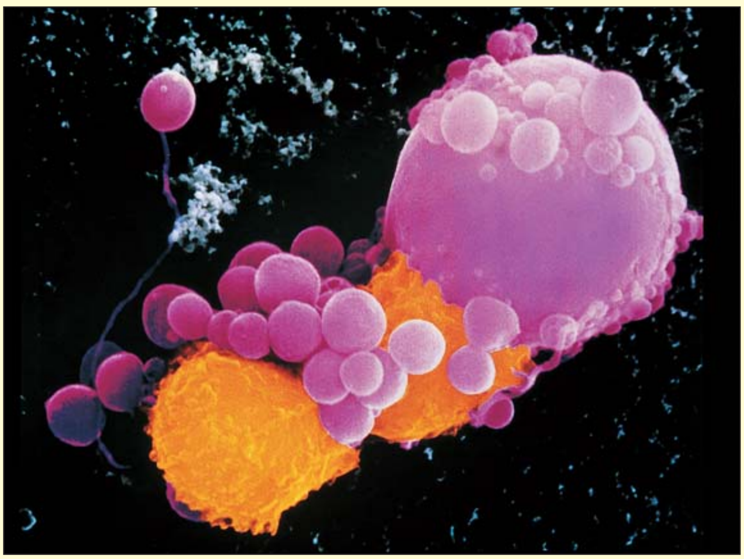


Figure 5.36 (a) How T-cells destroy infected cells (b) T-cell attacking a cancer cell

The AIDS virus attacks helper T-cells, thus inhibiting the whole immune system. The AIDS victim is therefore vulnerable to all sorts of diseases. It has also been found that mental stress, bereavement, loneliness and depression affect the operation of the lymphocytes and reduce T-cell activity.

Immunity

Individuals may recover from disease caused by pathogens as a result of the immune responses of the B-lymphocytes and T-cells. As a result of the formation of memory cells for a particular pathogen, the body builds up resistance or immunity to further attacks by the same organism. This is termed **natural active immunity**.

All animals have natural immunity to certain diseases that affect other species. For example, the herpes simplex virus is lethal to rabbits, but the same virus usually produces only a 'fever blister' in humans.

Natural passive immunity is obtained by an infant from the mother, from antibodies which

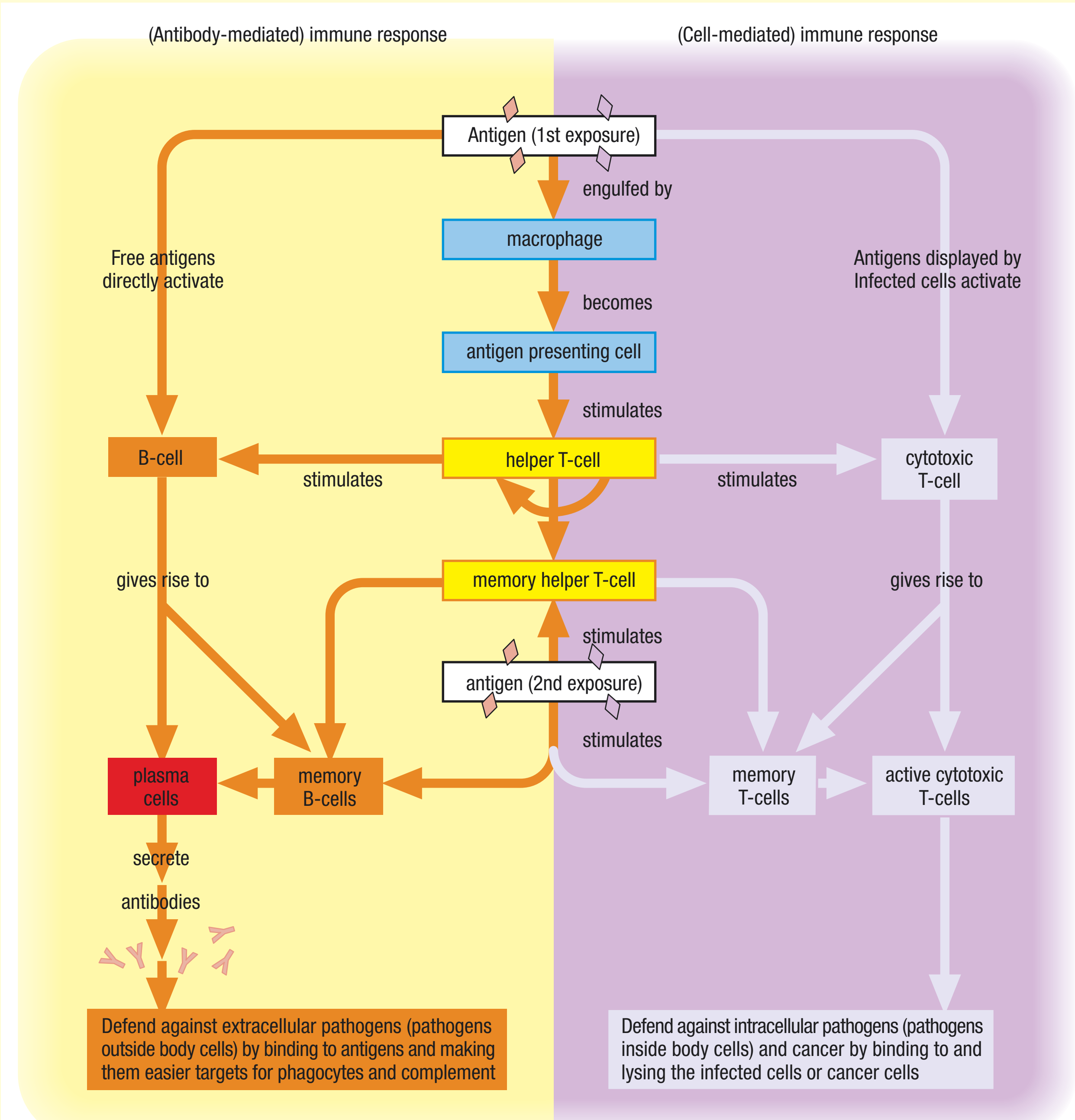


Figure 5.38 The interactions in the activation, action and suppression of the specific immune system (T-cells and B-cells)

diffuse across the placenta. These antibodies are also present in the first 'milk' (**colostrum**) secreted after birth. This immunity lasts for only a short time after birth, but further antibodies are contained in the true milk. Breast-feeding babies is therefore desirable.

Immunity can also be acquired artificially. Injection of an individual with certain types of antigens can induce the development of resistance to some diseases. This is **artificial active immunity**. Three general types of antigens used in inoculation (also known as vaccination or immunisation) are:

- sterile bacterial exotoxins
- sterile dead microorganisms
- living infectious microorganisms whose ability to cause serious infection has been altered.

Serums have been developed which contain antibodies to specific antigens. In the case of serious infections, such as diphtheria and tetanus, the reaction to the bacterial toxin may be too fast for the individual to develop antibodies. Specific antibody serums are administered to counteract the infection and produce immediate resistance. This is termed **artificial passive immunity**.

Experimental evidence indicates that the ability of lymphocytes to recognise 'self' from 'non-self' is learnt over a period of time. It has been possible, therefore, to introduce foreign matter into an individual that does not initiate the immune reaction. This condition is known as **immunological tolerance**. It is possible to develop this tolerance if the:

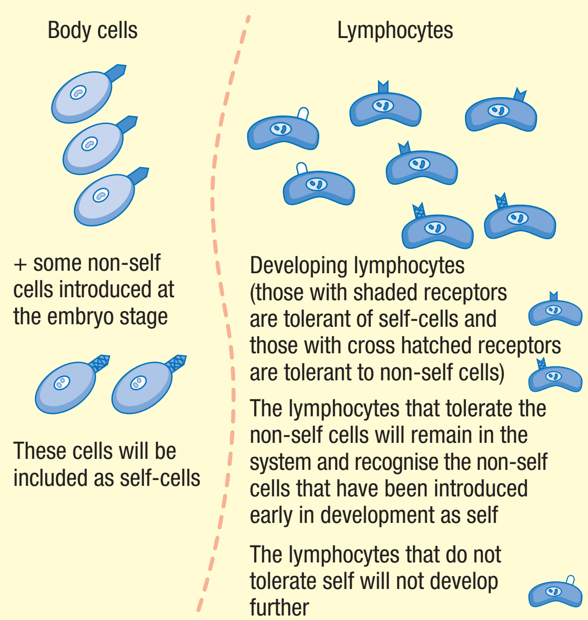


Figure 5.39 The development of immunological tolerance

- animal is very young
- dose of antigen is high
- antigen has a low molecular weight
- dose of antigen is prolonged or repeated.

Auto-immune disease occurs if an organism loses its ability to recognise 'self' from 'non-self'. It manufactures antibodies against certain of its own cells. Cells of the blood, liver, kidneys, endocrine glands and stomach lining are most susceptible. Some auto-immune diseases can be treated with immune-suppressive drugs to prevent destruction of healthy cells. These drugs are similar to those used in grafting when a tissue or organ comes from another individual.

Haemolytic anaemia occurs when antibodies are formed against the individual's own red blood cells. The red blood cells break down after only a few days in circulation instead of the normal 100–120 days. The body cannot produce enough red blood cells to compensate for the high levels of breakdown. This results in a much depleted oxygen supply to the cells.

Many animals, including humans, produce a group of substances in response to viral infections. These small protein molecules, collectively termed interferon, prohibit further increase in viral numbers. It is thought that interferons prevent viral DNA instructing the host cell to produce more virus organisms. Each species produces a specific interferon. Unlike other proteins, interferons are resistant to excessive heat and acidity.

5.6.4 Medicinal treatment of disease

Throughout time animals have used natural remedies to alleviate ill health. The grass eating of domestic cats and dogs and deliberate ingestion of kaolin clay by birds and other primates to cure intestinal upsets is well recognised. Early humans also developed a knowledge and understanding of curative aspects of particular plants. Even today approximately 60 per cent of the world's population does not have regular access to pharmaceutically produced medicines. They depend primarily on plants for preventing and treating illness. The forest people of the Amazon, for example, use 1300 plant species for medicinal purposes. The number of plant species used in healing in other parts of the world is also staggering—in India 2500 species, in South-East Asia approximately 6500 and in China 5000 species. A large number of plants in Australia were also used by Indigenous people. In recent times there has been a resurgence in investigating Australian plants for possible drug applications.

Table 5.12 Some healing plants used by Indigenous Australians

Plant	Preparation	Medicinal use
Wattles (*Acacia holosericea, A. monticola* of Western Australia)	Bark and roots soaked in water	Cough mixture
Australian bugle (*Ajuga australis*)	Bruised leaves and juices	Ulcers and sores
Red ash (*Alphotonia excelsa*)	Infusions of bark and roots Leaves	Linament; gargle for toothache Sore eyes
White mangrove (*Avicennia marina*)	Mixture of ash from burnt sticks and water	Scabies treatment
Musk basil (*Basilicum polystachyon*)	Infusion with water	Fevers
Konkerberry (*Carissa lanceolata*)	Oily sap	Rheumatism
Sneezewood (*Centipeda cunninghamii*)	Infusion of plant	Colds, sore eyes
Australian bindweed (*Convolvulus erubescens*)	Infusion of whole plant	Stomach ache and diarrhoea
Native lemongrass (*Cymbopogon obtectus*)	Crushed and inhaled Infusion	Congestion of nose Fevers
Wild hops (*Dodonaea viscosa*)	Chewed leaf and juice	Stonefish and stingray stings
Gum trees (*Eucalyptus*)	Kino (gum exudates) from bloodwoods Beaten bark of coolibah *E. tetrodonta* leaf infusions	Colds, toothache, venereal sores Snakebite compress Coughs, diarrhoea
Milky mangrove (*Excoecaria agallocha*)	Latex (single drop can cause temporary blindness)	Chronic ulcers
Native fig (*Ficus*)	Latex	Wounds, fungal infections
Dysentery plant (*Grewia retusifolia*)	Chewed leaves	Dysentery and diarrhoea
Beach convolvulus (*Ipomoea brasiliensis*)	Infusion of leaves Heated leaves	Marine stings Draw out boils
Broad-leaved paperbark (*Melaleuca quinquenervia*)	Young chewed leaves	Respiratory complaints
Native banana (*Musa acuminata*)	Mucilagenous sap	Ease pain from contact with the stinging tree
Native pepper (*Piper novae-hollandiae*)	Chewed plant	Sore gums
Peanut tree (*Sterculia quadrifida*)	Crushed leaves Infusion of bark	Wounds Sore eyes

The chemicals with healing properties are known as secondary plant products since they are not involved in manufacturing carbohydrates, proteins or lipids. These products are actively made by the plant and at least some are thought to be adaptations to protect the plant. As useful drugs these plant products act by:

- mimicking existing chemicals that inhibit or stimulate natural processes, e.g. ephedrine is similar to adrenaline and so increases blood pressure; phyto-oestrogens are similar to the female hormone oestrogen
- reaction to an organism that is causing illness as an antibiotic or antiseptic effect.

The main plant products used are contained within the following complex chemical groups:

- tannins which have an astringent action that contracts tissues (e.g. inflamed mucous membranes associated with coughs) or in bathing some wounds
- mucilage which is soothing to inflamed mucous membranes (e.g. from the European marshmallow)
- aromatic oils which are used as inhalants (e.g. eucalyptus oil) to relieve respiratory ailments or may have antimicrobial action (e.g. tea-tree oil)
- latex which contains protein-digesting enzymes used in removal of skin complaints such as warts or in cleaning ulcers and wounds (the latex of some plants causes contact dermatitis in those sensitive to these chemicals)
- alkaloids—these may be either therapeutic or poisonous, often depending on the concentration —the main chemical group used in pharmaceutical products.

Studies of these plants, isolation of their active ingredients and rigorous testing have resulted in the development of approximately 40 per cent of all prescription drugs. For example, the major surgical muscle relaxant, tubocurarine, is derived from the plant-based curare used by the South American Indians on the tips of their blowpipe darts in hunting.

The identification and isolation of the active ingredients from plants have allowed the production of synthetic drugs. A steroid in the Mexican yam enabled the development of the oral contraceptive pill. Although the Greek physician Dioscorides described the white willow (*Salix alba*) as a painkiller in the first century, the active ingredient (salicin) was not isolated until the nineteenth century. Around that time a similar compound (salicylic acid) was isolated from meadowsweet (*Spirea ulmaria*). When the two were mixed together with acetic acid in 1899, it was found that the painkilling properties were more effective. Aspirin, the most widely taken medicine in the world, was discovered. Both salicin and salicylic acid are now synthetically produced.

Not all plant chemical, however, can be synthesised. Thus digitalis, a heart stimulant that slows down and strengthens heart beat and that has saved millions of lives, is still produced from dried foxglove (*Digitalis purpurea*) leaves. After World War II, the anti-malarial drug quinine, produced from the bark of the *Cinchona* tree, was replaced by synthetic products. In recent years, however, the parasites have shown increasing resistance to these drugs. Quinine has had a revival as the only effective drug against certain *Plasmodium* strains. Less than 10 per cent of the active higher plant chemicals used in prescriptions are commercially prepared by synthesis. This is either because scientists have not as yet found a way to synthesise them or because they can be more economically produced from growing the plants.

Figure 5.40 Foxglove in flower

Plants are not the only organisms found to have therapeutic effects. Many modern antibiotics are either produced by various species of bacteria (Actinomycetes) or artificially synthesised from their natural products. Among these drugs used to control other bacteria are streptomycin and aureomycin. Several antibiotics are produced from fungi. Penicillin (used to combat many Gram-positive bacteria and all staphylococcal infections) is produced from several species of *Penicillium*, notably *P. notatum*. Griseofulvin, produced from *P. griseofulvum,* has antifungal properties; fumagillin, produced from *Aspergillus fumigatus*, is frequently used against amoebic dysentery. Research is currently being carried out on β, β-carotene produced by the green alga *Dunaliella salina* to investigate its properties as an agent against lung cancer.

Although only a small fraction of marine organisms have been examined, a large number of valuable chemicals have been found. A sea squirt, for example, produces a substance found to be active against a broad range of viruses responsible for such diseases as colds, influenza, herpes and meningitis. Serum from horseshoe crabs is able to isolate tumour cells from the blood of cancer victims. Shark livers contain lipids thought to increase human resistance to cancer. Over 500 marine organisms have been found to produce chemicals that have the potential to combat cancer.

Terrestrial animals have provided fewer chemicals to medicine. Bee venom is used to treat arthritis and captopril, produced from the venom from a Brazilian snake, aids in controlling hypertension.

SUMMARY

The human body has a variety of mechanisms to prevent or reduce the effects of pathogens. External barriers may provide both physical (e.g. skin, hair) and chemical (mucous membranes, secretions such as saliva and tears) defences against invading pathogens. If these barriers are breached, the immune system comes into action. White blood cells in the tissues and blood respond in a non-specific manner to pathogens, engulfing and destroying them by phagocytosis. This is accompanied by an inflammation reaction.

Specific responses occur against the 'marker' proteins or antigens that identify a particular type of pathogen. These responses involve the lymphocytes found in the lymphatic system. Those lymphocytes that pass through the thymus gland are called T-cells and those that do not are termed B-cells. B-cells produce antibodies that have a structure complimentary to the antigen. Binding of the antibody to the antigen induces neutralisation, agglutination, precipitation or complement reactions that destroy the pathogen. There are three types of T-cells —helper T-cells, cytotoxic (killer) T-cells and suppressor T-cells. Helper T-cells activate cytotoxic T-cells and B-cells. Cytotoxic T-cells destroy infected or foreign cells. Each of the T- and B-cells can be either active cells or produce memory cells that can become active if reinfection of the particular pathogen occurs at a later date. Once the particular immune response is completed, suppressor T-cells destroy the antibodies.

Immunity is the ability to resist disease. Natural immunity is acquired either passively or actively. Active natural immunity can occur when memory T-cells and B-cells have formed. Passive immunity results from the intake of antibodies. This may be from breast milk when a baby feeds (natural) or vaccination of antibodies from a previously infected individual (artificial). Artificial active immunity can be achieved by vaccination of inactivated antigens.

Immunological tolerance is the ability of some organisms to tolerate cells other than their own provided they are introduced to the organism during the early stages of its development.

Treatment for human diseases has traditionally been from plant extracts. A large proportion of the world's population still depends upon these traditional treatments. Although medicinal drugs have been extracted from a large variety of organisms, the higher plants are the main source of prescription medicines. In many cases the active ingredients have been isolated and are now synthetically produced.

Review questions

5.40 List ways in which pathogens can enter the body.

5.41 Describe preventative methods to minimise contracting pathogens.

5.42 Explain why many diseases are difficult to control.

5.43 What is the immune system?

5.44 One of the body's responses to tissue damage is an inflammatory reaction. How is this achieved and what is its purpose?

5.45 The human body is said to have three lines of defence against invading pathogens:

- The first line involves physical and chemical barriers to pathogen entry.
- The second line of defence is a non-specific response of the immune system.
- The third line of defence is a specific response of the immune system to the particular pathogen.

Describe how each of these mechanisms operates.

5.46 Differentiate between an antigen and an antibody.

5.47 How are memory cells formed? What is the function of a memory cell?

5.48 Describe ways in which a person can become immune to a pathogen.

? **5.49** Travellers to Africa are given gammaglobulin injections against hepatitis A infection. Identify, with reasons, the type of immunity that has been conferred.

5.50 What are the main active ingredients in plants that have medicinal value for people? How does each chemical group act?

5.51 Describe the ways in which plant/animal chemicals (active ingredients) can act on human pathogens.

5.52 What is an antibiotic? Why are antibiotics not prescribed for viral infections?

EXTENDING YOUR IDEAS

1. IB The graph below was obtained from experimental results of two pairs of rats.

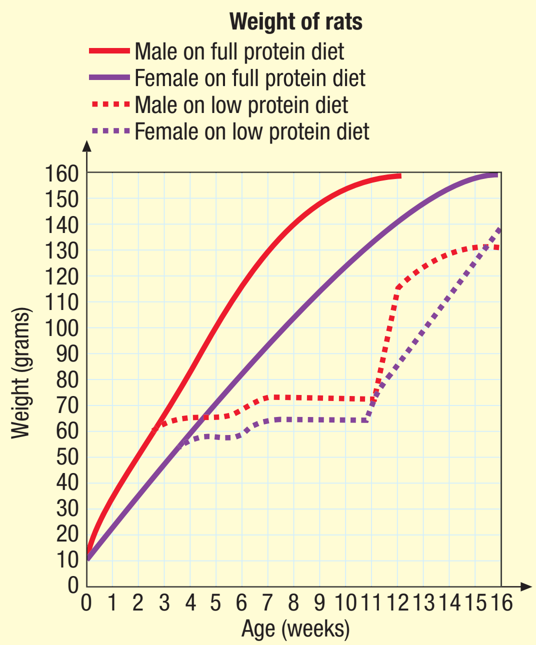


Figure 5.41 Effect of protein ingestion of weight gain in rats

(a) What conclusions can you draw from the rats on full protein diet?

(b) What was the weight of the female rat on a full protein diet at 2 weeks?

(c) The two rats on a low protein diet were given full protein at a certain age. At what age was this administered?

2. IB The following table shows the concentration of protein, sodium and potassium in some foods.

	Protein (gram per 100 g)	Sodium (mmol per 100 g)	Potassium (mmol per 100 g)	Grams per average portion
Apple				
cooking (baked without sugar)	0.3	0.1	3.3	100
cooking (stewed with sugar)	0.3	0.1	2.4	100
eating (weighed with skin and core)	0.2	2.4	2.4	100
Apricot				
canned	0.5	trace	6.6	100
dried (raw)	4.8	2.4	48.0	100
dried (stewed with sugar)	1.7	0.9	17.0	100
Avocado	4.2	0.1	10.0	100
Potato				
baked	2.6	0.3	17.0	100
chips	3.8	0.5	26.0	100
new (boiled)	1.6	1.6	8.5	100

A kidney transplant patient is allowed 1 mmol of potassium and 0.5 g of protein per kg of body weight per day. The patient weighs 64 kg.

How many average portions of avocado could the patient eat in a day without going over the limits of either protein or potassium? Show your working.

3. IB *Heliobacter pylori* is a bacterium found in the stomach and duodenum of many people. It is the second most common bacterial infection after those which cause chronic tooth decay. About 75 per cent of the world's population go through life with chronic inflammation of the stomach. About 1 in 6 of those infected develop ulcers, and 95 per cent of those with ulcers are infected by *H. pylori*.

A peptic ulcer is a painful and dangerously eroded area of the lining of the stomach or duodenum. Deepening, bleeding ulcers can perforate, with fatal consequences. It has long been thought that peptic ulcers are caused by excess acidity in the stomach and duodenum. Acid is regarded as being hostile to ingested microorganisms.

Treatment of ulcers with acid-suppressing drugs has some success, but the ulcer often recurs, even though the drugs may be taken for some years. Conversely, treatment with antibiotics for a week or two eliminates infection, the ulcers heal and do not recur. Reinfection does not often occur because the bacterium is usually acquired in childhood by oral–oral or faecal–oral contact.

The graph (Figure 5.42) below shows the percentage of infection of different age classes in India, a developing country, and the United Kingdom, a developed nation.

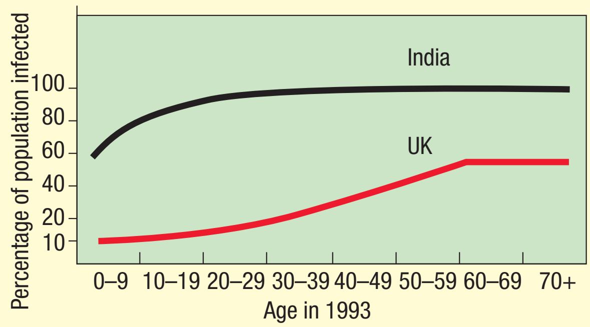


Figure 5.42 *Heliobacter pylori* infection in India and the United Kingdom (UK), 1993

(a) What evidence above supports the assertion that infection is related to the quantity of sanitation?

(b) What evidence supports the idea that improved sanitation in the Western world has reduced the incidence of *H. pylori* infection?

(c) How could acid-suppressing drugs be counter-productive in attempting to cure peptic ulcers?

(d) What evidence supports the contention that *H. pylori* may cause peptic ulcers?

(e) At what time in life should vaccination against *H. pylori* occur? Justify your answer.

4. IB A bacterium (which has a doubling or generation time of 30 minutes) produces sufficient toxin to cause food poisoning when it is present at 1000 cells per gram of food. How long, to the nearest hour, would it take for a single cell introduced into food to become a hazard to consumers of the food?

5. UB In a hospital outbreak of bacterial infection, the bacteria do not respond as expected to an antibiotic. Suggest reasons for this.

6. IB A scientist was investigating the cause of lung cancer. He had read about a mutant strain of a bacterium which could survive in an environment containing penicillin because it is able to produce penicillinase (an enzyme that breaks down penicillin). The 'normal' strain of this bacterium does not produce penicillinase and thus cannot survive in an environment containing penicillin. Hence, in a penicillin-free environment the normal strain of bacterium reproduces at a faster rate (about once every 20 minutes) than the mutant, but in an environment containing penicillin, only the mutant will survive and reproduce.

The scientist was also familiar with the following scientific observations:

1. Carbon monoxide inhibits cytochrome reactions (cytochromes are pigments involved in aerobic respiration, i.e with oxygen present).
2. Hydrogen cyanide is a specific poison of aerobic enzymes.
3. Both carbon monoxide and hydrogen cyanide are present in cigarette smoke in proportions greater than the recognised 'safe' level.
4. Epithelial cells lining the bronchial tract (the main passage to the lungs) may give rise to cancerous cells.
5. Normally, epithelial cells divide about once every 6 days.
6. Normal epithelial cells can respire both aerobically and anaerobically, although most energy for cell division comes from the former.
7. A high oxygen tension prevents epithelial cells from dividing rapidly.
8. Rapidly dividing cancerous cells of the bronchial tract (bronchogeniccarcinomas) can respire both aerobically and anaerobically.

Using the above information, answer the following questions:

(a) Describe the environmental conditions necessary for the initiation of a cancerous growth.

(b) How is the cancerous growth maintained?

(c) How would ceasing to smoke influence a developing cancerous growth?

7. UB Biologists at Colorado State University in the United States have disabled the LaCrosse virus, which causes encephalitis in children, in its vector, *Aedes triseriatus* mosquitoes. They spliced the genes for the disease into another virus which infects insects without causing disease. Female mosquitoes were then fed blood containing the genetically engineered virus. Once inside the mosquito cells, this virus produced large quantities of a chemical which blocked the production of the protein coat specific to LaCrosse virus. They had in effect produced an 'antisense gene'. When the mosquitoes were later infected with LaCrosse viruses, this protein could not be formed and thus the virus was unable to reproduce. Although LaCrosse encephalitis is relatively rare, the researchers are hopeful that the process could be applied to other viral diseases such as dengue and yellow fevers, which are the cause of mass fatalities in tropical regions.

A major difficulty in this process is related to the transfer of these 'antisense genes' into mosquitoes in the wild. Suggest methods by which this might be achieved.

8. Pesticides and public health programs are significant in the prevention of disease. Research the control measures that have been developed for a significant, named disease. Evaluate their effectiveness given the political and economic climate of the areas in which the disease is common.

9. Pressure marks made by the upper teeth onto a metal plate can be used to identify particular types of sharks. A scientist sampled this bite force on 1000 of each of four species of shark and found the following results. He discovered that the bite pattern can display either holes or slices, the size of which is related to the pressure exerted.

Type of shark	Maximum observed bite pressure (kgf cm^{-2})
Blue shark	50
Hammerhead shark	40
Mako shark	60
White shark	65

A scuba diver was attacked by a shark. Fortunately the air tank deflected the attack and the diver was able to escape. Later examination revealed the following bite pattern on the tank.

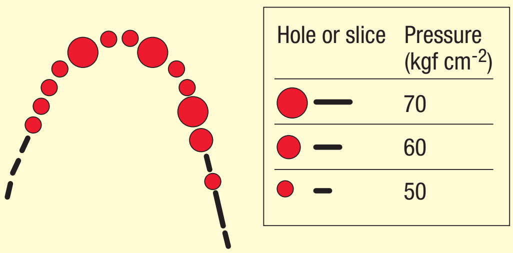


Figure 5.43 The bite pattern on the tank and pressure exerted by particular bites

Suggest, with reasons, the most probable type of shark that made the attack.

10. Suggest reasons why the World Health Organisation program to eliminate malaria is taking longer than expected. Justify your reasons.

11. Scientists wanted to test the hypothesis that a given B-cell makes only one specific antibody against an antigen. They inoculated an animal simultaneously with two different antigens. After waiting for the immune system to respond, they took a sample of blood. From the blood they isolated single plasma cells and tested whether each one produced antibodies to one or both of the antigens.

Predict the results you would expect for the B-cells based on your knowledge of the immune system. Explain your predictions.

12. The following table shows some of the characteristics of the different types of antibodies found in body fluids.

	Type of antibody				
	IgG	IgA	IgM	IgD	IgE
Ability to cross placenta	yes	no	no	no	no
Present in saliva and tears	no	yes	no	no	no
Present in milk	yes	yes	no	no	no
Active against viruses	yes	yes	some	no	no
Active against some bacteria	yes	yes	yes	no	no
Involved in allergy reactions	no	no	no	no	yes

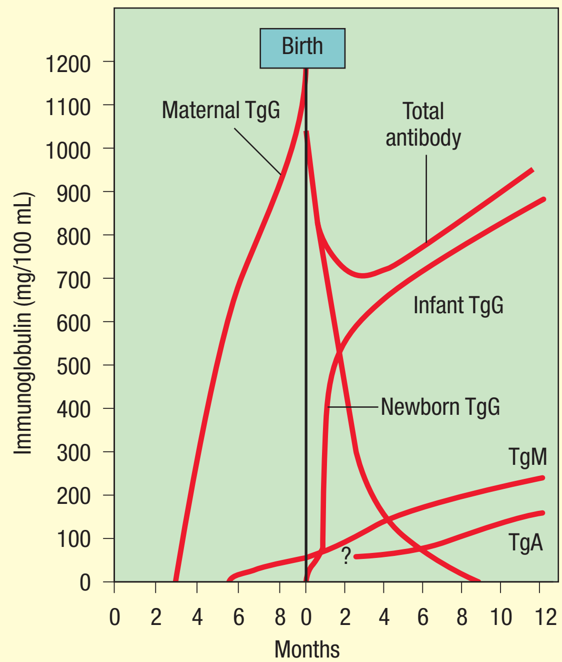


Figure 5.44 Changes in immunoglobulin levels

(a) From the graph, when would it appear that the newborn infant suffers the greatest chance of infection by bacteria? Explain your answer.

(b) Information about the levels of IgA have been deleted from the graph until 2 months after the birth. In terms of the *efficient use of available resources* and the information provided, suggest a logical explanation for the starting point of IgA production. (Your information need not be 'correct', but it must be a logical deduction based upon your understanding of the immune system and the information supplied.)

13. Explain why it is useful for B-cells to be highly variable, but essential that helper T-cells do not change.
UB

14. Imagine that you have been shipwrecked on a coral island east of New Guinea. The island is large and has adequate freshwater supplies, but as far as you can ascertain, has no people living on it. Because of its location among prolific coral reefs, it is not on the normal shipping channel and it is likely that you could be isolated for some time. Describe, with reasons, how you would survive and the possible dangers you might encounter.
EBI

15. In recent years a large number of human parasites have been investigated in the search for new drugs. It is argued that since many blood-sucking organisms have developed chemicals that reduce or eliminate the inflammatory and immune responses of their human hosts while they are feeding, these chemicals could be of potential medicinal use. To date a variety of chemicals have been isolated and their potential use is summarised below.
EBI

Parasite	Type of drug	Could be used to:
Leech	Blood thinner	Prevent blood clots after surgery (already available)
	Anti-inflammatory	Basis for drugs to treat asthma and psoriasis
Hookworm	Blood thinner	Prevent blood clots forming after surgery
		Prevent heart attack in unstable angina
Vampire bat	Clot buster	Dissolve blood clots after heart attack or stroke
Tick	Anti-inflammatory	Treat conjunctivitis, asthma, hay fever
	Vaccine	Prevent Lyme disease
Sandfly	Vaccine	Prevent Leishmaniasis ('black fever')

It is possible, however, that after extended periods of treatment with these drugs the person could develop an allergic reaction.

(a) Suggest, with reasons, why there could be a delayed allergic reaction to these drugs.

(b) Research ways in which the active substances from these parasites might be used to develop possible human treatments or vaccinations.

UNIT 3

Ecology

Every organism lives in a particular habitat with specific physical and chemical properties. Organisms must have adaptations (structural, physiological or behavioural) that allow them to carry out their life functions in that habitat. The survival of the species in any habitat also depends on interactions with other organisms. Thus the environment of a species includes both living and non-living features. Ecology is the study of an organism in relation to its environment.

Organisms do not live alone. They occur in populations of their own type, the abundance and distribution of which are related to the rest of the environment. Different populations within an area also interact as a community.

In ecosystems there is a dynamic interaction between organisms in a community and their abiotic environment. Constraints imposed by varying environmental conditions in different geographical and physical situations have resulted in a wide diversity of ecosystems.

Energy, derived primarily from solar energy and incorporated into chemical bond energy, flows through ecosystems via food chains. Energy conversions within an organism result in heat radiation from the organism into the atmosphere. Since this energy is not in a form to be used by autotrophs, it cannot be recycled.

Chemical matter comprising biomass, through the actions of decomposer organisms, can be returned to the environment for reuse by producers. Flow of matter through the biosphere occurs in biogeographical cycles. Some matter (e.g. fossils and deep-sea sediments) is locked away from living organisms in reservoir pools. Other matter, in the cycling pool, is transferred between biotic and abiotic components of the ecosystem in nutrient pools.

Models of the flow of energy and matter, both globally and at local levels, help biologists understand these interactions and how they might be applied in conservation measures.

The biosphere is that part of the earth which supports life. It consists of aquatic (marine, estuarine and freshwater), atmospheric and terrestrial environments. The terrestrial portion of the biosphere can be subdivided into biomes. These are vegetation groups with similar structural patterns, which have adaptations to particular temperature ranges and water availability.

A community is a group of different species living together in a particular habitat at any time. In a stable community the abiotic and biotic factors are in dynamic equilibrium—changes in one factor are offset by changes in another. Daily and seasonal changes in temperature and rainfall can alter the species composition of the community. Boundaries of communities are rarely distinct, since few abiotic conditions show abrupt changes. Thus the ocean biome blends, through the littoral zone, with terrestrial environments. At the boundaries, both communities will have some members in common. Since it is not likely to be possible to study all aspects of a particular area in detail, biologists use random sampling to ascertain community parameters and the abiotic conditions which sustain them.

Succession refers to changes in vegetation (and thus animal life) over a period of time through the effects of organisms on their environment. The human population has increased dramatically over the past few centuries. Humans, owing to their ever-increasing demand for resources, have had a profound effect upon communities.

Increase in the human population, and agricultural and technological development, have resulted in three main ecosystems: natural, agricultural and urban. Each has different requirements and outputs. Supply of inputs into agricultural and urban ecosystems requires high levels of energy. The outputs of both can lead to land, water and air pollution. The dynamics of these ecosystems can have far-reaching effects on other communities.

The aim of conservation is to balance the sustainable use of resources with the maintenance of natural ecosystems and their biodiversity. Biodiversity ensures continued recycling of matter in the biosphere, and healthy natural ecosystems provide aesthetic and recreational areas for human populations. In recent years many new species have been discovered, the chemicals from which may provide a cure for many human diseases.

Key concepts

- Organisms live an interdependent existence in environments to which they are adapted.
- A variety of mechanisms result in continual change at all levels of the natural world.
- There are processes which maintain dynamic equilibrium at all organisational levels.

Key ideas

- Energy required by all living things is obtained in different ways.
- Abiotic and biotic factors in an environment influence the size of populations and the composition of communities.
- Energy and matter move within an ecosystem.
- Human actions have significant impacts on interactions within an environment.
- Different organisms perform different interdependent roles in an ecosystem.
- An organism has adaptations specific to its environment.
- The activity of organisms changes the environment.
- Evidence shows that organisms and ecosystems change through time.

6 Organisms and their environment

Ecology is the study of relationships of living things, with each other and with their environment. The word 'ecology' is derived from the Greek word *oikos* (= home), and thus in its broadest sense, ecology is the study of the area of the world which provides homes for living things, known as the **biosphere**.

Each organism shares its living place or **habitat** with other organisms of the same type as part of a **population**. It also shares its habitat with many other types of organisms which together form a **community**. Each type of organism has a particular **niche** or role in the community. The niche includes the species' requirements, the physical conditions and resources in its environment and its adaptations to meet those requirements and utilise the resources.

All organisms perform the same basic life functions. However, the ways in which these are achieved vary, and depend on the type of habitat to which the organism is adapted.

6.1 The environment

6.1.1 Abiotic factors

Different organisms live in different living places, or habitats. The physical conditions (temperature range, humidity, wind and air currents, water currents, pH, availability of light, water, nutrients etc.) of habitats vary dramatically. These conditions are known as **abiotic** conditions (from the Greek *a* = without and *bios* = life). In order to carry out its life functions successfully, each organism in a particular habitat must be adapted to the physical and chemical conditions imposed upon it. Major differences in structure, related to habitats, have been examined in Unit 2.

Abiotic factors directly associated with climate

Temperature

The temperature range over which biochemical processes can function is narrow. Organisms must therefore have physiological or behavioural adaptations to combat or avoid environmental temperature extremes.

Water

Water is essential for life. The extent to which an organism can tolerate dry environmental conditions is tied to its ability to conserve water. As with temperature extremes, this involves behavioural and/or physiological adaptations of the organism.

Radiant energy

Light is essential for all green plants and photosynthetic bacteria, and for all animals which are directly or indirectly dependent on the plants. Plants have numerous adaptations for obtaining optimum illumination.

Humidity

Humidity affects the rate of water evaporation from the surface of an organism. High humidity can affect the ability of an organism to cool itself by evaporative water loss, and low humidity can affect its ability to withstand drought.

Wind and air currents

Only plants with a strong root system and tough stem can live in exposed areas with persistent strong winds. On the other hand, wind and air currents provide an important means of dispersing spores and seeds, and are important factors in animal flight or gliding modes of locomotion.

Abiotic factors connected with soil

pH

pH (a measure of acidity) influences the distribution of plants in soil and freshwater ponds. Some plants thrive in acid conditions; others in neutral or alkaline conditions. Most are highly sensitive to changes in pH.

Mineral salts and trace elements

The chemical composition of the soil especially affects the distribution of plants. Plants living in soil that is deficient in a particular element must have special methods for obtaining it. For example, some plants that grow in nitrogen-deficient soil harbour nitrogen-fixing bacteria or mycorrhizae, and some are carnivorous.

Water retention

Some soils (e.g. sands) do not retain water well, whereas others (e.g. clay) can hold water so well that air spaces in the soil are obliterated in wet conditions. Many soils are intermediate between these extremes. Plants need adaptations if they are to survive in either of the extremes.

Abiotic factors related to geography

Water currents

Water currents are particularly important in oceans, rivers and streams. Only organisms capable of swimming or avoiding strong currents can survive where this is a persistent feature of the environment.

Salinity

There is a sharp distinction between marine and freshwater species. Estuarine organisms must have special physiological or behavioural adaptations for withstanding the daily fluctuations in salinity that accompany tidal rhythm.

Wave action

This particularly affects organisms living in the intertidal zone. To survive periodic buffeting by waves and exposure to air, special adaptations are required.

Topography

Topographic features (geographical surface features) influence illumination, temperature, moisture and so on. Within a relatively small area (e.g. the slopes and base of a gully), these topographic differences may have significant effects on the distribution of organisms.

Background

The general texture and pattern of the habitat may be significant. Some organisms (**cryptic** organisms) are adapted to their environment by having shape or colouration that camouflages them when viewed against a particular background.

Shelter

Shelter is a critical factor for some organisms. For instance, insectivorous bats need caves, and the desert hopping mouse must have an underground system of tunnels. The soil or rock, therefore, will strongly influence the presence or absence of such organisms, even if all other conditions are favourable.

Thus different habitats have different energy levels, chemical and physical features which will influence the types of plants that can grow and survive there. These plants, together with the abiotic features, will influence the kinds of animals that can survive.

Each species has an **optimal range** for *each* abiotic factor in the environment. This is the level at which it can best survive. For example, a certain plant will grow very well in a pH range of 6.5 to 8.0. This is its preferred niche for that particular factor. Although it can grow in soils of pH 6 or pH 8.5, it does not function as efficiently; that is, it suffers **physiological stress**. Habitats with these pH values provide only a marginal niche. This plant cannot survive in soils with a pH outside this range and thus these habitats become an unavailable niche. For this species, therefore, the **tolerance range** for soil pH is 6 to 8.5. An organism will only be found in an area where it encounters the tolerance range for all of its abiotic requirements.

Figure 6.1 The shape of this tree has been dramatically distorted by persistent prevailing winds.

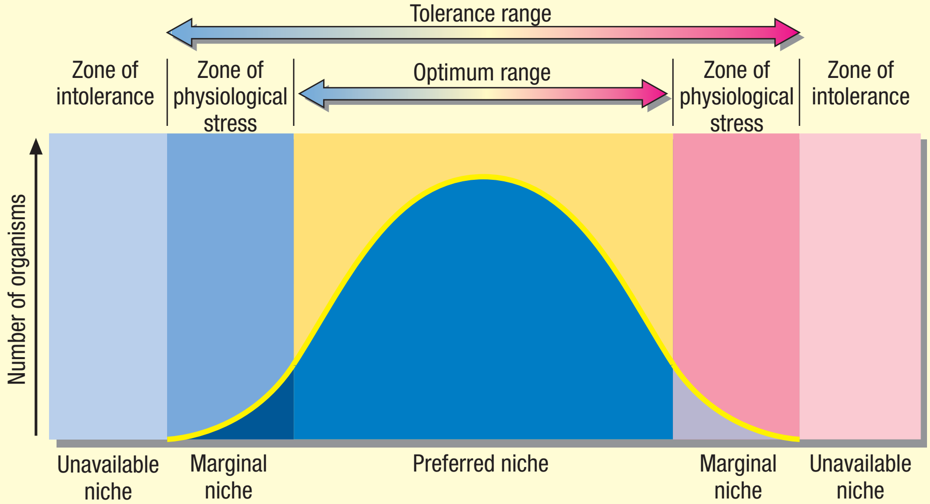


Figure 6.2 The relationship between tolerance range and optimum range of any particular abiotic requirement of an organism

The three main habitats for organisms are: water (the sea, estuaries and fresh water), the land and the air. Within each of these, many different conditions exist. Thus freshwater habitats include large deep lakes, fast-flowing mountain streams, slow meandering rivers and creeks, billabongs and so on. Because different physical and chemical conditions occur in each of these places, different types of organisms will be found living in them.

Case study 6.1: The influence of abiotic factors on Australian flora

Between 65 and 40 million years ago climatic conditions in Australia were humid and temperate, and the predominant vegetation was rainforest. The main tree species was the Antarctic beech (*Nothofagus moorei*), a species which still survives in isolated areas such as the McPherson Ranges on the NSW–Queensland border. When Antarctica separated from the Australian continental plate, an oceanic current developed around Antarctica, causing rainfall to decrease and temperatures to fall over parts of Australia. (The mechanisms by which continents drift apart are discussed in Chapter 22.) During drier periods occasional lightning strikes created fires which would have been damaging to the fire-intolerant rainforest plants. These plants depend on plentiful soil water and generally have soft leaves. They are **mesophytes**.

It was not until about 2.5 million years ago that Australia was really influenced by westerly winds with wet winters and hot, dry summers. This coincided with the beginning of worldwide climatic fluctuations which resulted in cool, arid glacial periods and warmer interglacial periods. Although this continent did not experience the major expansions of ice seen in the Northern Hemisphere, some glaciation did occur in the Snowy Mountains and the highlands of Tasmania. As a result of these climatic fluctuations, rainforests became restricted to patches similar to those of today, with forests dominated by she-oaks (*Casuarina*) taking their place.

Fires became more prevalent in the dry periods and led to the evolution of fire-tolerant species such as the eucalypts, wattles and low shrubs and herbs of the heath. This process was hastened, before and during the last interglacial period, with the arrival of the first humans. Hunting in small groups, they burnt areas to flush out prey and only the fire-tolerant plants could survive.

Many Australian soils are extremely low in both nitrogen and phosphate salts. They are termed ‘ancient soils’ because there have been no ‘recent’ major volcanic activities which bring new minerals to the surface. The Australian continent has been comparatively stable for many millions of years, during which time minerals have been eroded and leached away. Adaptations to these conditions evolved. For example, plants in the pea family (Fabaceae) and wattle family (Mimosaceae) have a symbiotic relationship with **nitrogen-fixing bacteria**. They have special **root nodules** housing the bacteria, which can convert atmospheric nitrogen to organic nitrogenous compounds that the plant can use. The **coralloid roots** of she-oaks (*Casuarina*) and cycads (*Macrozamia*) result from infection by other bacteria which fix nitrogen. Banksias have **root clusters**—mats of hairy rootlets at the soil surface—which improve phosphate uptake by the plants. Phosphate absorption is also increased by the presence of **mycorrhizae**, a mutualistic relationship between roots and fungi, particularly in orchids and heath plants.

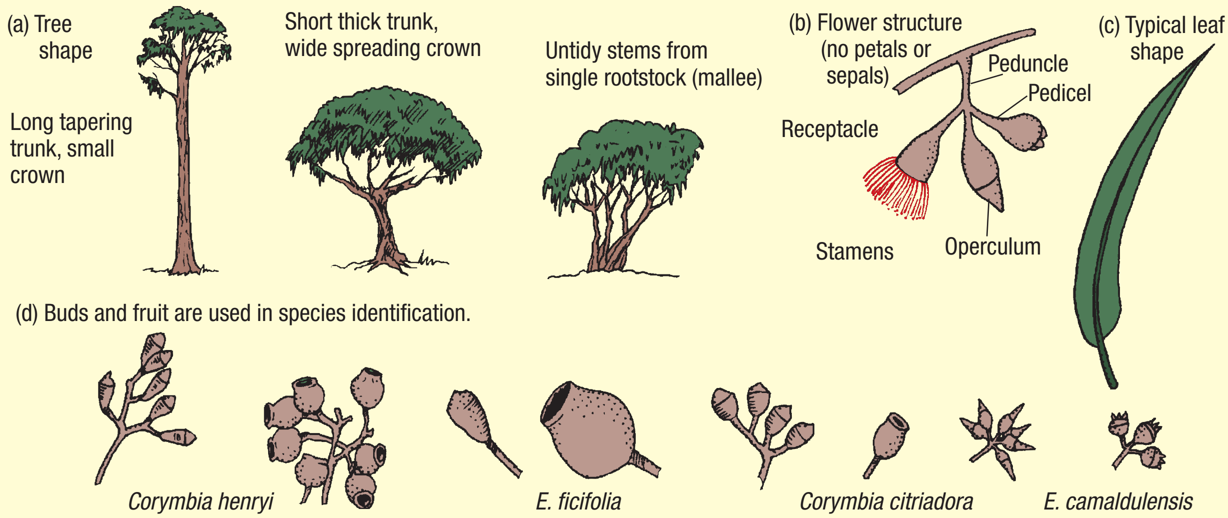


Figure 6.3 Features of Eucalyptus species (family *Myrtaceae*)

Australian plants are strikingly different from the vegetation of other continents and islands. Many species, genera and families are **endemic** to this country. They naturally occur only in this particular geographic zone. Others originated here and dispersed and further evolved in adjacent areas.

Over 70 per cent of the continent is dominated by eucalypts and wattles. Hummock grasses (*Triodia* and *Plectrachne*) are the characteristic ground cover in arid and semi-arid regions. Heath and members of the pea family occupy coastal plains and alpine regions. All are characterised by rigid, often small leaves which

Figure 6.4 Grasstree (*Xanthorrhoea*) and flower

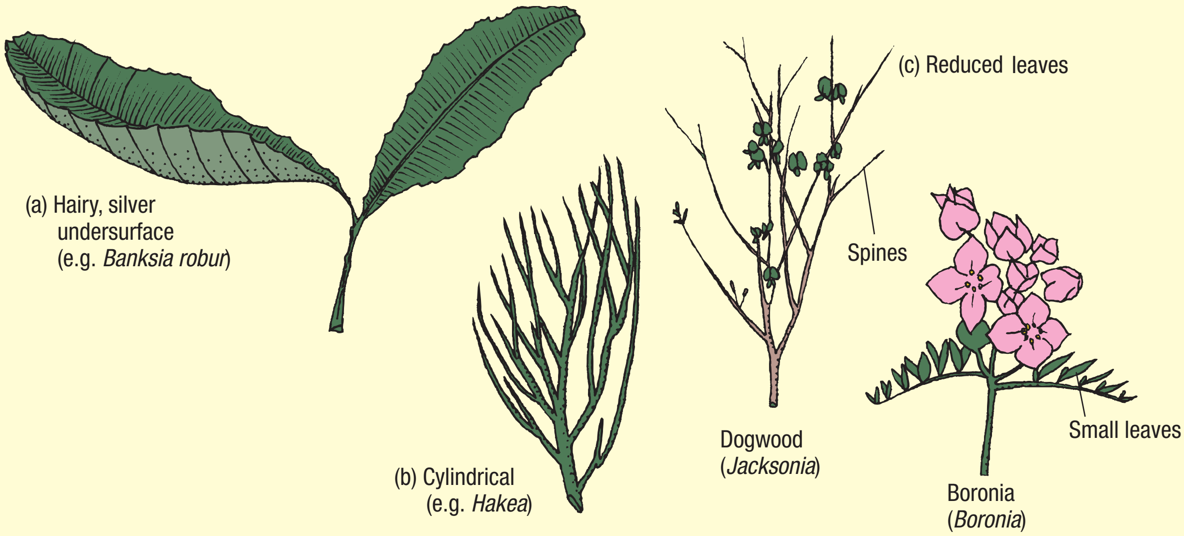


Figure 6.5 Leaf adaptations of xerophytes

are adaptations to soils of low fertility and also allow the plants to survive water stress and fire. Plants showing these adaptations are termed **sclerophytes**. Plants adapted to poor groundwater levels are termed **xerophytes**. Some of the adaptations exhibited by these plants include the following:

- They have an extensive root system (often greater than the shoot system) to take up ground water.
- The shape of leaves and stems is such that water is directed down the trunk to the roots—for example, 'grasstrees' (*Xanthorrhoea*) and mulga (*Acacia aneura*).
- The leaves are waxy, reflecting long-wavelength infrared radiation and thus keeping the plant cooler (e.g. saltbush, *Atriplex*).
- The stomata are open only for short periods at dawn and dusk when the air temperature is lower (e.g. the black box, *Eucalyptus largiflorens*).
- The stomata may be sunken below the leaf surface, creating a humid chamber which decreases water loss (e.g. *Hakea*).
- The leaf may be coated with fine hairs, increasing the humidity around the leaf and so reducing water loss (e.g. many *Banksia* species).
- The leaf may be curled up, creating a humid cylinder which decreases water loss (e.g. hummock grass, *Triodia*).
- Leaves may be so reduced in size that specialised stems take over the role of photosynthesis (e.g. she-oaks (*Casuarina*).)

6.1.2 Biotic factors

Organisms are influenced by all the other organisms with which they come in contact. These influences are the **biotic** (living) factors which can affect the survival of a species in a particular habitat. The combination of abiotic and biotic factors in any area make up the **environment** for that particular organism.

When two species of organisms interact with each other in any way, the relationship is called symbiosis. Seven types of symbiosis can be observed:

1. **Mutualism:** Both species benefit from the obligatory interaction (e.g. lichen, or algae living within coral polyps).
2. **Cooperation:** Each species benefits from the association, but the presence of one is not essential to the survival of the other (e.g. sea anemones living on the shells of crabs).
3. **Commensalism:** One organism benefits and the other is not affected (e.g. epiphytic ferns and orchids on rainforest trees). True examples of animal commensalism are hard to find, because it is unlikely that one animal will be totally unaffected by the presence of another. The relationship most likely to be commensal, however, is that between cattle egrets and cattle, in which the egrets feed on insects disturbed by the grazing cattle.
4. **Amensalism:** One species inhibits the other (e.g. antibiotics produced by moulds inhibit the growth of bacteria, or the tannins in fallen eucalypt leaves inhibit the growth of plants).
5. **Parasitism:** Parasites obtain food by living in (endoparasites) or on (ectoparasites) a host organism, which they harm in some way.
6. **Predation:** One organism (the predator) attacks and kills another living organism (the prey) to obtain food (e.g. the noisy pitta feeding on rainforest snails; insectivorous plants trapping and digesting insects).

(a) (b)

Figure 6.6 Camouflage of (a) a beetle (b) a stone curlew

7. **Competition**: Competition is rivalry between individuals for a specific resource or resources, and can occur between members of the same species (**intraspecific**) or different ones (**interspecific**). Kangaroos and sheep, for example, compete for grass; this is interspecific competition. Some of the resources for which organisms compete are food, space, water, air, light, shelter and mates. If a resource is scarce, competition can be fierce and lead to fighting. The aggressive interactions of magpies competing for nesting sites is an example of intraspecific competition.

These seven relationships can be summarised as shown below:

Relationship	Species A	Species B
Mutualism	+	+
Cooperation	+	+
Commensalism	+	0
Amensalism	0	–
Parasitism	+	–
Predation	+	–
Competition	+ or –	–

Key: + = advantaged; 0 = not affected; – = disadvantaged

In some cases the relationship between organisms may be more subtle, giving categories 8, 9 and 10.

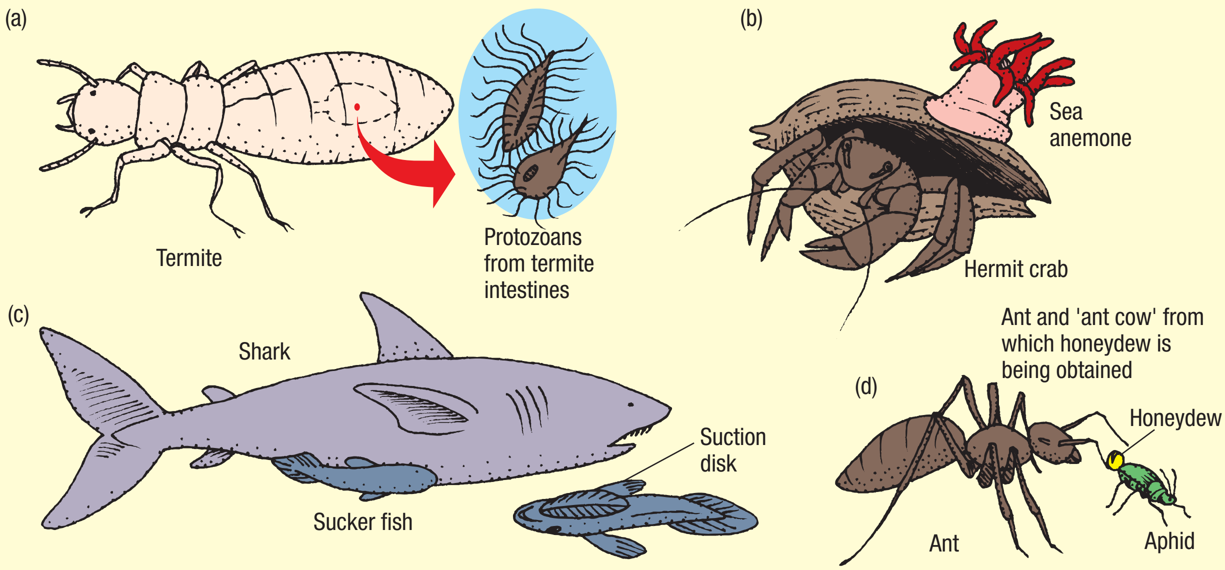


Figure 6.7 Examples of symbiosis

Figure 6.8 The hoverfly (*Syrphus damastor*) mimics the honeybee (*Apis mellifera*)

8. **Camouflage:** In the course of evolution some animals have come to bear a striking resemblance to parts of a plant, thereby making themselves virtually invisible to predators; stick insects are a striking example of this. In such cases the plant species concerned forms a most important part of the insect's biotic environment. Other species have cryptic colour patterns, or are able to change colour to blend with their background.
9. **Mimicry:** Some animals closely resemble another species of plant or animal that their predators have learnt to avoid. For example, some have the visual characteristics of a species which is unpalatable to the predator. The unpalatable species generally has distinctive colours, odours or markings which the predators learn to recognise and avoid. Similarly, the stingless hover fly mimics the honeybee which has a protective sting.
10. **Humans:** The most powerful biotic factor is the human species, the influence of whom will be dealt with in detail in Chapter 10.

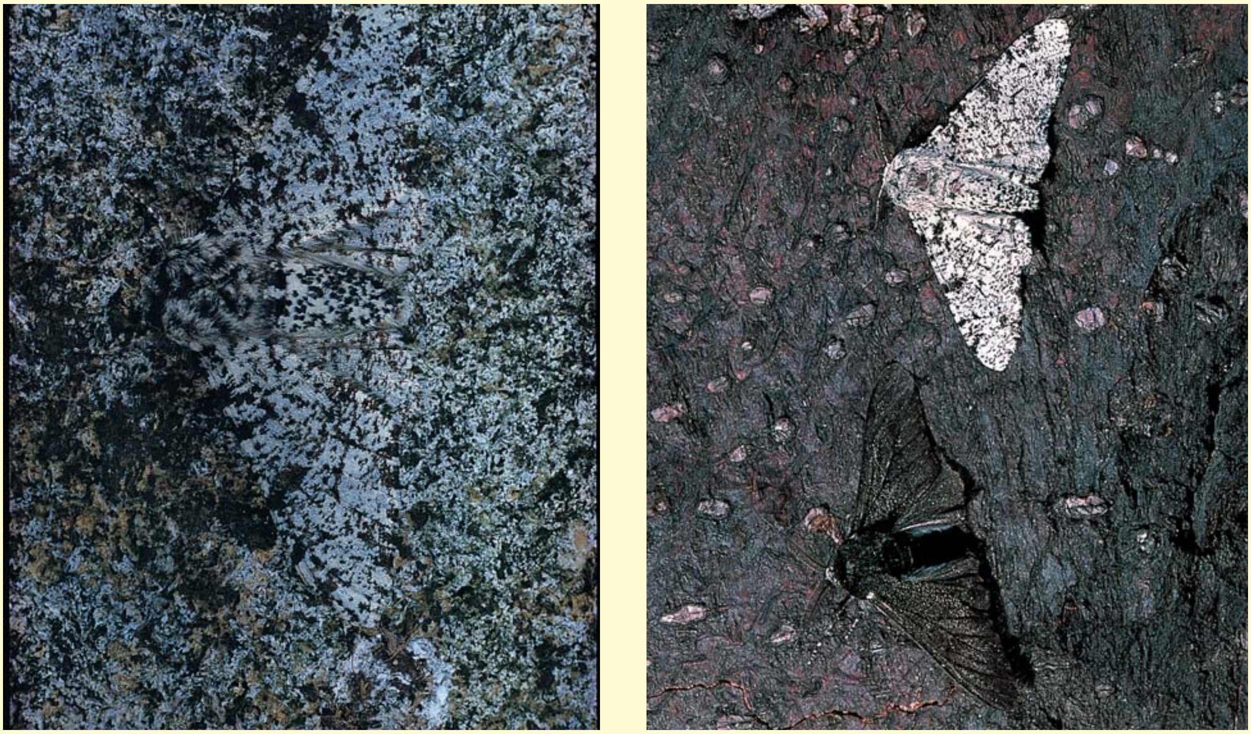
Case study 6.2: The peppered moth

The peppered moth (*Bison betularia*) has been observed in Manchester, in the north of England, for more than a century. Although a rare black form was occasionally observed (one from a collection made before 1819), the moths collected in the first part of the nineteenth century were light coloured with darker speckles. Active at night, they rested during the day on lichen-covered tree trunks and rocks where they were well camouflaged from insect-eating birds such as robins and sparrows.

Manchester became industrialised at the beginning of the nineteenth century, so that by the 1850s soot covered buildings and trees, and chemicals in the smoke from factory chimneys killed the lichen. At this time the black form of the moth started to increase in numbers, and by 1895 it was estimated that they comprised 98 per cent of all the moths.

A group of scientists investigated this change in colour predominance over many years. They selected two woodland areas (one polluted and one unpolluted) where robins and sparrows were found, and released a large and equal number of each coloured moth into the trees of each. The predation by birds was observed by the scientists in hides. In the unpolluted woodland, they found that the birds mainly captured the dark moths (164 to 26 light) whereas in the polluted areas it was mainly the light moths that were eaten.

Other experiments, such as releasing marked moths of both colours into polluted and unpolluted woodlands and recapturing the survivors at a later date, confirmed the scientists' findings. They concluded that both colours of the moth existed in nature and that colour was genetically determined. In unpolluted environments where light coloured lichen existed on the bark and rocks, the light form was predominant because they were better camouflaged from insect-eating birds. In polluted environments, where lichen could not survive and soot covered the tree trunks and rocks, the dark form was better adapted to survive predation.



(a) (b)

Figure 6.9 The influence of background colour on the survival of different coloured peppered moths. Can you see the white moth on the lichen-covered bark in (a)? Which moth is the most difficult to see in (b)?

In this case both biotic (predation by birds) and abiotic factors (level of industrial pollution) influence the particular colour form of the peppered moth in a specific location.

SUMMARY

There is constant interaction between an organism and its abiotic and biotic environment. Abiotic features of a habitat are directly or indirectly related to climate and soil conditions. Symbiotic relationships and the ability to be camouflaged or mimic another species are important biotic influences.

Australia's unique plant forms have resulted from adaptations to specific physical conditions, which include:

- a long history of isolation from other continents
- climatic changes over time, resulting in a large proportion of the country prone to drought
- increasing fires, particularly in the last 50 000 years
- nutrient-poor soils.

Xerophytes are plants adapted to living in areas with low water levels. They often have hard, tough leaves or are succulent. Sclerophytes are plants adapted to living in areas of nutrient-poor soils and frequent fire, and are often water stressed. These also have tough, hard leaves. Mesophytes are plants adapted to high-rainfall areas where soils can retain moisture.

Review questions

6.1 Distinguish between:
(a) abiotic and biotic
(b) habitat and environment.

6.2 Abiotic factors in an environment can be classified in different ways. Regroup the factors listed in this section (e.g. temperature, water etc.) under the headings 'Energy', 'Physical' and 'Chemical'.

6.3 Resources are everything that a particular organism needs to survive. List general resources required by the human species under the headings 'Biotic' and 'Abiotic'.

6.4 Refer to Question 1.2 on page 4 to answer the following questions:
(a) In what type of habitat does the red kangaroo live?

?

(b) What abiotic factors in the environment control where it is found?

(c) What biotic factors control where it is found?

(d) What are its natural enemies?

(e) How does it survive unfavourable conditions?

(f) To what extent do its structure, physiology and life history:

(i) make it adapted to its natural environment?

(ii) limit its ability to exploit its habitat?

6.5 Camouflage may be an adaptation to a biotic or abiotic factor. Give an example of each.

6.6 List abiotic differences between the habitat of an east-facing slope compared with that of a west-facing one on the eastern Australian coast. How would these differences influence plants growing on them?

6.7 What factors contributed to the evolution of the plants unique to Australia?

6.8 Distinguish between a xerophyte and a mesophyte.

6.9 The vast majority of Australian plants are sclerophytes.

(a) Define the term 'sclerophyte'.

(b) To what primary environmental factor are these plants adapted?

(c) Why was this a significant adaptation for Australian plants?

6.10 Which

(a) biotic factor(s)

(b) abiotic factor(s)

contributes to the predominant colour of the peppered moth in a locality?

6.11 Why did the researchers release the same number of light and dark moths into both a polluted and an unpolluted locality?

6.2 The environment shapes organisms

Distribution (where a particular species is found) and **abundance** (number of the species in that locality) are directly influenced by all of the biotic and abiotic conditions of that species' environment.

Organisms coexisting in a particular locality at a particular time make up a community. For example, all the marine plants and animals found on a coastal rock platform make up a rocky shore community; but the composition of the community can change, because sand may be washed into the rock pools for periods of time but be absent at other times. A community of organisms and their environment interacting as a unit is termed an **ecosystem**. Ecosystems are often named after their most dominant feature: for instance, an open forest ecosystem, a desert ecosystem, a wallum ecosystem.

As Case study 6.2 has shown, changes in either an abiotic or a biotic factor may change the overall composition of an ecosystem. Case studies 6.3 and 6.4 illustrate how the abiotic and biotic environment shape the organisms in any particular habitat.

Case study 6.3: Wallum heathland

Wallum is the name given in Queensland to a type of country and a type of vegetation found close to the sea. These areas have poorly drained sandy flats interspersed with low sandy ridges, and sometimes slightly higher gravelly rises. The sandy flats may be rich in humus. Layers impervious to water often form and the area becomes swampy. Wallum grows in areas of high rainfall where soil is naturally low in mineral nutrients, particularly nitrates and phosphates. The term 'wallum' refers to the most obvious tree of the area, a banksia known as the wallum oak (*Banksia aemula*).

The plants of the flats are typical of any heathland, comprising stunted trees (particularly banksias) which are rarely more than 2 m in height, boronias, heath, small-leafed tea-trees, bush peas, Christmas bells and vanilla lily. The low sandy ridges carry banksias and other low trees including she-oaks, wedding bush and bush peas. The higher ridges can support eucalypts, particularly scribbly gum, bloodwoods and ironbarks. Where conditions are swampy, melaleucas (tea-trees) dominate, and patches of rainforest may occur along moist gullies.

Several factors control the vegetation of the wallum.

Low-nutrient soils

The plants show various adaptations to lack of nutrients:

- Wattles harbour nitrogen-fixing bacteria in root nodules.
- Mycorrhizal fungi grow in association with the roots of many species.
- Extensive, shallow root systems maximise absorption of minerals and moisture.
- Lignotubers (swollen roots) store excess nutrients and/or water.
- Some plants, such as the sundew, are insectivorous.

Figure 6.10 Plants of the wallum

(a) low trees

(b) Shrubs

A. (*Persoonia*) 1. flowers 2. fruit; B. Wallum wedge pea (*Gompholobium*); C. (*Phebalium*); D. Yellow pea (*Phyllota*); E. Boronia (*Boronia*); F. (*Pultenea*); G. Paperbark (*Melaleuca nodosa*); H. Teatree (*Leptospermum petersonii*); I. Wedding bush (*Rhynocarpus*); J. Drumsticks (*Isopogon*)

(c) Herbs

1. Purple violet (*Viola betonicifolia*); 2. Milkmaid (*Burchardia umbellate*); 3. Fringed lily (*Thysonotus tuberoses*); 4. Flag lily (*Patersonia glabra*); 5. Slender rice flower (*Pimelea linifolia*); 6. Dogwood (*Jacksonia stackhousii*); 7. Heath (*Epacris*); 8. Sundew (*Drosera*); 9. Wallum heath (*Epacris pulchella*); 10. Curly sedge (*Restio*)

Water stress

Plants experience water stress when there is too little or too much ground water present for their normal life functions. There can be water stress in wallum areas for the following reasons:

- The predominant rainfall is in the summer months and there can be prolonged periods of drought at other times.
- Soils tend to be sandy and thus do not retain moisture.
- Highly leached sandy soils tend to have an underlying hardpan of clay which severely restricts water penetration, resulting in large surface run-off. In some flat areas, absorption of water by the hardpan can result in waterlogging.
- Seasonal flooding of flats decreases the oxygen content of the soil. The root cells need oxygen to survive and transport materials to the rest of the plant. Low levels of soil oxygen, therefore, reduce the uptake of water and mineral nutrients by the root hairs.
- Summer is characterised by long hot days, with persistent prevailing winds which increase evaporation of water from both the soil and the plants themselves.

Some adaptations of wallum plants to water stress include:

- a large root system (surface and deeper) to collect and store water
- stiff, leathery leaves (sclerophylly). Broadleaved forms angle the leaf blades, reducing direct exposure to the sun; leaves tend to be lightly coloured, increasing reflection of light.
- small, narrow leaves in many species, reducing the surface area from which water is lost
- sunken stomata in some, rolled leaves in others
- the presence of hairs on the undersurfaces of the leaves of some plants (e.g. *Banksia robur*), slowing air movement and thus evaporation from the stomata
- upwardly directed leaves and branches which channel rainwater to the base of the tree (e.g. *Hakea*); generally stunted aerial growth.

Fire

Fire is a common phenomenon of heathlands and has played a significant role in eliminating potential colonisers. Two survival strategies are used by heath plants: fire-tolerant plants and fire-resistant seeds.

Fire-tolerant plants are adapted to withstand the ravages of fire. They may:

- produce oils and tannins which result in rapid fires with little chance of damage to inner tissues (e.g. *Leptospermum*)
- possess papery bark which contains large amounts of water (paperbarks), reducing damage to tissues
- have dormant buds or lignotubers which can grow after the fire
- regrow from underground tubers, rhizomes or bulbs
- have thick bark (e.g. banksias) which prevents fire damage to underlying tissues.

Usually heathland plants which are not themselves fire tolerant produce fire-resistant seeds protected by hard woody capsules which are opened only by the heat of a fire. These plants thus not only have a means of surviving fires but rely on them for the germination of their seeds (e.g. *Hakea* and *Banksia*).

Some plants of the wallum are illustrated in Figure 6.10.

Case study 6.4: The introduction of honeybees to Australia

Honey is an important human food. Native bees do not produce as great a quantity of honey as their European relatives, nor are they as amenable to domestication. Thus the honeybee was brought into Australia during times of early European colonisation. A more robust species, honeybees are able to forage widely and are not selective in the flowers they visit.

A mutualistic relationship has evolved between some native species of bees and rainforest trees. These bees, while gaining a food resource, are the sole pollinating agent for particular tree species. Introduced honeybees, due to their size, are able to obtain the nectar from these flowers without picking up pollen. They are also more competitive in obtaining the nectar. As a result there has been a decline in native bee species in some rainforest areas of Queensland.

Biologists are concerned that rainforest tree species will eventually die out as the result of diminished reproduction. As old trees die, they will be replaced by other species which are not pollinated by native bees. Over time, the composition of the rainforest vegetation and thus the animals adapted to live in it could be dramatically altered, with the extinction of a far-ranging number of species.

Other vegetation communities, such as heathland, are also affected. A recent survey has shown that the invasive actions of the honeybee have resulted in a decrease of up to 50 per cent in pollination of bottlebrushes (*Callistemon*).

6.2.1 Changes in the composition of communities

Changes in the composition of communities may be short-term or long-term. Annual plants are usually adapted to a particular season, responding either to rainfall patterns or to temperature. Thus certain species will be present at different times of the year.

Temperature changes affect land plants and animals more than water organisms because changes in land air temperatures are greater and more rapid than changes in water temperatures.

Many animals respond to seasonal temperature changes and the associated changes in plant life by migrating to new areas to escape adverse conditions. Migratory animals (particularly birds and fish, which may travel enormous distances) are believed to use a variety of navigation aids which may include celestial clues (sun or stars) and the earth's magnetic field which varies geographically.

Other animals respond to changes in climate and food availability by going into a state of torpor. Torpor involves lowering the body temperature and metabolic rate, and thus energy use and activity, of the animal. The length of time that this state can be maintained varies from organism to organism. The feathertail glider can sustain this condition for only 48 hours, whereas some tortoises can remain torpid for up to 6 months.

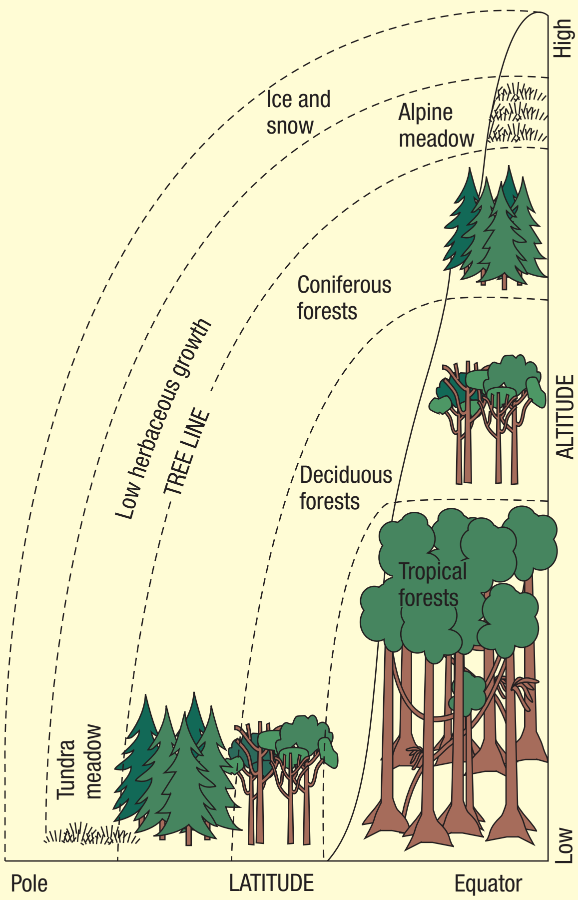


Figure 6.11 Latitudinal zonation is paralleled by altitudinal zonation.

Temperature varies with altitude and latitude. It decreases from sea level upward and from the equator north and south to the poles. These temperature changes result in changes in wind, rainfall and humidity and thus different distributions of life forms. There is, therefore, a continuous progression of community types from the equator to the poles (**latitudinal zonation**) which is paralleled by changes in communities with height above sea level (**altitudinal zonation**).

SUMMARY

The interactions between the abiotic and biotic components of an environment are constantly changing. This influences:

- where particular species are found;
- the numbers of any particular species in an area; and thus
- the type of community found in any particular locality.

Review questions

6.12 To what does the term 'wallum' refer?

6.13 Describe two plant adaptations to each of the following:

(a) low-nutrient soil

(b) water stress

(c) fire.

6.14 Discuss factors which could bring about seasonal changes in community composition.

6.3 ORGANISMS INFLUENCE THEIR ENVIRONMENT

All organisms require specific resources, which include food, to survive. They must obtain nutrients, and eliminate unwanted substances, which are usually different from those taken in.

The bandicoot (*Isoodon macrourus*) digs up the ground both in nest formation and in its search for food. It eats insects, spiders and earthworms as well as berries, grass seeds and plant fibres, and respires aerobically. The undigested organic matter eliminated and metabolic wastes excreted are different from materials taken in. Thus the bandicoot has an effect on both plants and animals, as well as contributing to changes in the physical and chemical aspects of its environment.

Organisms therefore bring about changes in their environment because they may:

- provide food for others
- provide a habitat for others
- eliminate waste
- remove water
- add organic matter
- absorb light
- take in food from others
- use others for a habitat
- alter carbon dioxide levels
- remove minerals
- provide shade
- alter oxygen levels.

Case study 6.5: Colonisation of Rakata

In a series of violent volcanic eruptions in 1883, much of the island of Krakatoa (between Sumatra and Java) was destroyed. All life on the remainder (now called Rakata) and nearby islands was buried under a deep layer of hot ash and pumice stone. In 1930 a new volcanic island arose from the sea nearby. Since it originated from the sunken crater of Krakatoa, it was named Anak Krakatoa (Krakatoa's child).

These two islands have been the subject of considerable investigation since they provided natural laboratories for observing colonisation of bare land, relatively free from human interference.

On Rakata, the first plants to become established in the volcanic ash were grasses. The seeds could have been wind-blown from Sumatra or Java, or accidentally carried by birds (attached to their legs or feathers). By 1930 much of the grassland had been replaced by she-oak woodland and trees of the open forest. In parts of the forest the canopy (upper leafy layer) was beginning to close over as a result of colonisation by new tree species. A closed canopy is typical of rainforest. Light penetration to the forest floor is obscured by the heavy foliage of these trees, limiting the growth of plants (grasses, herbs and shrubs) in these areas.

By 1980, however, the extent of the closed forest was still limited. The animal life on the island, too, is restricted to those which can cross the water. Thus insects, birds, bats and a few reptiles (presumably crossing to the island on organic debris) form the nucleus of the island fauna. Their survival on the island was dependent on the availability of suitable resources.

6.3.1 Succession

The change observed from bare volcanic ash to closed forest on Rakata is a process called **primary succession**. Colonisation is initiated by the dispersal, usually by wind, of spores or seeds of hardy autotrophs (**pioneer species**). These autotrophs are able to survive in areas in which limiting factors probably include very high light intensity, and low water-holding capacity of the soil due to lack of organic matter.

Lichens are often the pioneer species of bare rock. A product of their metabolism is an acid which may cause the rock to become eroded. Temperature differences (day and night, or seasonal) cause expansion and contraction of the rocks, creating cracks and fragmentation. As lichens age and die, bacteria break them down, small amounts of organic matter can collect in the rock cracks, and thus soil begins to form.

The gradual build-up of soil makes these places unsuitable for the rock-dwelling lichens but suitable for the colonisation of mosses. Further soil enrichment is provided by the decomposition of the mosses as they die. More complex plants are then able to grow, progressing from ferns to grasses, to shrubs, to small trees and finally a forest.

With changes in vegetation there are changes in the animal life found in the area. Bacteria and worms become more abundant in the ever-deepening soil. Insects and birds above ground level aid dispersal and pollination of flowering species of plants. Denser vegetation provides habitats for reptiles and mammals, and so on.

Succession occurs on sand and coral islands. The area near the sea, just above the high tide level, is not an easy place for plants to live. Spray is blown onto them by the wind, and fresh water is in short supply. The sand is unstable and tends to move with wind action. A few plants are able to cope with these conditions and begin to colonise the area. These pioneer plants include the grass *Spinifex hirsuta*, which sends out runners, and the prostrate creeper *Ipomoea pes-caprae*. Once established, the pioneer plants trap wind-blown sand around them and the dune begins to build up and stabilise.

Stabilised areas which are out of direct contact with sea water can support other species of plants such as *Pandanus*, *Casuarina* and stunted wattles and banksias. These plants increase the humus layer within the sand and the soil is able to retain moisture better. Wattles, through their symbiotic nitrogen-fixing bacteria, also add nitrogen to the soil. Blady grass (*Imperata cylindrica*), couch and vines such as *Hibbertia scandens* form the ground cover in these areas.

Animals living in and on these plants add to the nutrient value of the soil through their excretions and decomposition when they die. With further

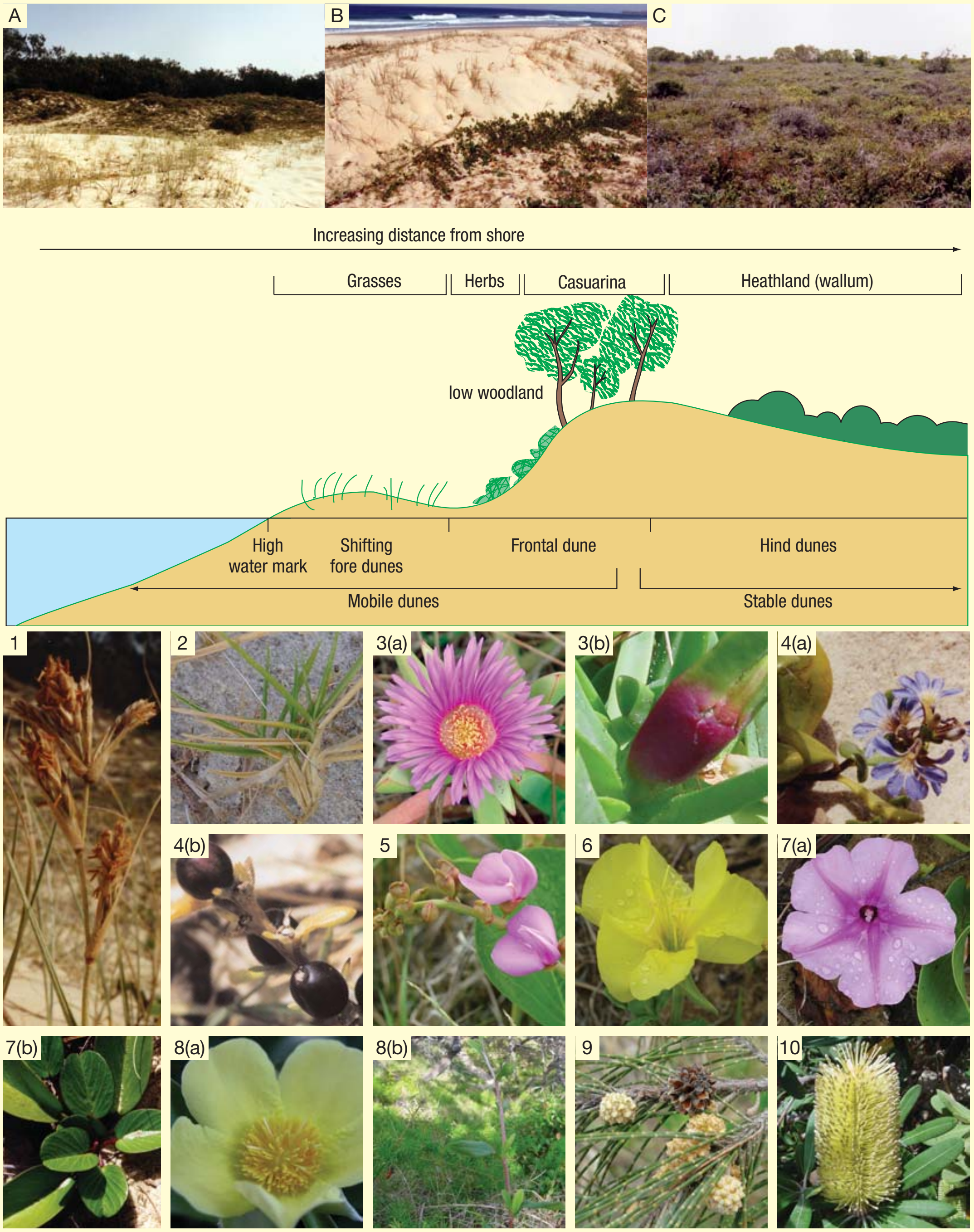


Figure 6.12 Sand-dune zonation

A fore dune B swale between fore and hind dune C wallum on hind dune

1. Hairy spinifex (*Spinifex sericeus*), male flower
2. Prickly couch (*Zoysia macrantha*)
3. Pigface (*Carpobrotus glaucescens*) (a) flower (b) fruit
4 Scented fan flower (*Scaevola calendulacea*) (a) flower (b) fruit
5. Coastal jackbean (*Sanavalia rosea*)
6. Beach evening primrose (*Oenothera drumondii*)
7. Goat's foot (*Ipomea pes-caprae*) (a) flower (b) leaves
8. Snake vine (*Hibbertia scandens*) (a) flower (b) vine
9. Coast she-oak (*Casuarina equisetifolia*)
10. Honeysuckle oak/coastal banksias (*Banksia integrifolia*)

increases in humus, and thus water retention, other plants such as heath and forest species can grow. The community seen inland will depend upon general climatic conditions, the humus build-up in the soil and the seeds dispersed by birds, ocean currents and wind.

A walk from an open sandy beach on the mainland, across the dunes to forest behind, shows different zonations. These zones are often described as illustrating the stages of succession through which the vegetation behind the dunes would have passed during their development. Other scientists claim that these zones merely reflect different environmental conditions. Since the zones along the coastline remain fairly stable over time, it is most likely that they result from gradients in salinity, wind, availability of fresh water and erosion from storms as distance from the surf increases.

During succession, each step changes the abiotic and biotic conditions of the environment. This paves the way for another species to colonise the area. For example, larger plants cast shadows that result in subtle changes in temperature, moisture and light in some parts of the community. These slight differences result in the formation of **micro-environments** which will support some species but not others. Finally, a stable stage comprising a complex community is reached. Usually a particular plant, the **dominant species**, is prevalent. This stage is termed the **climax community**, since it tends to remain much the same over long periods of time.

When the dominant species of a plant community is removed (e.g. by natural disasters such as fire, disease or violent storm activity, or from interference by humans) and the area is left to natural interactions, **secondary succession** will occur. Abandoned grazing land will become overgrown with weeds and small shrubs and trees such as wattles. Eventually the wattles will be replaced by the climax open forest community. Secondary succession is invariably faster than primary succession, because there is an existing soil, and species of plants and animals are usually already present in the area that is being colonised.

A **disclimax community** results from degradation of a community due to activities of organisms. Typical of this process are the changes resulting from overgrazing of natural grassland. As grasses are depleted, the water cycle (evaporation from plants, condensation and rain) is disrupted, and the area becomes even more arid than normal. The grasses have soil-binding roots which aid in preventing wind and water erosion. As the grasses decrease, erosion increases and this accelerates the change process. Ultimately only desert plants can survive in the area. Grazing practices in Australia have resulted in this country having the highest rate of **desertification** in the world.

SUMMARY

The activities of organisms affect their environment. These changes often make the environment suitable for another species which may move in and replace the original inhabitants. Primary succession refers to community changes over time from bare ground to a stable climax community. Secondary succession occurs when a community is disturbed in some major way. Disclimax communities result from degradation of the environment.

Review questions

6.15 Describe how the actions of organisms can influence the environment.

6.16 Define the following terms:
- (a) pioneer species
- (b) climax community
- (c) disclimax community
- (d) primary succession
- (e) secondary succession.

EXTENDING YOUR IDEAS

1. UB The mammals of the wallum area tend to be small and are either insectivorous or eat fruit, flowers and nectar. Honeyeaters and small insectivorous birds abound and there is a great variety of lizards and snakes. Give reasons for the types of fauna found in these areas.
2. UB The Hawkesbury sandstone areas of New South Wales have climatic conditions which should sustain subtropical rainforest communities. Suggest reasons why rainforests do not exist in this area.
3. IB The sirex wood wasp, *Sirex noctilis*, lays eggs by boring holes in the trunks of pine trees (*Pinus radiata*) and depositing eggs, together with filaments of a symbiotic fungus, *Amystereum*. It is this fungus which may kill the tree. The sirex wasp, therefore, threatens plantations of *Pinus radiata*.

   Although birds kill adult wood wasps and their young, they are not able to effectively control them. Biologists have introduced two parasitic wasps to plantations, *Megarhyssa* and *Ibalia*. Both of these lay their eggs in the larvae of the sirex wasp. When the eggs hatch, these larvae eat their way through the developing sirex, so killing it. A species of the nematode worm genus *Deladenus* also parasitises all three of the mentioned wasps. It sterilises the females, which then lay only eggs packed with young nematode worms. These worms can also live in a free-living form that feeds on the fungus *Amystereum*.

(a) List all of the different types of biotic relationships described above.

(b) A field worker noticed that in an area where large numbers of *Megarhyssa* were seen, few infections of the fungus *Amystereum* were detected. Using the data, explain this observation.

(c) In an area where the parasites *Megarhyssa*, *Ibalia* and *Deladenus* had been introduced in large numbers some years previously, the existence of *Sirex noctilis* is still reported. Suggest a hypothesis to explain this observation.

4. UB The relationship between biotic and abiotic factors of an environment can be summarised as in Figure 6.13. (Insolation refers to exposure to the sun's rays.)

Using this outline, describe the interactions between organisms and their habitat for a community of your choice.

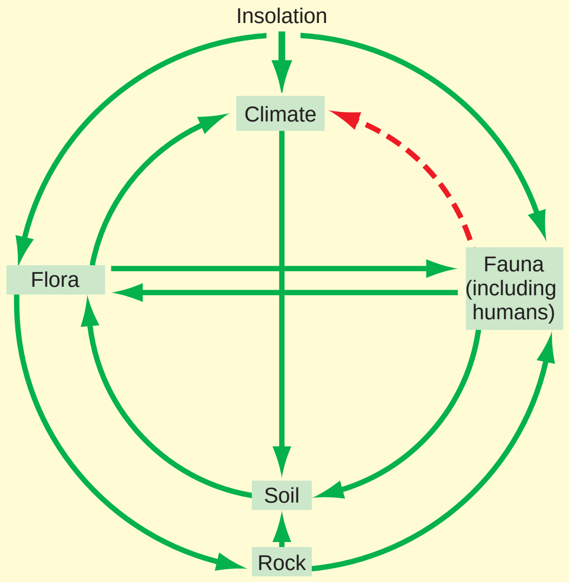


Figure 6.13 Relationship between abiotic and biotic factors in the environment

5. IB Figure 6.14 shows the distribution of wallaroos in Australia; Figures 6.15 and 6.16 provide some environmental information. Choose three of the four wallaroos and, for each, name the wallaroo and give two preferred environmental conditions for that animal.

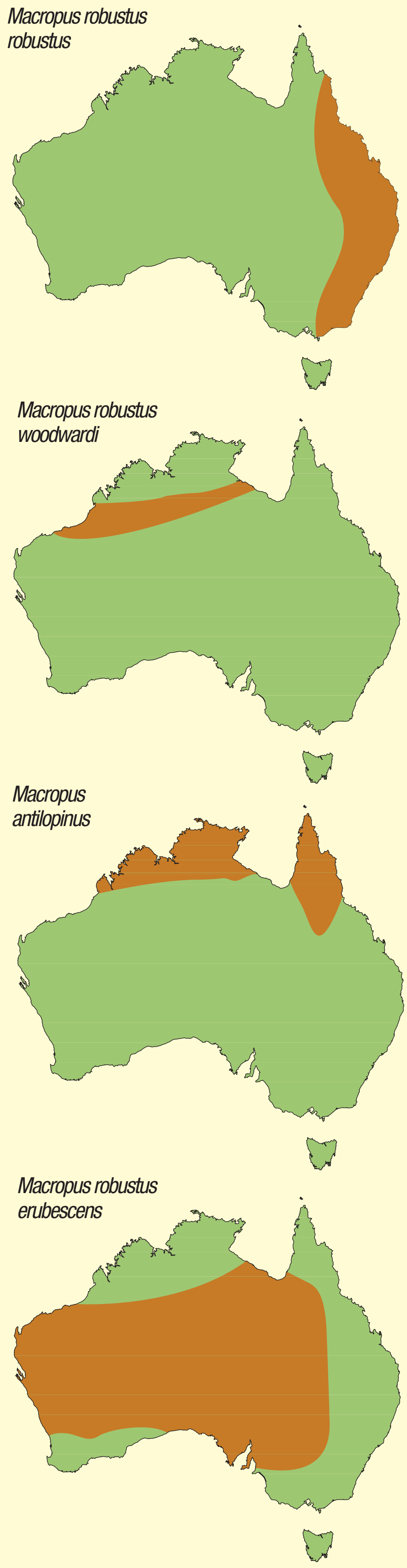


Figure 6.14 Distribution of wallaroos in Australia

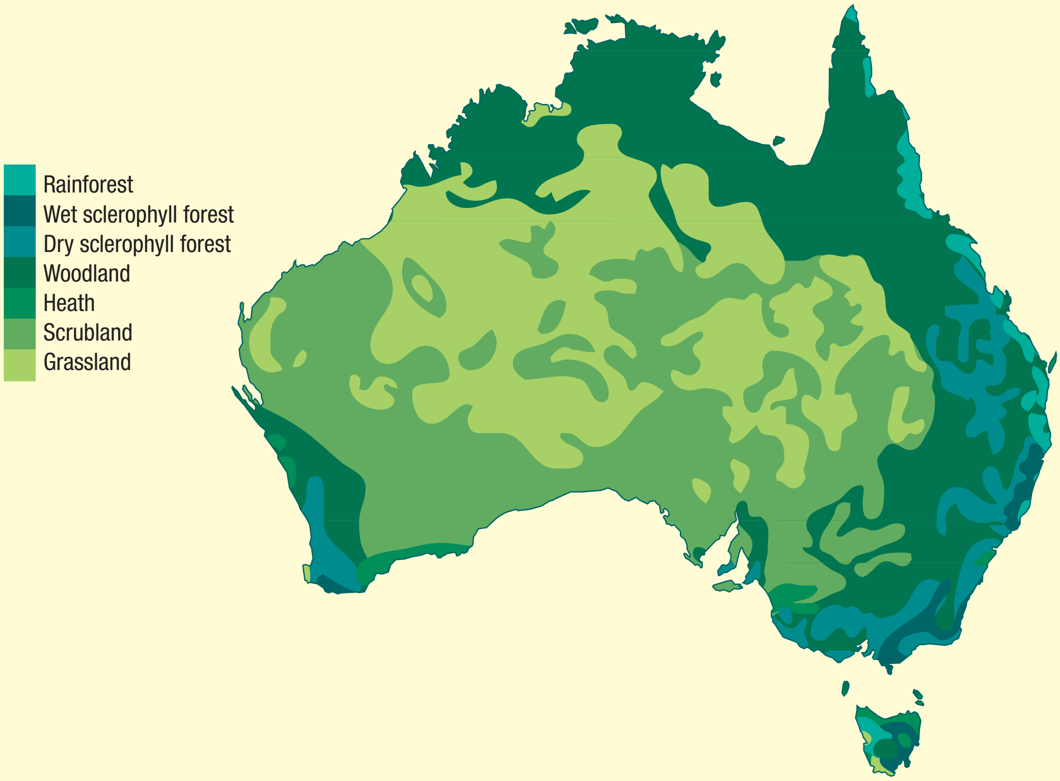


Figure 6.15 Vegetation types, Australia

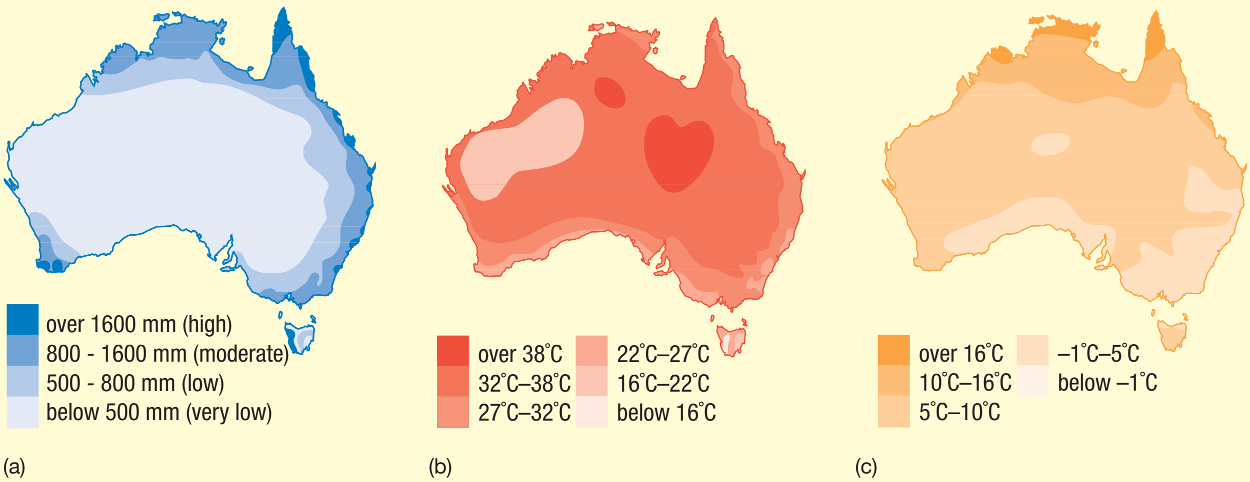


Figure 6.16 Rainfall patterns and maximum and minimum temperatures, Australia

6. Figure 6.17 shows the relationship between the temperature **IB** of the environment and the evaporation of water from three different organisms.

Given that evaporation decreases with increasing humidity, and that all three organisms are terrestrial, suggest the most likely habitat for each of these animals.

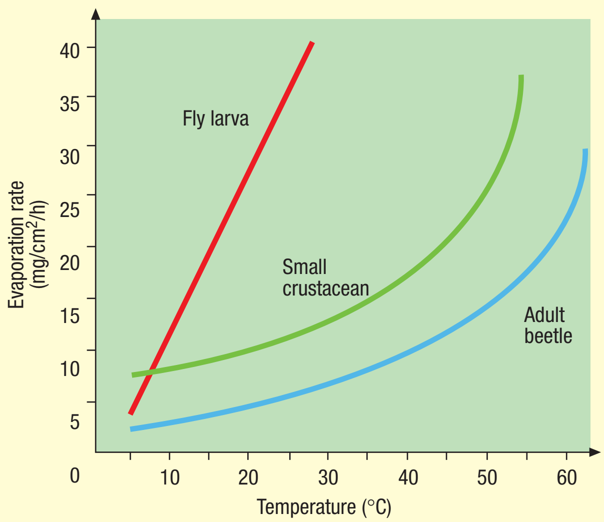


Figure 6.17 Evaporation of water from three organisms over a range of temperatures

Figure 6.18 Occurrence of bird species in Kakadu National Park at various times after fire

7. Using field or second-hand data from a sand dune study and **UB** any relevant literature, critically analyse the argument that coastal dunes in Australia display succession.

8. Different resources are used by different organisms. A study **IB** of the birds found at various times after fire in Kakadu National Park (NT) was conducted. The results are given in Figure 6.18. From these:
   (a) Suggest the resources which each group of birds utilises.
   (b) Discuss changes in community structure after a fire.

9. Choose a non-domestic animal and research its characteris- **EBI** tics and distribution.
   (a) List the abiotic and biotic features of its environment.
   (b) Construct a concept map to demonstrate its ecological niche.
   (c) Choose one significant aspect of its environment and predict the outcomes for this species if that were to change.

7 Populations

A **population** refers to the members of the same species occupying a given area at the same time. Populations of all species have some common characteristics related to environmental factors. These factors determine where the populations are found, how they increase in number and the total number of individuals.

7.1 Distribution and abundance

Distribution refers to the region in which one or more members of the species may be found; **abundance** refers to the numbers of each species in that region at that time. In any particular locality, abundance can be referred to as **population density**—the number of individuals per unit area. Both distribution and abundance are affected by evolution, through mutations which enhance the organism's ability to survive and multiply, and the rate of increase in numbers.

The individuals of a population may be distributed at random, evenly spaced or clumped in some way.

Random distribution

Random distributions are found only in uniform surroundings, and involve species that have no tendency to aggregate. Such distributions usually occur only for a short time while the resources are greater than the demand. For example, weed seeds blown by wind over a bare fertile soil will produce a random distribution of seedlings if the soil surface is even.

Even spacing

Evenly spaced distributions are also fairly rare in nature and usually result from intense competition for space. In some mature forests the large trees may have an almost uniform distribution (spaced at regular intervals) because of competition for sunlight and soil nutrients. For animals, territorial behaviour may play a significant role in even distribution.

Clumping

Clumping is by far the most common pattern of distribution of plants and animals in nature, for the following reasons:

- Environmental conditions are seldom uniform throughout even a small area.
- Reproductive patterns frequently favour clumping (e.g. young animals often stay with their parents).
- Animals often exhibit behaviour patterns that lead to active congregation in loose groups, schools, flocks and herds.

A clumped distribution may increase competition for nutrients, food, space or light, but the deleterious effects are often offset by beneficial ones. Trees growing together may compete more for nutrients and light than they would if they were spread apart, but they may be better able to withstand strong winds. For some animals (e.g. the hyena), hunting in a pack makes it possible to bring down a large prey, which a single individual cannot do. A solitary hyena must compete with other scavengers for food.

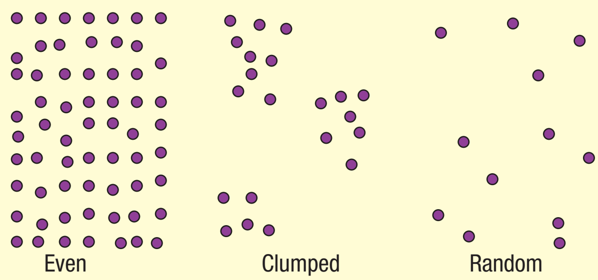


Figure 7.1 The three distribution patterns seen in nature

Case study 7.1: Possum and glider distribution in the Eden (NSW) forests

A study by CSIRO scientists revealed a patchy distribution of eight species of possums and gliders in forest in the Eden area. Sixty-three per cent were found in only 9 per cent of the forest area studied; none were found in 52 per cent of the area. Further investigation showed that there was a close correlation between the distribution of these animals and that of peppermint eucalypts. Analysis of the nutrient levels of various trees showed that the peppermints were rich in nutrients, particularly potassium, nitrogen and phosphorus. These trees, as distinct from other species in the forest, had wide tree trunk bases, were found in areas which had not been subjected to recent fire, and grew only in fertile soils. Thus the distribution of both the trees and the arboreal mammals was related to the underlying rock types which produced high-nutrient soils.

SUMMARY

Distribution and abundance of a species are measures of populations which reflect the environmental conditions that are important for their survival.

The presence or absence of a particular species in any locality can be related to many features of the environment, as shown in Figure 7.2.

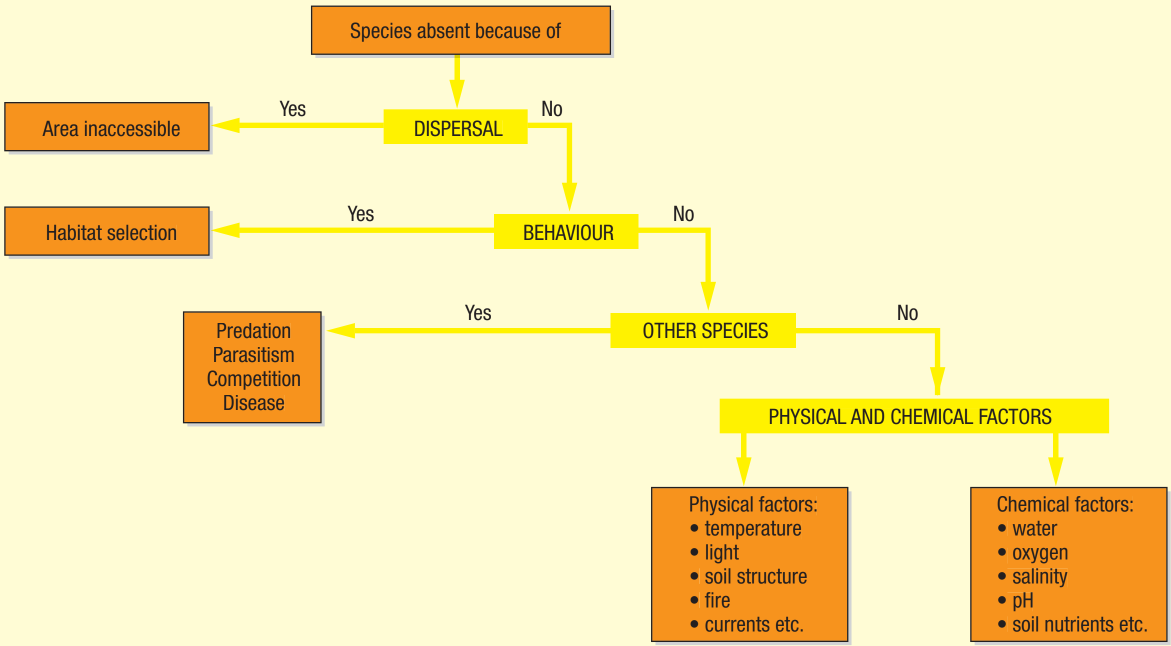


Figure 7.2 The distribution of an organism depends on both biotic and abiotic factors.

Review question

7.1 Examine the 10 m x 10 m plot shown in Figure 7.3.

(a) For each of the three plants illustrated in Figure 7.3, determine (giving reasons):

(i) type of distribution

(ii) population density.

(b) Suggest abiotic differences which might account for the distribution patterns.

(c) Which is the dominant plant?

(d) Suggest a descriptive name for this community.

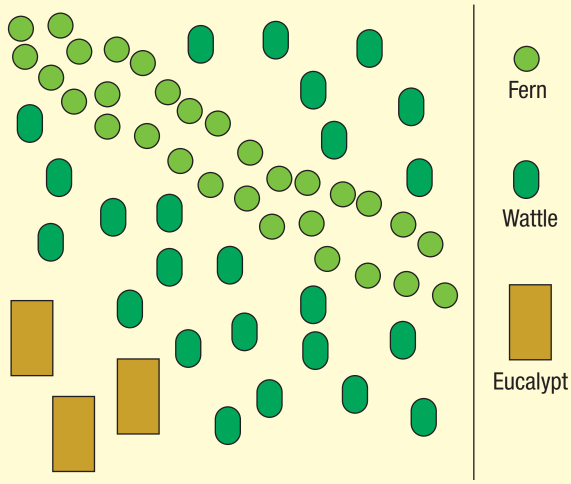


Figure 7.3

7.2 Population growth

The size of a population depends on the rates of birth, death, immigration and emigration. The rate of increase or decrease in a population, r, can be calculated by:

$$r = (b + i) - (d + e)$$

where b = number of births, i = number of immigrants, d = number of deaths and e = number of emigrants.

Population size can vary significantly from time to time, particularly in animal species. For example, there are periodic mouse plagues on the Darling Downs in Queensland. Not only do they lead to devastation of crops but they also cause considerable damage as the mice infest homes. Numbers can also decline rapidly: the mice population may be massive in April but may be insignificant in July.

Each population has specific limiting factors which influence its growth. The range of tolerance to light, temperature, available water, salinity, nesting space and required nutrients differs from species to species. Regardless of other factors, if any essential requirement is in short supply for a particular species, or an environmental feature is too extreme, the population cannot increase. It will either remain the same size or decrease.

Factors that influence population growth as the number of individuals increases are termed **density-dependent**. For example, as a population grows it may deplete its food supply, leading to increased competition for food among the members and ultimately to increased mortality or decreased birth rates. Predators may be attracted to the area and capture a significantly higher proportion of the population. Infectious diseases, too, may be spread more easily when the population density is high.

Birth rates and death rates may vary regardless of population density. Factors which bring about these changes are termed **density-independent**, and are usually associated with environmental changes. In some cases these changes are clear-cut, such as the sudden flooding of an area or destruction from volcanic eruptions. Other changes, however, are more complicated and probably have both density-dependent and density-independent components. For example, mortality resulting from a sudden temperature drop (density-independent) may mainly affect those animals that do not have a suitable shelter (density-dependent).

Examination of an isolated group of one species, neglecting small amounts of immigration and emigration, reveals a pattern of population growth. At first a new, small, active population grows slowly due to the small numbers of individuals involved. Since there are few individuals in a suitable environment, resources will be plentiful and predators, parasites and disease will be low. Those factors which would normally inhibit population growth—**environmental limiting factors**—will be non-existent, and as a consequence the death rate will be very low. This can lead to exponential growth of the population, where the number of individuals increases at a constant rate. This is because the new members of the population contribute their powers of reproduction as well as adding to the numbers by their own presence. The species realises its full reproductive **biotic potential**. If this were to continue indefinitely, the population would continue to rise without limit, as shown in Figure 7.4.

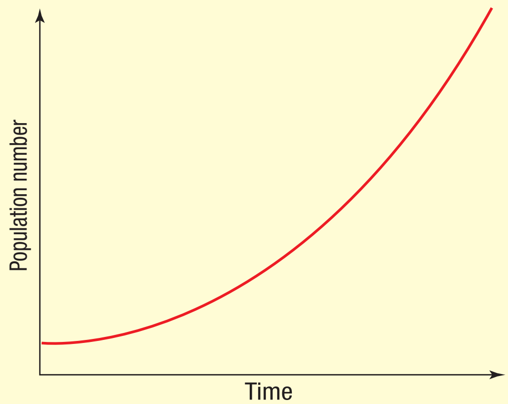


Figure 7.4 Exponential growth of a population. After an initial slow phase the population grows at a constant rate.

The house fly (*Musca domestica*) can produce seven generations in 1 year. Each female can lay 120 eggs. On the assumption that each fly lives only one generation, and that half the eggs hatch into females, a total of 5 598 720 000 000 flies can be produced in 1 year from one original pair of flies. This is prevented by **environmental resistance** (the sum total of all environmental limiting factors) such as lack of resources, increase in predators, parasites and disease, accumulation of toxic wastes or other factors such as overcrowding. Each environment has a particular **carrying capacity** for the population—the number of that species which the environment can sustain.

After the initial unrestricted growth of the population, two different types of population growth can be identified. Some species continue the rapid growth until either they are above the carrying capacity of the environment, or some climatic factor dramatically reduces the population or most migrate. This results in a 'J'-shaped curve—a 'boom and bust' situation (Figure 7.5). In nature, short-term growth patterns of this type are characteristic of opportunistic species, such as weeds or insects, which invade an area, rapidly use up the local resources and then either enter a phase of dormancy or move on.

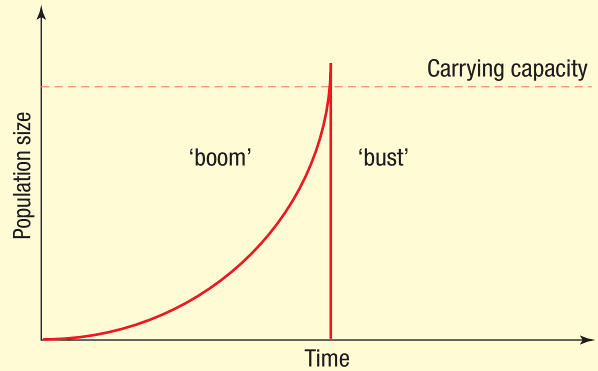


Figure 7.5 Population growth curve of the flour beetle, *Tribolium sp*. (density-independent)

In other species the increasing density of the population smoothly slows down the rate of growth as environmental resistance increases, and the carrying capacity is reached. The results are reflected in the formation of an 'S'-shaped curve. For animals the carrying capacity may be determined by factors such as available shelter or nest sites, while for plants access to sunlight might be the limiting factor. This type of growth pattern is typical of species which are density-dependent (Figure 7.6).

There is usually a time lag before the organisms respond to environmental resistance, which may be limited by individual growth rates, or by the gap of a generation before reproduction rate decreases. More typically, therefore, the population growth curve fluctuates around the carrying capacity. Figure 7.7 shows this pattern.

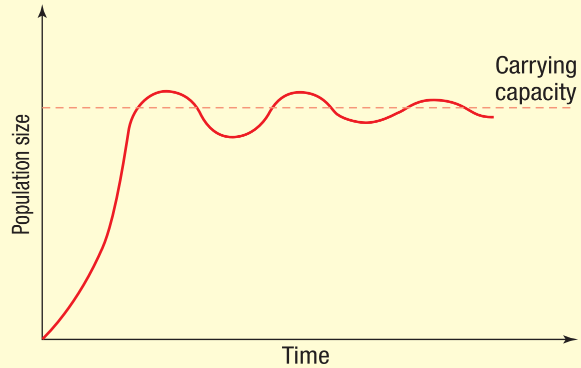


Figure 7.7 Typical response of a density-dependent population at carrying capacity

For a given species in a particular environmental situation there will be a certain optimum population which the environment can support. This is the **norm** or set point. If the population rises above the norm, competition, predation or increased disease takes place to such an extent that the population falls. If it falls below the norm, environmental resistance is relieved temporarily and the population again rises. Thus the population will tend to fluctuate around a set point, as shown in Figure 7.8. This is an example

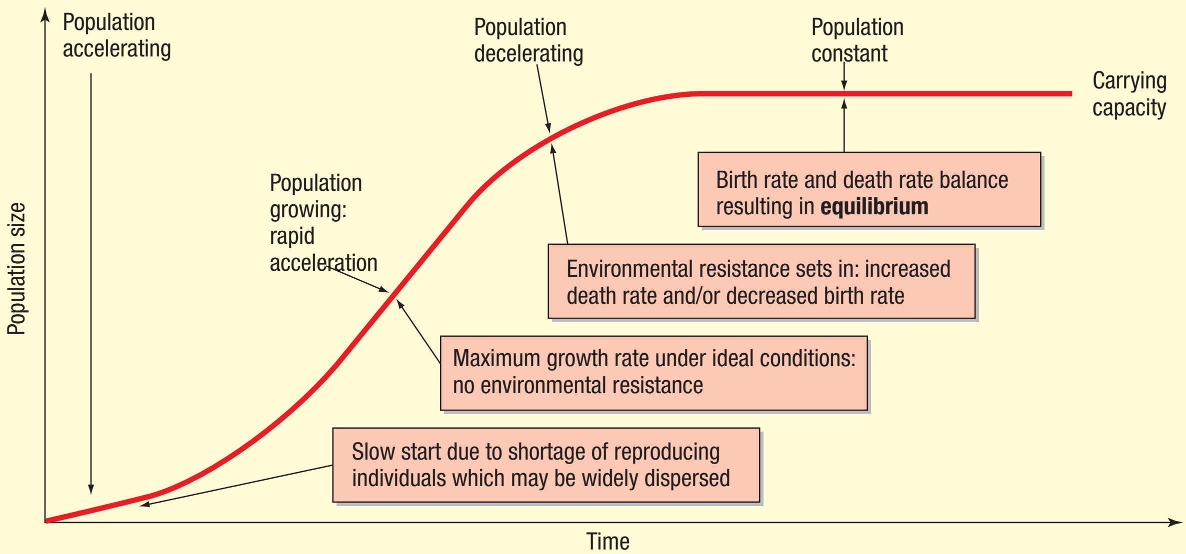


Figure 7.6 Generalised graph of density-dependent population growth

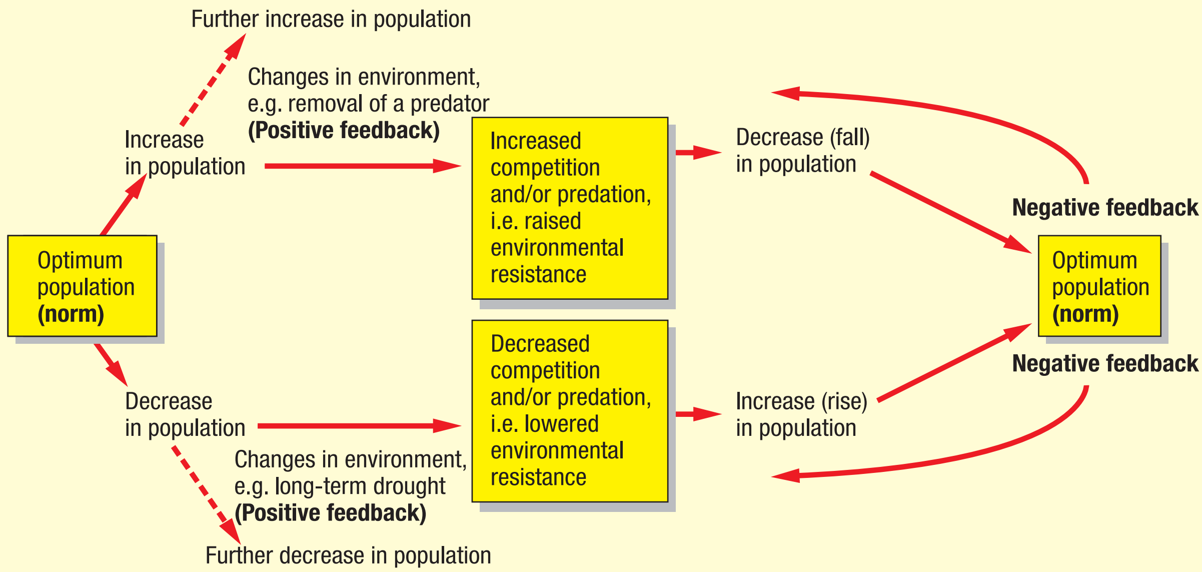


Figure 7.8 Homeostatic control of population growth

of homeostasis. An increase or decrease in population sets into motion reverse processes (**negative feedback**) which keep the population at the carrying capacity of the environment.

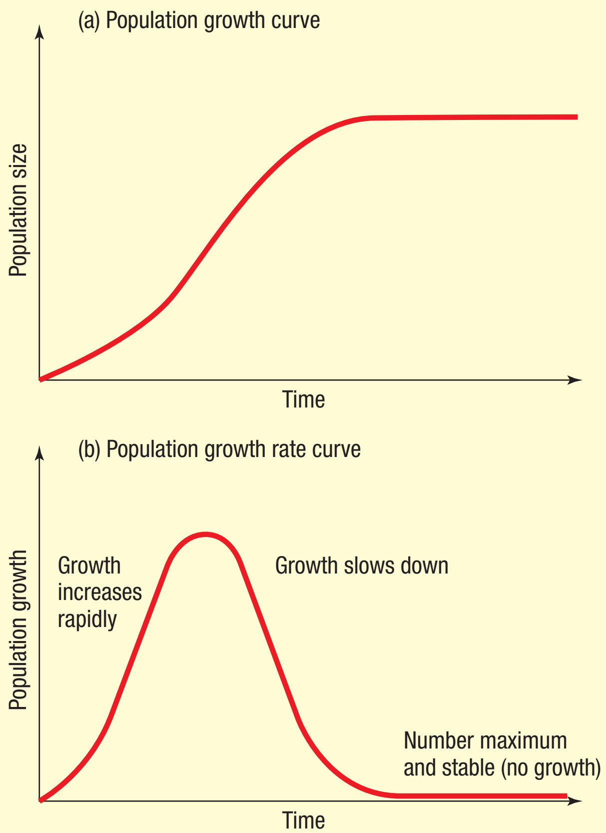


Figure 7.9 Comparison of (a) the growth curve and (b) the growth rate curve for the same population

Population growth is often expressed as the rate of increase (or decrease). The graphs in Figure 7.9 show the relationship between population growth (actual numbers in the population) and population growth rate (change in numbers in the population).

SUMMARY

Population growth (the rate of change of which is a measure of birth rate, death rate, immigration and emigration) may be controlled by density-dependent and/or density-independent factors. In most density-dependent species, population size is influenced by a variety of environmental resistances and therefore fluctuates around the carrying capacity for that particular locality. As conditions change, the carrying capacity in a locality for any particular species varies.

? Review questions

7.2 Compare and contrast a J-shaped and an S-shaped population growth curve.

7.3 List resources (both biotic and abiotic) which would act as environmental resistance. Which of these resources could be classified as density-independent?

7.4 (a) What four factors determine population size for a species?

(b) At the beginning of a year, a population contained 2000 individuals. During the year 1700 individuals died, 240 migrated out of the area, 601 moved in and 870 were born. What overall change occurred?

(c) What was the overall rate of change during that year?

7.5 Define the following terms:

(a) homeostasis

(b) negative feedback

(c) environmental resistance.

7.3 Competition

Competition is one of the chief density-dependent limiting factors on population size. The continued healthy existence of most organisms depends upon utilisation of some resources that are in limited supply, such as food, water, space or light. As the population density increases, the competition for these resources becomes more intense and thus limits the increase in population size. This competition may be interspecific or intraspecific.

The **competitive exclusion principle**, developed by Gause, states that two species cannot simultaneously occupy the same **niche** (i.e. have exactly the same requirements and thus the same role in a community) in the same place for very long. One species or the other would use the resources more efficiently and thus reproduce more rapidly. This would result in the elimination of the inferior competitor.

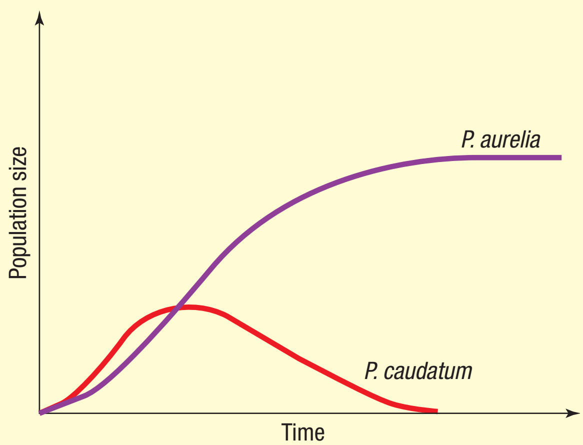


Figure 7.10 Effect of competition between two species of *Paramecium*, *P. caudatum* and *P. aurelia*, both of which have very similar niches

The more similar the two niches are, the more likely it is that both species will utilise, in common and in the same way, at least one limited resource. Competition will therefore occur between them. Gause's principle, based on laboratory observations, suggests that only dissimilar species would be found together in natural communities.

In reality, many species with similar requirements and lifestyles coexist in an area. The niche of any particular species is difficult to determine in natural conditions since it is an expression of the total environment and way of life of all the members of that species in the community. Its description includes:

- physical limitations (temperature range, water requirements etc.)
- nature and amount of food and other resources (nest sites, shelter etc.)
- behaviour patterns (type of movement, daily or seasonal rhythms etc.).

Competitive superiority may depend upon abiotic environmental conditions. Thus when flour beetles are kept together in the laboratory, *Tribolium castaneum* is superior when the conditions are hot and humid, but *T. confusum* is superior in cool, dry conditions. In natural conditions this would result in the two species having different ranges.

If two species have very similar requirements and lifestyles, there are two possible outcomes:

- One species may be competitively superior to the other, leading to the rival's extinction in the area.
- The two species may undergo evolution which results in minimising competition by allowing exploitation of different niches. Divergence in those characteristics that overlap is known as **character displacement**. This may lead to **resource partitioning**, with at least one significant difference in resource requirements between the similar species. For example, the restless flycatcher (*Myiagra inquieta*) hovers a metre or so above the ground, emitting a grinding call which disturbs insects. It then suddenly becomes silent as it pounces on an insect which it takes back to a perch to eat. The leaden flycatcher (*Myiagra rubecula*) takes insects from the leaves of trees or chases and captures flying insects. Thus the two species, whose requirements are otherwise similar, are able to live together in the same woodlands and open forests along the east coast of Australia.

SUMMARY

Competition for resources in any particular locality may be interspecific or intraspecific. The more similar the niche of two species in any particular locality are, the greater is the likelihood of:

- extinction of the less competitive species
- resource partitioning
- character displacement.

Review questions

7.6 Define the following terms:
(a) niche
(b) resource partitioning
(c) character displacement.

7.7 What is the competitive exclusion principle?

7.8 Many species living in the same area appear to have the same resource requirements. How can they coexist in this community?

7.4 Predator–prey relationships

Predator–prey relationships can be significant as limiting factors for each of the species involved.

The population size of desert mice is normally limited by the scarce supply of food (grass seed etc.) and by the brown hawk, which preys upon it. At cyclic intervals the desert is inundated with water carried to it by channels from areas that receive monsoonal rain. The increased water supply leads to rapid growth of plants, allowing the mouse population to increase dramatically. The sudden abundance of mice can result in the immigration of hawks from surrounding areas and a greater survival of hawk chicks. This decreases the mouse population. The hawk population can no longer be sustained by the decreased food supply and so they must either emigrate from the area or starve. Removal of the predation pressure allows the mouse population to return to the norm for the environmental conditions, until another influx of water to the area results in another large increase in population size and sets off the cycle again.

Usually the relationship is not as simple as this, since few organisms rely on a single source of food. A decrease in one source of food for the predator is often offset by an increase in another. Similarly, it has been shown that in natural situations predation does not necessarily reduce the number of prey below the carrying capacity of their environment, even though it may alter the age structure of the population because young, diseased or aged members are more easily captured. It has been argued that sudden declines in numbers may be associated more with the stress of overcrowding (which may result in a decreased reproductive rate), or with a timelag in response to density-dependent factors, than to predation.

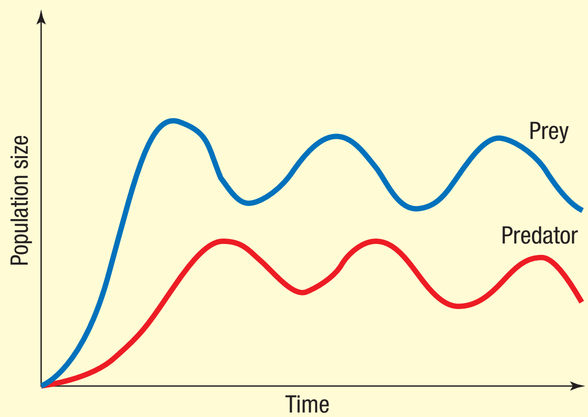


Figure 7.11 Predator–prey relationships

SUMMARY

Although predator–prey relationships may act in limiting population sizes of both predator and prey, population size is controlled by a variety of factors.

Review questions

7.9 Many organisms undergo a periodic population explosion followed by a dramatic decline in numbers. List factors that contribute to both the increase and the decrease in numbers.

7.10 Why are predators not considered the main contributors to the maintenance of a stable population size of the prey?

7.5 The human population

It is difficult to estimate numbers of early human populations but evidence points to three major population explosions throughout human history, each associated with a major cultural change. The first explosion occurred about 20 000 years ago and was probably brought about by the use of tools which allowed more effective hunting and food-gathering techniques. At this time, however, the birth rate was still relatively low. In typical hunter-gatherer societies women are unable to conceive until they are about 20 years old and breastfeed for 3–4 years, during which time they usually do not ovulate. This behaviour pattern, probably combined with poor nutrition, leads to a low reproductive potential.

The second population explosion, about 6000 years ago, was brought about by improvements in farming and therefore increased food supplies (the agricultural revolution). Better nutrition may have led to the breakdown in the mechanisms which previously controlled birth rate. About 300 years ago, the third explosion was caused by improvements in food production, industry and medicine (the scientific–industrial revolution).

Each of these bursts is associated with a substantial shift in the population norm; the birth rate rises, the death rate falls, and the population surges up to a new level. In January 2004 the world population was estimated at 6.4 billion people. It is likely that this is an underestimate due to the difficulty of obtaining an accurate census in some countries. This is particularly the case where large numbers of transient refugees occur such as in parts of Africa. The annual growth rate is currently 1.2 per cent but even if the current trend of decreasing annual growth rate continues, it is estimated that the population will be 9.3 billion by 2050.

Humans have created the environmental changes which raise the norm. This inevitably brings new problems such as food shortages and physical overcrowding. Perhaps surprisingly, increased standards of living have resulted in a decrease in birth rate in some countries. This is probably due to a combination of factors, which may include:

- better medical care and thus decreased infant mortality, giving parents more confidence that each child has a good chance of reaching adulthood
- ready access to, and societal acceptance of, a wide range of contraceptive methods
- both parents at work
- breakdown in the extended family, leading to decreased help with child-rearing

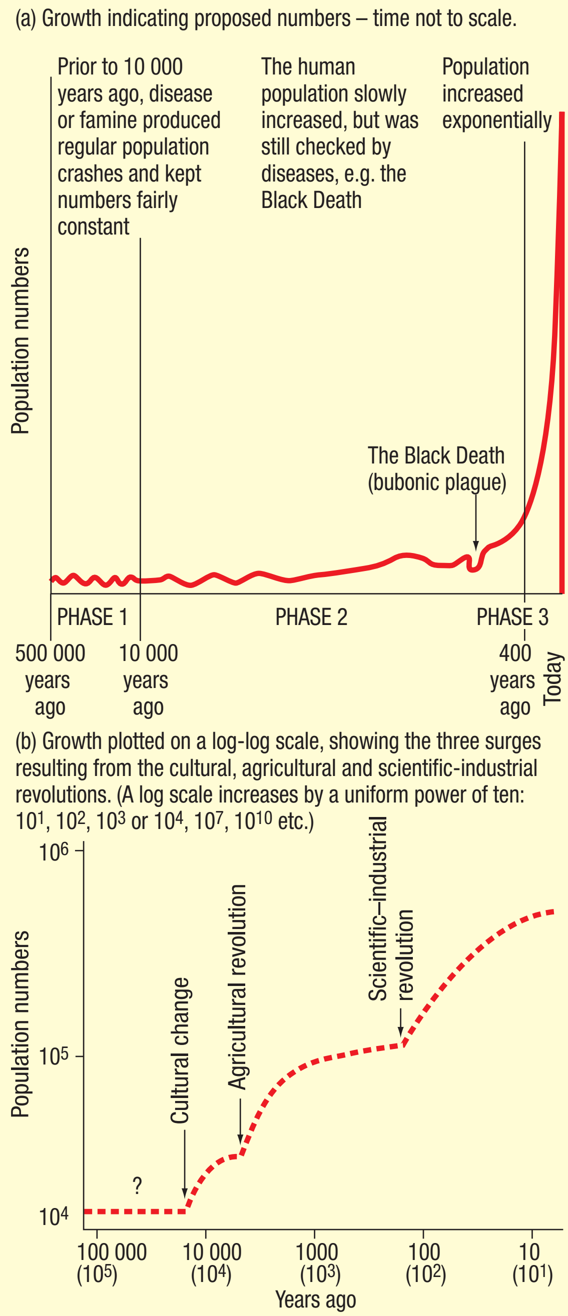


Figure 7.12 Human population growth

- encouragement from environmental groups to attain zero population growth
- the stress of overcrowding in large cities, which can decrease reproduction rate.

It has been argued, however, that a significant rise in the standard of living in many parts of the world is an unattainable goal. Thus the world population will continue to rise. To what extent, however, can the human species continue to change the environment to sustain an ever-increasing population norm?

SUMMARY

The world human population has undergone three major explosions in the past 20 000 years, each associated with a cultural change. The greatest rate of increase has occurred in the last 300 years and shows no sign of abating.

Review questions

7.11 What factors are believed to have contributed to the human population explosions that occurred over time?

7.12 List as many factors as you can that affect human survival. To what extent are these factors similar to those that affect the survival of the red kangaroo? (See data for Question 1.2, pages 4–5.)

EXTENDING YOUR IDEAS

1. **IB** It is extremely difficult to accurately determine the population density of some organisms, but an estimate can be calculated. One method used with small animals is that of capture–recapture. The animals are caught, marked and released. On subsequent occasions, more animals are caught and the number of marked versus unmarked animals are compared. The density can then be calculated.

   Work out a formula which could give estimated population density using the capture-recapture method. (*Hint:* the ratio of number marked to number unmarked will give an indication of population size; and the area over which the population was examined is important in any calculation of density.)

2. **UB** The rabbit came originally from a climate very much like that of southern Australia. Breeding begins when the first green growth comes through after winter rains, and ends when the grass dries out and summer temperatures rise. Nutrients in the green shoots are apparently essential for breeding. During a typical breeding season an adult female may produce a total of 20–25 young. Young rabbits born in winter are easy prey for cats, owls and goshawks. In the difficult summer months, with food in short supply, rabbits of all ages often have to travel long distances in search of food—a period when both young and old are killed by foxes, cats and eagles. In general, the number of deaths due to predation is balanced by the births.

   Rabbits spend the daytime hours in warrens which are cooperatively dug. The size of the warren and thus the number of rabbits inhabiting it, are related to the soil type. Rabbits do not thrive in damp ground—the young are susceptible to cold, wet conditions. In wet, poorly drained soils, rabbits do not build warrens but shelter under logs, shrubs and even in rubbish tips. Foxes and goannas can dig into warrens built in sandy soil. Mosquitoes and fleas carrying the viral disease myxomatosis, and flies carrying calicivirus can enter all warrens.

   If the size of the warren becomes too large, young males and females are driven away. Some of these may stay at the edge of the warren and breed, but their chance of survival is diminished without the protection of a warren.

   In drier inland deserts, the rabbit can still survive but desiccation, and lack of food, are added to the problem of predation. Often, with the onset of drought, these rabbits move out of the area en masse eating everything in their path until stopped by an obstacle such as a fence.

   Rabbits also inhabit mountain areas, but warrens must be built in well-drained soil and there is a great shortage of food in the winter months. The rabbits must therefore travel great distances from the warren in search of food, making them more susceptible to predators. At a time when food is scarce, the wet conditions increase susceptibility to disease, making it even more difficult for them to survive. The late spring and summer plants in the mountain regions take up little sodium, and the young rabbits born later in the season often die of sodium deficiency.

   (a) List all the density-dependent factors which affect survival of rabbits in various localities in Australia.

   (b) List the density-independent factors which affect rabbit survival.

   (c) Give examples of the way in which each of the following can affect the survival of a rabbit:
      (i) other organisms around it
      (ii) its non-living surroundings
      (iii) the activities of other rabbits.

   (d) From the descriptions given, which do you think is the most suitable environment in Australia for rabbits? Explain.

   (e) What might happen to a rabbit population in an area in which there are no predators?

3. **EBI** A knowledge of population growth curves can help in controlling pests as well as in the conservation of endangered species.

   (a) Discuss the most effective time to control a rat outbreak in a racing stables complex. Justify your answer.

   (b) A minimum viable population is the size of population below which numbers of a species must not fall if the species is to survive in the long term. How would you estimate the minimum viable population size necessary to save an endangered species such as the ghost bat (*Macroderma gigas*), the bilby (*Macrotis lagotis*) or the dusky hopping mouse (*Notomys fuscus*)? (You will need to research and evaluate the requirements of the species you select.)

4. **IB** In a study of competition among frogs, a zoologist manipulates the numbers of frogs in a number of isolated farm dams. Fifteen almost identical, initially empty dams are stocked with tadpoles at five different densities (three dams for each density) in the early spring. The number of adult frogs in each dam is determined by sampling on three successive years. The mean adult abundance for each treatment is given in the table below.
   (a) Discuss these results in the context of intraspecific competition and a variable environment.
   (b) What other experiments could be conducted to explore the possibility that resources are limiting?

Initial stocking density in each dam	Mean adult abundance for each stocking density		
	1992	1993	1994
10	8	0	0
20	30	30	80
40	60	40	100
80	60	80	100
160	20	30	60

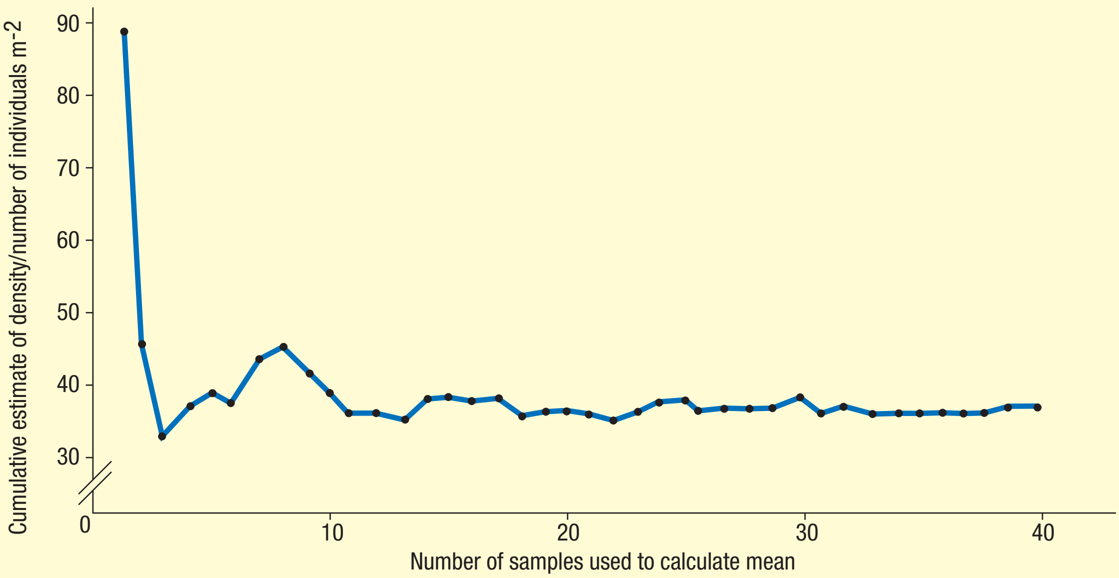


Figure 7.13

5. **IB** One method of sampling populations in an ecological study is to use a quadrat. A quadrat is an area of known size. Individuals of a population are not distributed uniformly, so if an estimate of density is to be made, a system of random sampling must be adopted. In order to determine how many samples need to be taken, it is helpful to plot the *cumulative estimate* of density against the number of samples taken. Cumulative density is found by dividing the total number of individuals per unit area by the number of samples taken. Figure 7.13 is an example of such a graph.

   From the graph, find the minimum number of samples required to give a reliable estimate of the mean density. Explain how you arrived at your answer.

8 ECOSYSTEM DYNAMICS

One of the characteristics of living organisms is that they are energy converters. They take in energy, convert it from one form to another in order to carry out life functions, and release energy. Photosynthetic organisms convert radiant energy to chemical bond energy. Heterotrophs obtain their energy from the chemical bond energy in the foods they eat. Some obtain their food from plant material; some eat other heterotrophs, or both plant and animal matter. Both autotrophs and heterotrophs display adaptations which make them efficient in capturing energy in their particular habitat.

Most heterotrophs do not digest all of the food they take in. Some of the chemical bond energy incorporated in that food will be eliminated without ever becoming incorporated into the organism's body. All organisms lose some energy in the form of heat as they carry out life functions, and so must continually replenish their supplies.

As organisms eliminate waste matter or die, their organic chemicals are broken down, by decomposer organisms, into simple organic chemicals which are returned to the environment. During the conversion of complex chemicals to simple ones, chemical bond energy is also returned to the atmosphere as heat.

8.1 ENERGY IN ECOSYSTEMS

The energy that sustains the majority of living systems is solar energy; the contribution produced by chemosynthesis is insignificant. Solar energy is converted to chemical energy in photosynthesis, and is held briefly in the biosphere before it is radiated into space once again as heat. The total amount of solar energy 'fixed' on earth sets one limit on the total amount of life. The patterns of flow of this energy through the biosphere set other limits on the kinds of life on earth.

8.1.1 FOOD CHAINS

Autotrophs produce food. They are eaten by other organisms, which in turn are eaten, and in this way the food passes through the ecosystem. The path that the food takes from organism to organism is termed a **food chain**.

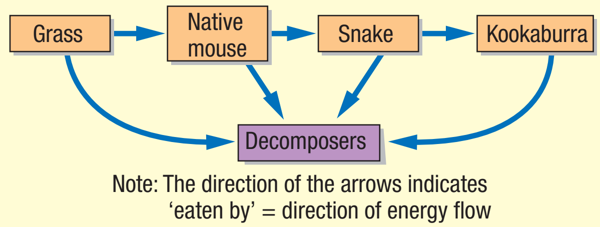


Figure 8.1 A food chain

On the basis of the way they obtain food, organisms can be categorised into three groups: producers, consumers and decomposers.

Producers

Producers convert simple inorganic chemicals to complex organic molecules (food). Most of them use solar radiation as an energy source. **Productivity** is measured by the amount of energy that is fixed in chemical compounds or by increase in biomass in a particular length of time. Temperature influences the rate at which chemical reactions take place. Since photosynthesis is a complex series of chemical reactions, productivity is affected by the environmental temperature of any particular habitat. This temperature changes throughout the year. Production of glucose by plants and its conversion into other organic compounds is influenced by season, latitude and altitude.

Productivity is also influenced by other factors such as soil mineral availability and water. Although deserts may experience suitable temperatures for chemical reactions, there is little water present and as a consequence their productivity is low. Plants and algae also vary in their ability to convert light energy into the chemical energy of organic compounds. This ability is termed **photosynthetic efficiency**. The total amount of organic matter in an ecosystem, which is produced as a result of photosynthesis, is termed **gross primary production**, whereas the amount of this energy available for herbivores is termed **net primary production**.

Consumers

Consumers use food produced by other organisms as their energy source. First-order consumers are

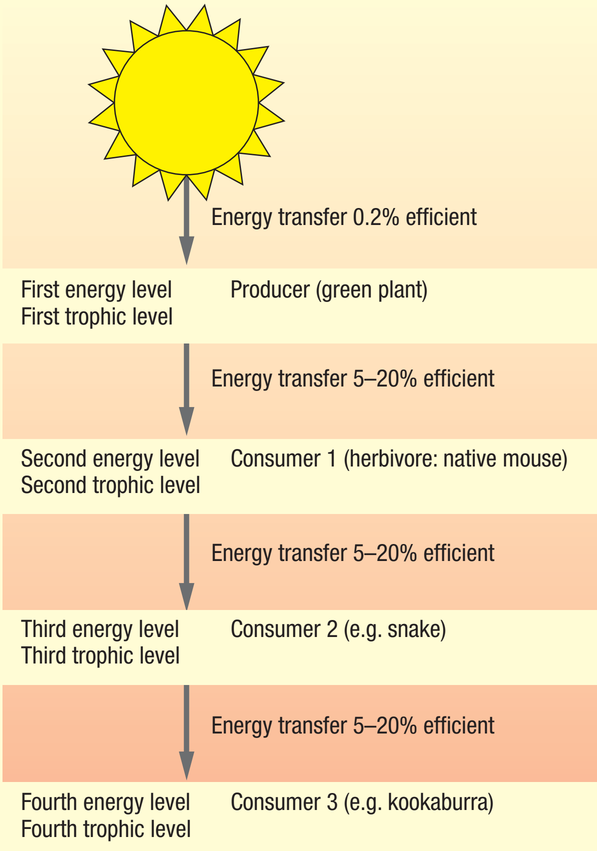


Figure 8.2 Energy relationships in a food chain

herbivores, which eat plant material. Second-order consumers are carnivores that eat herbivores. Third- and higher-order consumers are carnivores that eat other carnivores. These latter carnivores may be either predators (killing other animals for food), parasites or scavengers (eating animals they have not themselves killed). Some consumers—the omnivores—may occupy different levels simultaneously.

Decomposers

Most decomposers are simple forms of life (bacteria, fungi and some protozoans), most of which have external digestion and break down the dead bodies and waste products of other living things. They convert complex organic molecules into simple inorganic chemicals which are released into the environment and can be reused.

Trophic (feeding) **levels** describe the relative positions of producers and consumers in a food chain. A food chain shows a series of organisms existing in any ecosystem, through which energy is transferred. Each organism in the series feeds on, and therefore derives energy from, the preceding one. In turn it is consumed by, and provides energy for, the following one.

There are very rarely more than six links in any food chain; usually there are only three to four. This is because much energy is lost to the environment in the form of heat at each level of the food chain. It has been estimated that energy transfer between any two levels of the food chain is only 5–20 per cent efficient. Therefore the closer a consumer is to the producer, the more efficient is the energy transfer. For example:

phytoplankton ⟶ krill ⟶ whale

Let us assume that 100 energy units of grass are available for transfer along the food chain illustrated in Figure 8.2, and that energy transfer is 10 per cent efficient. This means that only 10 per cent of the energy contained in the food material becomes incorporated into chemical bonds in the tissues of the consumer. The other 90 units of the grass will be used up in energy-consuming activities which will release energy to the environment, either as heat or as waste matter. Thus:

100 units of grass will become 10 units of native mouse matter.

Similarly:

10 units of native mouse will become 1 unit of snake matter;

and:

1 unit of snake will become 0.1 units of kookaburra matter.

In most cases, higher-order consumers tend to be larger than lower-order consumers (particularly when they are carnivores). Food chains, therefore, generally have fewer members in each successive energy level. Because energy is released to the environment at each level, the number of levels in any food chain is limited. Ultimately there will be too little energy available to support another level. The energy released to the environment is eventually re-radiated into space as heat. **Energy is not recycled in an ecosystem.**

8.1.2 Food webs

A food chain is a simple linear series in which each organism is completely dependent on a single food source. Except in ecosystems where there are relatively few interacting organisms, such as a desert community, such simple food chains are rare. More often the range of plant species is sufficiently great for a herbivore to have several alternative sources of food, and carnivores normally prey upon a variety of animals. The nutritional relationships between such organisms constitute a food web (see Figure 8.3).

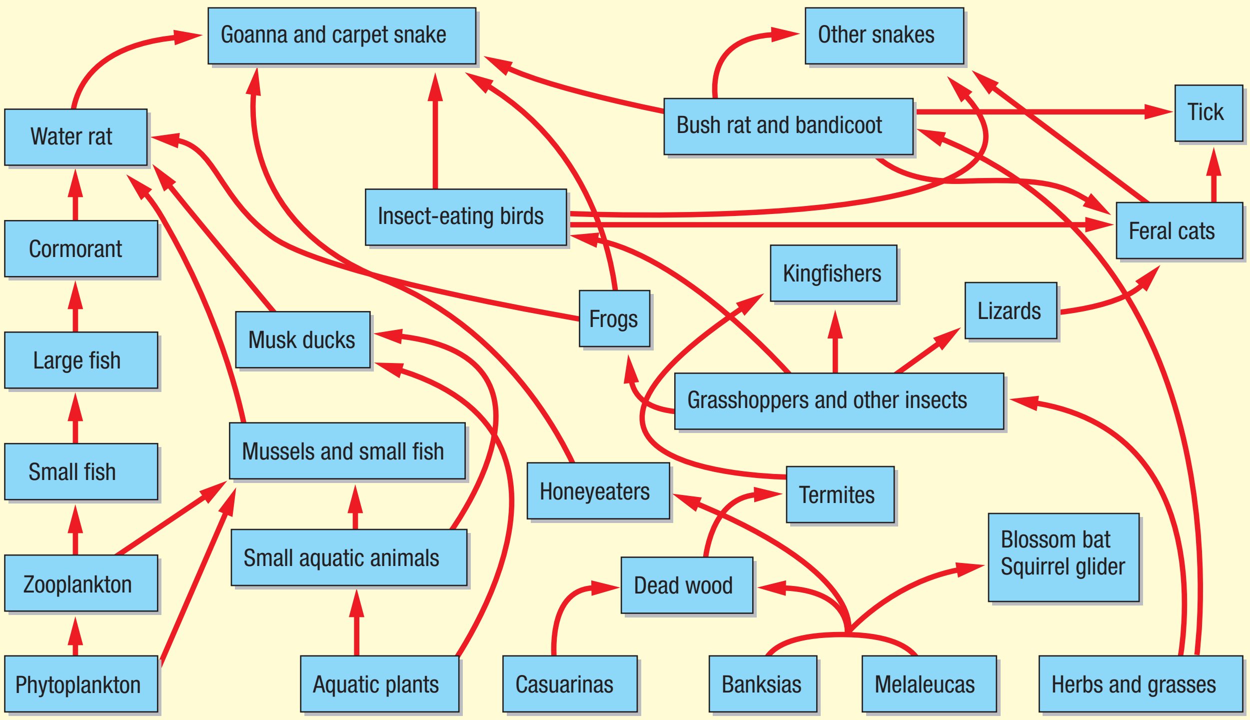


Figure 8.3 A simplified food web of the major organisms found on Moreton Island, Queensland (The decomposers have not been included.)

In a food web there is greater stability, since the variety of food sources compensates for seasonal fluctuations in productivity of any one source. Decomposers are present in the food web illustrated in Figure 8.3, but have been omitted for the sake of simplicity.

All waste and dead materials are acted upon by decomposers. The organic debris may be totally consumed by the bacteria, fungi and small animals of decay, releasing carbon dioxide, water and heat. Alternatively, it may enter far more complex food webs when scavenging organisms such as crabs utilise the remains of dead animals and in turn are eaten by fish such as mullet. Ultimately, however, decomposer organisms release mineral nutrients back into the environment. This process is not always complete, and only partially broken down products such as methane and alcohol may be released.

Ecosystems conform to the **law of conservation of matter and energy**, which states that matter and energy cannot be created or destroyed but can be changed to other forms.

The complexity of structure of an ecosystem (indicated by the variety of organisms at each trophic level, and thus the types of feeding interactions) regulates population sizes, maintaining the same pattern of energy distribution in the system over very long periods of time.

SUMMARY

Energy is needed for all life processes. The vast majority of energy in living systems is derived from solar energy through photosynthesis by plants and algae. This energy is passed (in the form of chemical bond energy) from organism to organism in a food chain.

Since organisms rarely rely on a single food source, the interactions between organisms in a community are usually best represented by food webs. Decomposer organisms return simple chemicals to the environment as they break down the complex chemicals of dead matter in their metabolic activities.

At each step in a food chain, energy and matter are used in maintaining the organism. Much energy (as heat) and matter (as undigested food or wastes) are also lost to the environment. Thus only 5–20 per cent of the biomass (amount of living matter) is transferred from each living thing to its consumer. This limits the number of trophic (feeding) levels that can exist in a food chain.

Energy cannot be recycled, because it returns to the atmosphere in a form that cannot be used by producers. To sustain living systems, however, *matter* must be recycled.

Energy flows through an ecosystem, whereas matter is recycled.

Review questions

8.1 In what ways do the movement of energy and the movement of matter through an ecosystem differ?

8.2 Decomposers are considered to be important within an ecosystem because:

A. large quantities of dead plant and animal matter would not otherwise be consumed.

B. the dead plant and animal matter would otherwise harbour dangerous decay organisms.

C. they release nutrients, otherwise locked up in the dead matter, for the use of producers.

D. the food web of the community is a dynamic, continuously changing system.

8.3 Several large geckoes are found in Australian rainforests; for example, the banded gecko, the chameleon gecko and the leaf-tailed gecko. They feed on insects and other small animals which they encounter as they forage through the forest. These lizards blend into the general pattern of bark and leaves around them and are extremely difficult to observe when they are motionless. All geckoes are insectivorous but will eat smaller lizards and sometimes frogs. They are nocturnal in habit.

(a) What position in the rainforest food web would a gecko occupy?

(b) Discuss abiotic requirements of these geckoes.

(c) Describe adaptations to the environment exhibited by the gecko.

(d) In terms of diet, would you consider geckoes to be specialists or generalists?

What effect would this have on their survival?

8.4 Explain why food chains usually do not have more than three or four components.

8.2 Ecological pyramids

The flow of energy through a food chain is often represented by a graph of quantitative relationships among the various trophic levels. **Biomass** is a measure of the amount of organic matter in a system. Large amounts of energy and biomass are dissipated at every trophic level, so each level retains a smaller amount than the preceding level. For this reason, diagrams showing these quantitative relationships nearly always take the form of a pyramid.

An **ecological pyramid** may be: a **pyramid of numbers**, showing the numbers of individual organisms at each level; a **pyramid of biomass**, based on the total dry mass of the organisms at each level; or a **pyramid of energy** showing the productivity of the different trophic levels. **Productivity** is measured by the amount of energy that is fixed in chemical compounds or by increase in biomass in a particular length of time.

The shape of any particular pyramid tells a great deal about the ecosystem it represents. In a pyramid of numbers for a grassland ecosystem (Figure 8.4a) the primary producers (usually grasses) are small, so a large quantity of them is required to support the primary consumers (herbivores). In a food chain in which the primary producers are large (for instance, trees), one primary producer may support many herbivores (Figure 8.4b).

A pyramid of biomass for a grassland ecosystem (Figure 8.4c) takes the form of an upright pyramid. Inverted pyramids of biomass occur only when the producers and primary consumers are small. For example, in the ocean, the biomass of the phytoplankton is measured by the '**standing crop**', which is the biomass at any particular moment; this may be smaller than the biomass of the zooplankton feeding upon it (Figure 8.4d). This situation can occur

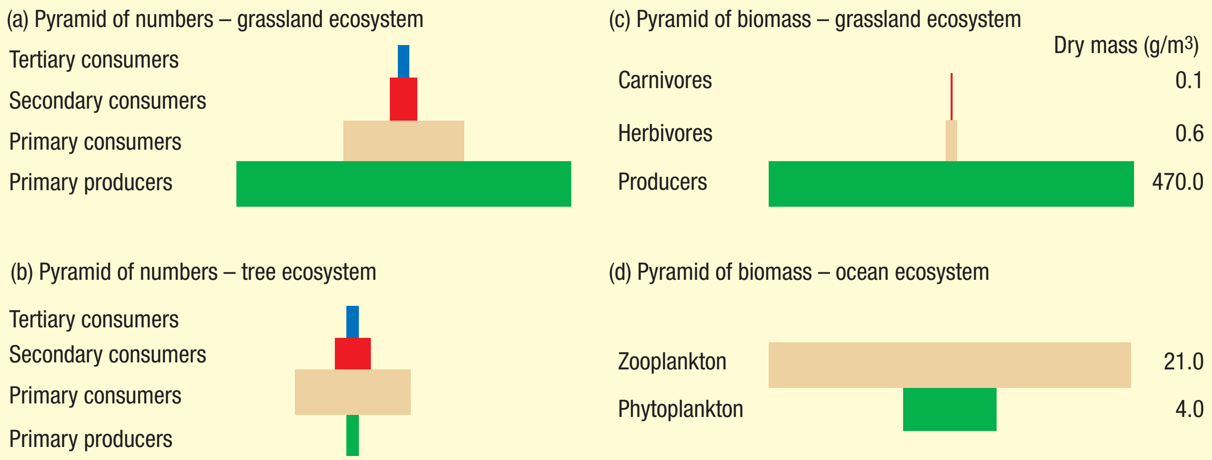


Figure 8.4 Some ecological pyramids

because the growth rate of the phytoplankton is much more rapid than that of the zooplankton.

Energy pyramids show the productivity relationships of the trophic levels and thus all have the same general shape (similar to Figure 8.4c) for every ecosystem.

SUMMARY

The relationship of the flow of biomass (or energy) or the number of organisms at each trophic level can be represented by an ecological pyramid. Graphs of energy or biomass flowing into successive trophic levels are represented by an upright ecological pyramid. Pyramids may be inverted if they are based on numbers or on biomass where producers have a high rate of productivity relative to the consumers in that food chain.

Review questions

8.5 Define the terms 'biomass', 'productivity' and 'standing crop'.

8.6 What is an 'ecological pyramid'?

Questions 8.7–8.9 all refer to the following information and Figure 8.5 below:

The number of individuals of the different species is often indicated by means of a pyramid of numbers diagram.

Which of the pyramids in Figure 8.5 would best show the relative numbers of individuals in a food chain containing:

8.7 sheep, sheep ticks and grass?

A. 1
B. 2
C. 3
D. 4

8.8 tree, caterpillars and insectivorous birds?

A. 1
B. 2
C. 3
D. 4

8.9 trees, beetles and frogs?

A. 1
B. 2
C. 3
D. 4

8.10 If an ecological pyramid is drawn for the food chains involving a large tree as the producer organism, different-shaped pyramids can be obtained depending on the parameter used (e.g. number of organisms, biomass, energy flow). Explain why the pyramids for the same food chain differ.

8.3 BIOGEOCHEMICAL CYCLES

8.3.1 GENERAL FEATURES

Chemical elements tend to circulate in the biosphere in characteristic paths, from the environment to organisms and back to the environment. These are known as **biogeochemical cycles** (*bio* = life; *geochemical* = the study of chemical exchanges between different parts of the earth). There are approximately forty elements that are essential to living organisms. The pathway for a particular element between living and non-living components of an ecosystem is usually referred to as a **nutrient cycle**.

Biogeochemical cycles have two basic components: the **reservoir pool** and one or more **cycling**

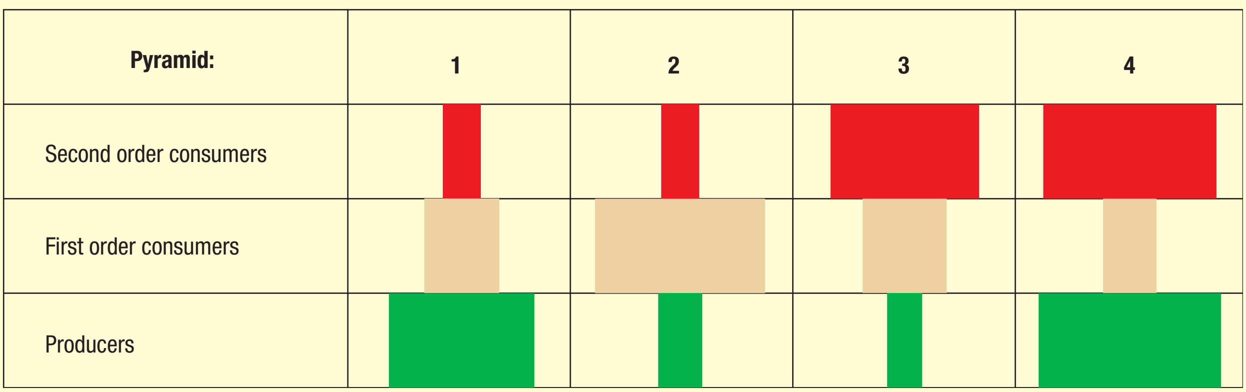


Figure 8.5

Table 8.1 Cycling of some major macronutrients

Nutrient	Reservoir pool	Cycling pool
Water	artesian; glaciers	transpiration – evaporation – precipitation – uptake
Oxygen	metallic compounds	photosynthesis – respiration
Carbon	fossils; peat; coal, oil and gas	respiration – photosynthesis
Nitrogen	deep-sea sediments	nitrogen fixation – denitrification
Phosphorus	phosphate rock; deep-sea sediments	erosion – uptake – dephosphatising

pools. The reservoir pool is a large, generally non-biological component with relatively little turnover of materials. The cycling pools are smaller and more active, and are constantly exchanging their contents with the environment and with organisms. Cycles in which the element is returned to the environment as rapidly as it is removed by living organisms are said to be more perfect cycles. This is in contrast with those in which part of the material is locked up in inaccessible chemical forms or geological formations for extended times as fossils or in deep-sea sediments.

Biogeochemical cycles are important because:

- They help retain necessary nutrients in usable forms for the living components of an ecosystem. Animals and plants in the community develop adaptive features that aid the uptake of nutrients. The shallow, spreading root system of rainforest trees is such an adaptation.
- They help to maintain a steady state (homeostasis) in ecosystems. If nutrient amounts constantly decrease or vary in quantity in the ecosystem, organisms are likely to adapt to the change but no stability will develop.

Many nutrient elements are washed out to sea and become part of the deep-sea sediments. Deep-sea currents gradually move these sediments over the ocean floor and much becomes incorporated into sedimentary rock. Most of the minerals are therefore 'lost' to the ecosystem for great periods of time (millions of years), only entering the cycling pool once again when geological uplift or undersea volcanic activity takes place. Due to the movement of the ocean currents, some of these deep marine sediments and most of the shallow ones can be brought to the surface waters at particular places on the earth's surface where there are **upwellings** of deep water. The surface waters of these areas, therefore, are rich in plant and animal life.

8.3.2 The phosphorus cycle

Phosphorus is a rare element on earth but an essential nutrient which is needed in the formation of bones, teeth, nucleic acids and other chemicals containing phosphorus. The principal reservoir for the cycle is phosphate rock formed in past geological ages. Erosion by rainfall dissolves phosphate out of the rock, forming a phosphate pool in the soil of the ecosystem. Much phosphate escapes, however, via run-off into streams and thence into the sea, before it is assimilated by plants.

Many plants have adapted to growing in phosphate-poor soils with mechanisms that maintain sufficient levels of this nutrient for growth. Some enter into a mutualistic relationship with fungal mycorrhizae. Others have a mechanism for internally recycling phosphate, by extracting it from their leaves before they fall. These plants tend to grow more slowly than those from more fertile soils, thus avoiding the need for large amounts of phosphate at any particular time. Animals obtain phosphate by eating plants. When they excrete waste products or die, the phosphate is returned to the dissolved phosphate pool.

In the past, huge colonies of sea birds have played an important role in returning a substantial amount of the phosphate to the land. Their food consisted of fish and other organisms near the shore, which were rich in phosphates previously washed down from the land. The sea birds' excreta, deposited at their breeding areas on islands and on coastlines, built up over time into large deposits of soluble phosphate (**guano**) which has been mined and used as fertiliser. The rate of mining, however, far outweighs the rate of guano formation.

Human exploitation of many islands and coastal areas has disturbed a large number of the sea-bird breeding grounds. Modern fishing and the removal of much marine life from the area has also depleted

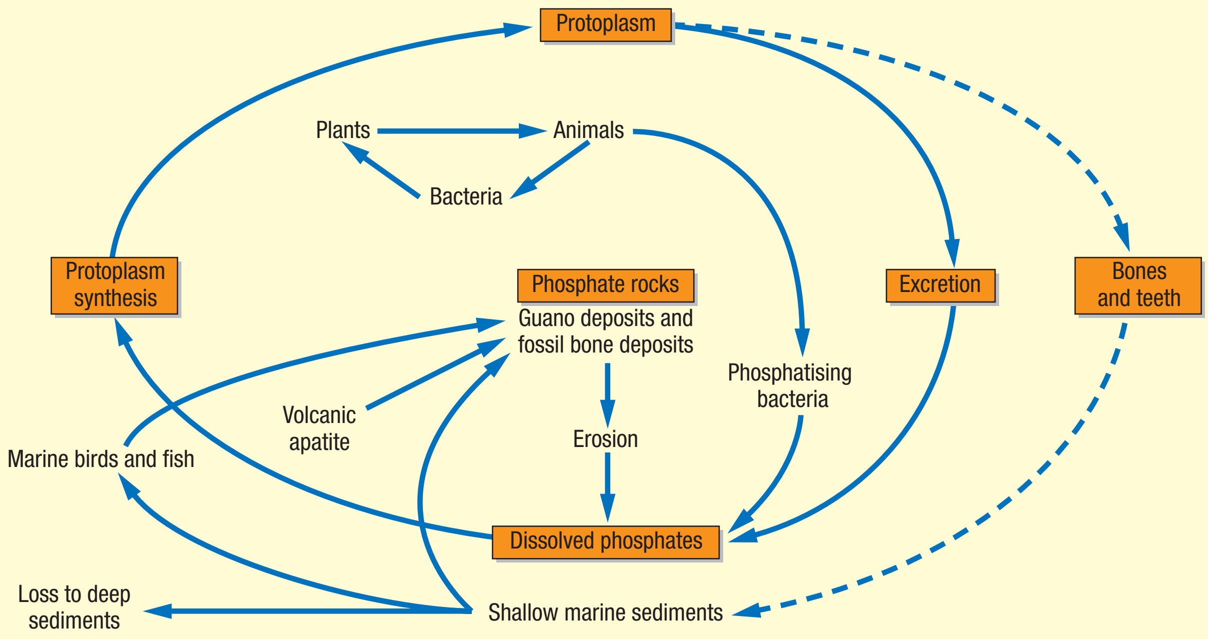


Figure 8.6 The phosphate cycle

the phosphate levels. Underwater currents and geological subsidence carry the majority of phosphate compounds to deeper marine sediments where they may remain locked for millions of years.

8.3.3 The water cycle

All living things need water. It is a major component of protoplasm, a solvent in which many metabolic reactions take place, a reactant in some chemical reactions (e.g. photosynthesis) and, for some organisms, the habitat in which they live. The distribution of plants and animals in terrestrial environments is therefore closely linked to the availability of water.

About 98 per cent of the water on earth is found in the oceans, rivers and wetlands. Of the remainder, some is frozen, some is in the soil, some is incorporated in the bodies of living things and some occurs as water vapour in the atmosphere. Solar energy powers the evaporation of water from the oceans (and to a minor extent from freshwater environments, the soil and organisms). The water vapour is carried by air currents into the atmosphere. When it meets cool air the water vapour condenses and forms clouds of liquid water droplets or ice. When the volume of water in the clouds reaches a critical level, it falls to the ground as precipitation.

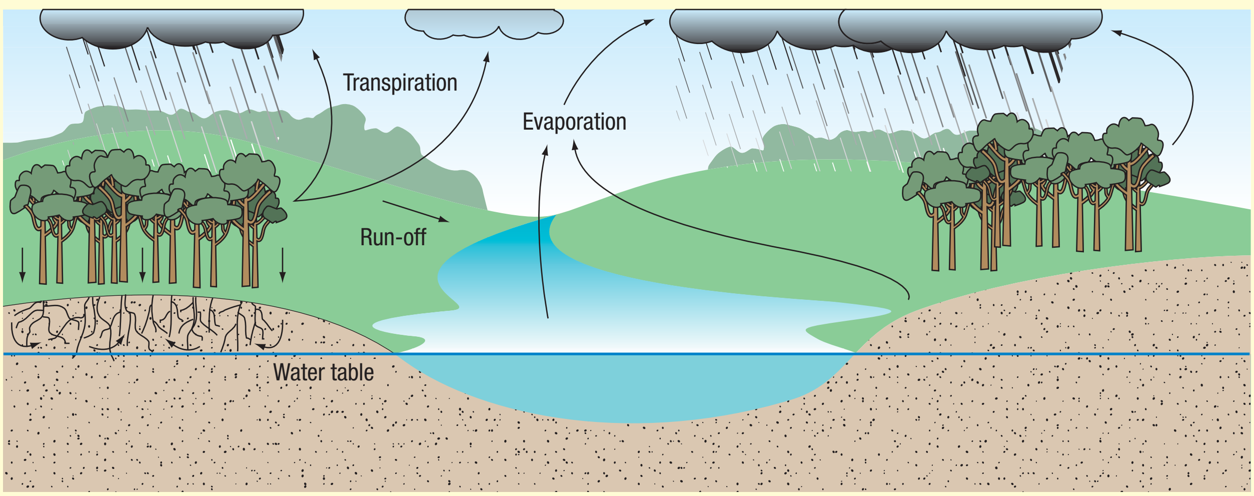


Figure 8.7 The water cycle

Most rain falls on the oceans. That which falls on land is pulled by gravity back to the sea in the form of surface run-off, streams, rivers and lakes. Some of the water soaks into the soil, percolating down until it reaches a zone of saturation, the upper levels of which form a water table. This ground water also moves towards the oceans, though some is used by organisms. Thus the majority of water cycles from the oceans and back.

On land, the amount of rainfall is determined by the prevailing wind direction, temperature (which determines evaporation rate) and topography. Mountain ranges close to continental edges force vapour-laden air to higher altitudes where clouds form. The ocean sides of these ranges, therefore, have a higher rainfall than the inland side. The further away from the ocean, the less rainfall will be experienced.

8.3.4 Oxygen and carbon cycles

The carbon and oxygen cycles are interwoven. In photosynthesis, living systems incorporate carbon from the atmosphere into complex organic molecules and oxygen is released. These compounds are broken down in the oxygen-requiring process of respiration, to release carbon dioxide and water back into the atmosphere. At any one time a great deal of carbon is tied up in living matter as it is passed along food chains. Further large quantities are contained in the dead bodies of plants and animals, as well as in leaf litter, excretory wastes and animal faeces. Detrital organisms and decomposers are responsible for the final release of carbon back into the environment for recycling.

Over long periods of geological time, much carbon has been locked into the reservoir pool as coal and oil. As humans exploit this fossil fuel in combustion processes, carbon is returned to the cycling pool.

8.3.5 The nitrogen cycle

Nitrogen, although plentiful in the atmosphere, is a relatively inert gas and as a consequence is not readily available for plant use. Since it is an essential component of amino acids (and thus of proteins), nitrogen limits the supply of food available in a food chain more than any other plant nutrient. Nitrogen fixation (conversion of atmospheric nitrogen to soluble nitrate) is an essential process for life on earth and is carried out by chemosynthetic microorganisms either in the soil or within the roots of plants. Chemical energy released in the respiration of inorganic chemicals is used in the production of organic 'food' molecules by these bacteria.

The best-known nitrogen-fixing organisms are bacteria which live in a mutualistic association in the roots of leguminous plants such as peas, lucerne and clover. The bacteria enter the root hairs of young plants where they form swellings called nodules.

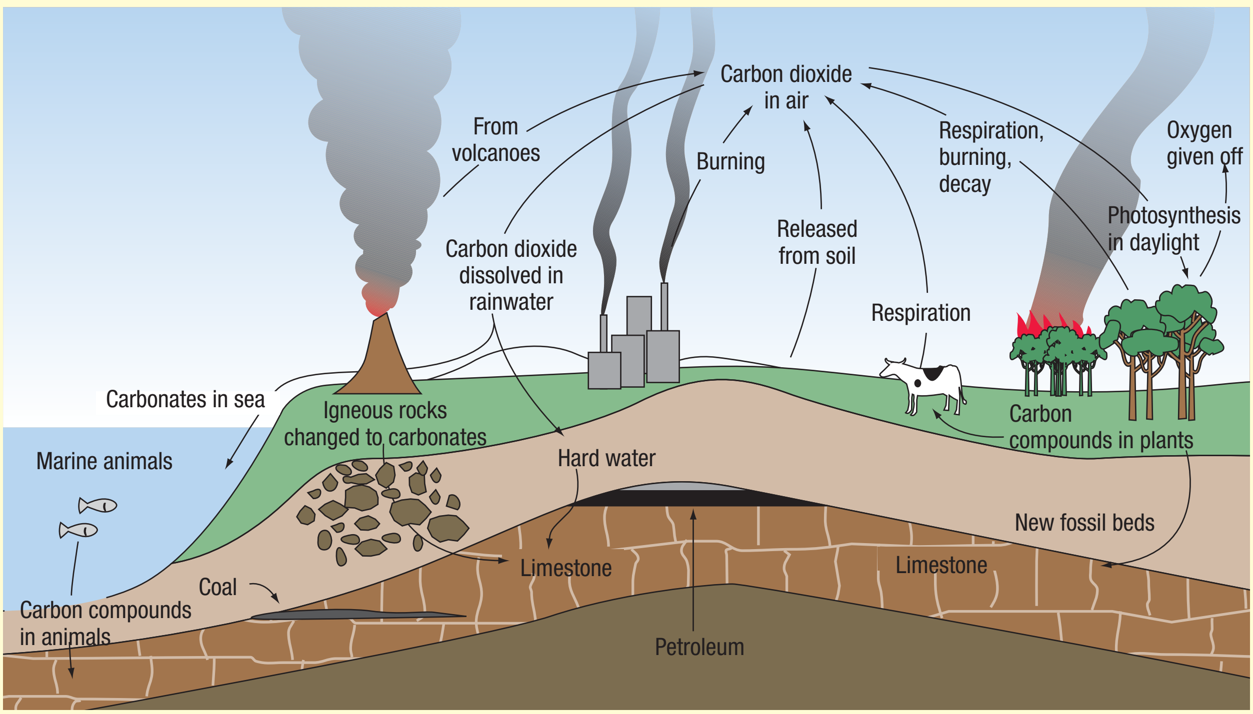


Figure 8.8 A simplified carbon cycle

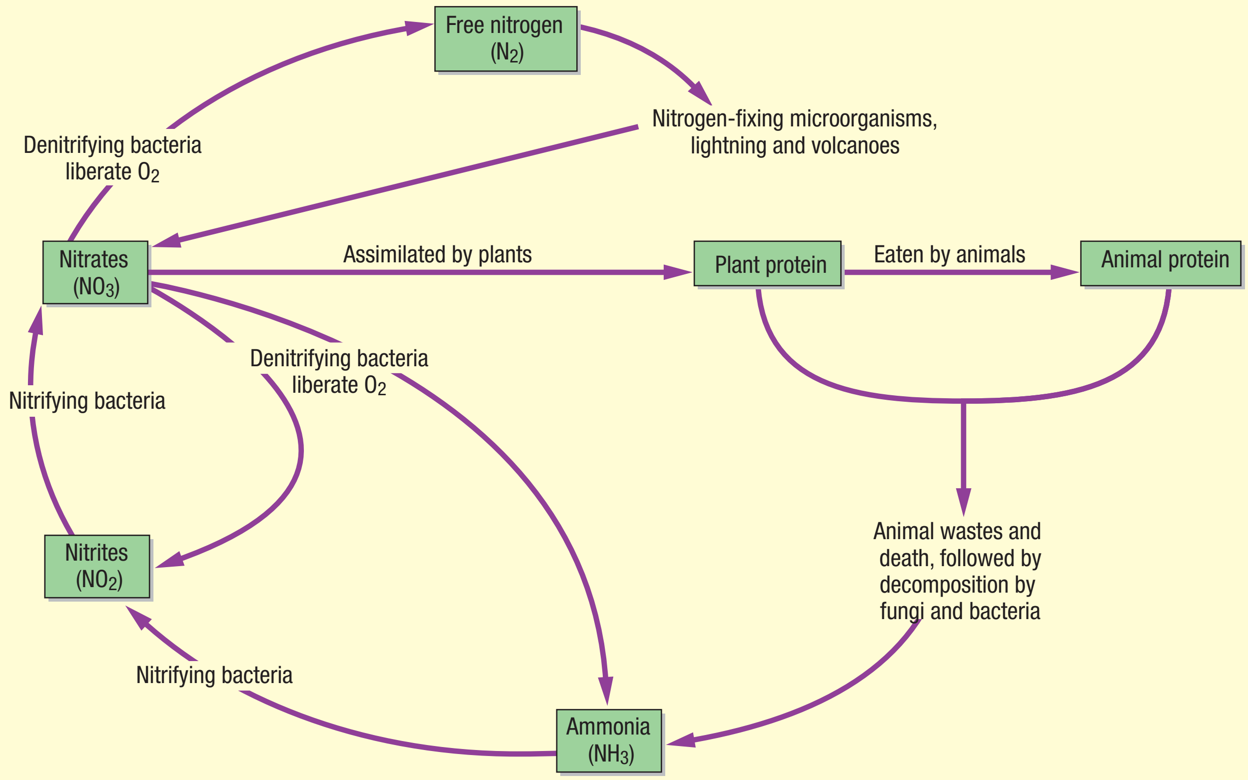


Figure 8.9 Simplified nitrogen cycle

They utilise the free nitrogen in their metabolic reactions and release nitrates which are used by the plant to form protein. The plant obtains the proteins necessary for existence, while the bacteria derive protection and a supply of carbohydrate (from the plant's photosynthesis) for the synthesis of protein.

A particularly important group of chemosynthetic organisms are the **nitrifying bacteria**, which enrich the soil with nitrates through their metabolic activities. The nitrates can be absorbed and used by plants in the production of amino acids and proteins. These products are then available to animals as they pass from organism to organism in the food chain. Some of the chemosynthetic nitrifying bacteria, such as *Nitrosomonas*, obtain energy by converting ammonia (NH_3), resulting from the breakdown of animal and plant proteins, to nitrite (NO_2). Other nitrifying bacteria, *Nitrobacter*, convert nitrites to nitrates. In both of these cases, the conversion releases energy which is used by the bacteria to synthesise the organic compounds it needs. The fact that plants can utilise the nitrate formed is incidental to the bacteria.

Nitrifying bacteria do not exist in isolation, but form part of a natural system. The full sequence of conversions constitutes the nitrogen cycle.

Those bacteria which remove nitrate from the soil are called **denitrifying bacteria**. These bacteria tend to live in conditions of oxygen shortage. By reducing nitrate to nitrite or ammonia or nitrogen, they liberate oxygen. The oxygen liberated is then utilised in aerobic respiration, and the energy released is used for the synthesis of the organic compounds required by the bacteria.

SUMMARY

The flow of matter through the biosphere occurs in biogeochemical cycles. Some matter (e.g. fossils and deep-sea sediments) is locked away from living organisms in reservoir pools. Other matter, in the cycling pool, is transferred between biotic and abiotic components of the ecosystem in nutrient cycles.

Soil phosphates are derived from erosion of phosphate-bearing rocks. Since they are soluble, there is a tendency for these compounds to be washed out to sea where they may subside into the deep-sea sediments. Terrestrial environments which are geologically stable therefore have soils which have a low level of this essential mineral. Plants in low-phosphate soils are able to recycle phosphates internally, and mycorrhizal

associations are also important in returning phosphates from plant and animal litter.

Water falls to earth as some form of precipitation and returns to the air by evaporation. The carbon and oxygen cycles, between the abiotic and biotic environment, interact via photosynthesis and respiration.

Soil microorganisms are the main agents in both fixing and releasing nitrogen.

Review questions

8.11 Not all the carbon on earth is being cycled continuously. How might carbon be removed from the cycle for periods lasting millions of years?

8.12 Distinguish between a reservoir pool and a cycling pool of a nutrient.

8.13 Why is it considered that the available phosphate resources of the world are being depleted?

EXTENDING YOUR IDEAS

1. UB Caves are frequently inhabited by bats, which go out at night to feed on flying insects and live inside the cave during the day clinging to the rocky walls. On these cave walls are generally to be found small blood-sucking flies and bat bugs, which suck the blood of bats. The droppings of bats accumulate on the cave floor and form a suitable medium for certain fungi, particularly moulds. These moulds provide food for the cave crickets, which themselves are eaten by other insects, spiders and scorpions. These 'other insects' may also fall victim to the spiders.
   (a) Draw a food web to show the relationships existing in such a cave community.
   (b) What constitutes the boundary of such a community? Explain.
2. IB *Frankia* are bacteria that can provide nitrogen to a plant. Trees in a forest plantation were treated in three different ways. The results are shown in Figure 8.10.
   (a) Describe the experimental conditions of the 'control' trees.
   (b) Explain the rationale for the treatment of the 'control' trees.
   (c) Using supporting evidence from the graph, draw a conclusion from these results.

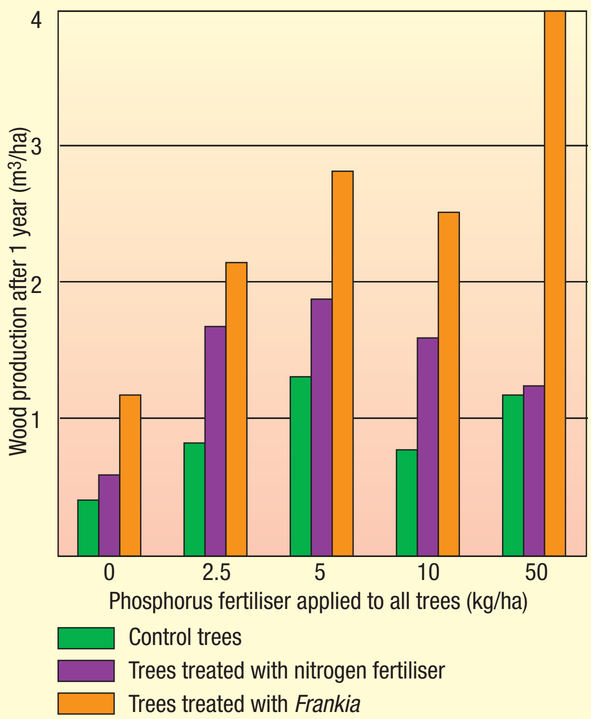


Figure 8.10 Responses of forest trees to phosphorus, nitrogen and *Frankia*

3. IB In an experiment investigating the rate of disappearance of leaf litter, uniform discs were cut from leaves, placed in nylon mesh bags and buried in newly cultivated pasture. The table shows the disappearance of the leaf discs from bags made from 7 mm and 0.5 mm mesh from June of one year to April of the next.

Month	Percentage (%) of leaf area remaining in bags of mesh size:	
	7 mm	0.5 mm
June	100	100
August	81	94
October	30	91
December	13	66
February	9	62
April	6	60

   (a) Plot the data on graph paper.
   (b) Describe the effect of mesh size on the rate of disappearance of leaf litter between June and October. Evaluate causes for this.

(c) Explain the variation in the rate of disappearance of litter from the 0.5 mm mesh bags during the period of the experiment.

4. **UB** Herbivores have generally been considered to have a negative impact on their plant prey. However, a controlled study of a natural community provides evidence to the contrary. The crustacean herbivore *Daphnia pulex* was fed on planktonic algae, and it was shown that the *Daphnia* had a stimulatory effect on the algal populations that approximately balanced its impact on algal mortality. Predict, with justification, mechanisms for the *Daphnia*-induced stimulation of algal growth.

5. **IB** Design an experiment to test whether the amount of leaf litter that accumulates in water-filled hollows depends on their depth. If the experiment showed a correlation between depth of hollow and amount of leaf litter, discuss the implications for the development of litter food webs.

   A typical food chain for eucalypt woodland detritus is shown in Figure 8.11.

6. **UB** The data below shows the rates of primary productivity for different ecosystems.

Desert scrub	Temperate grasslands	Temperate forests	Tropical forests	Continental shelf	Open ocean
1.3	9.2	22.2	36.2	6.6	2.4

(a) The ocean covers most of the earth's surface and yet only has a primary productivity of 2.4 compared with the tropical forest (36.2) that only grows on about 4 per cent of the surface. Account for this difference.

(b) Some plants only photosynthesise for a short period of time each day, at dawn and dusk. They do this by controlling when the stomata, small pores on the surface of the leaf, are open and thus when carbon dioxide is available for photosynthesis. Propose, with reasons, the most likely ecosystem in which this occurs.

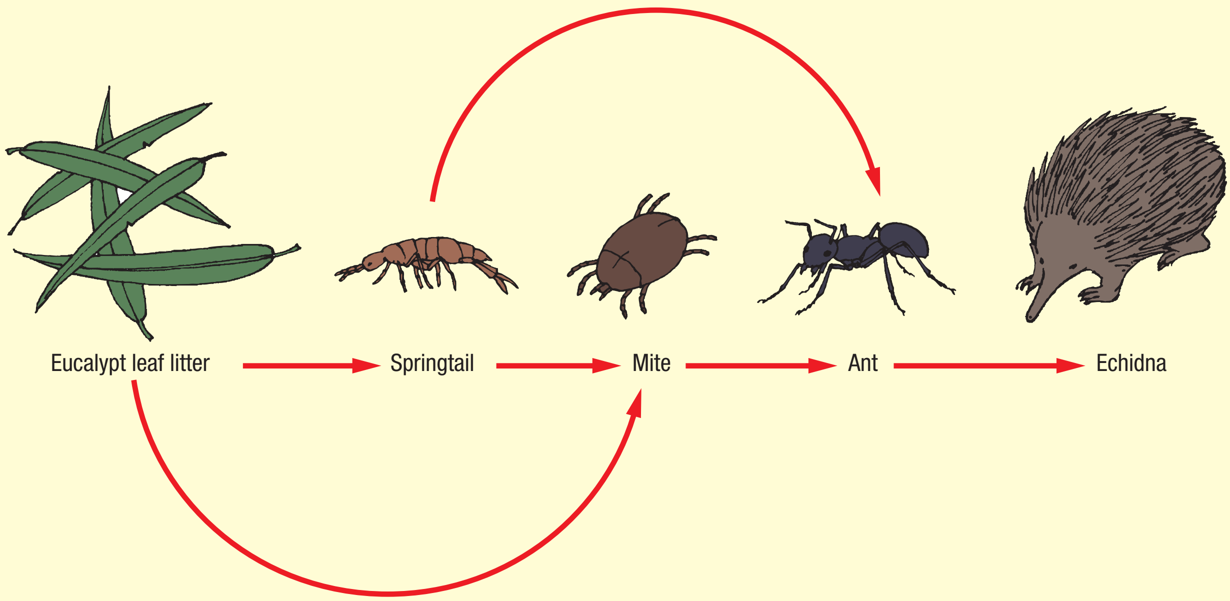


Figure 8.11

9 COMMUNITIES AND THEIR HABITATS

The **biosphere** is the 'layer' of earth that supports life. It is affected by the position and movements of the earth in relation to the sun, the movements of air and water, and the irregularities in composition of the earth's crust. These conditions cause wide variations in temperature and rainfall from place to place and from season to season on the earth's surface. Differences are reflected in the kinds of plants and animals found in any area.

As has been seen, the producers present in any particular area have particular tolerance levels to a range of abiotic conditions. The number and diversity of producers and their photosynthetic efficiency influence the productivity of the area. This in turn affects the types of animals (each of which has its own set of tolerance levels) that can be supported by these plants. The community of organisms found in any area of the biosphere is determined by the physical environment or habitat. Each ecosystem, therefore, has a unique set of abiotic and biotic factors. Thus an ecosystem is a self-sustaining unit made up of living things (a community) interacting with and within a particular habitat.

The biosphere is composed of aquatic (marine, estuarine and freshwater) and terrestrial environments (the soil, its surface and surrounding air). These can be divided into areas called **biomes** which have features that distinguish them from each other.

9.1 TERRESTRIAL BIOMES OF THE WORLD

Large-scale similarities in vegetation patterns exist throughout the world because of similarities in climate and geography. This has resulted from

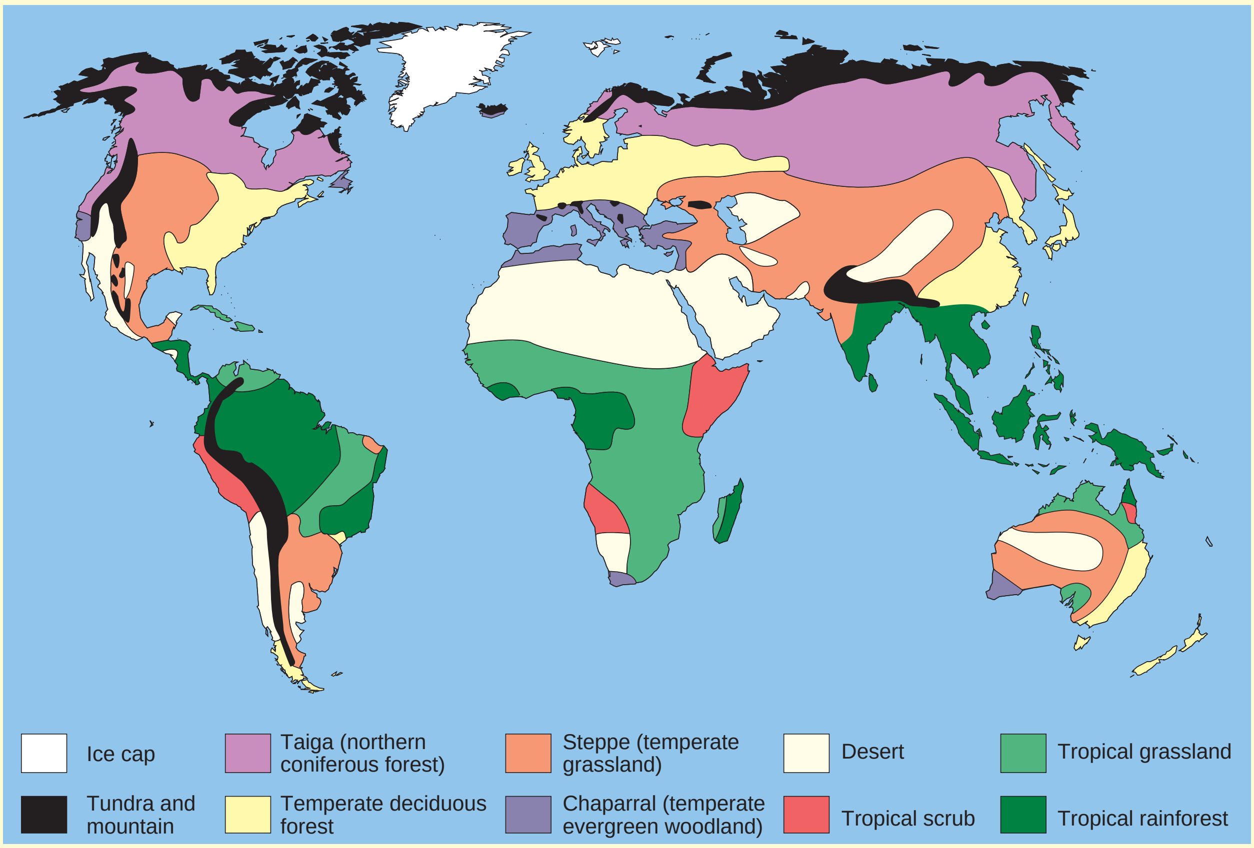


Figure 9.1 The major world biomes: areas with similar climate belong to the same biome.

convergent evolution: species which live in habitats with similar abiotic conditions share common adaptations, each of which has evolved independently. Although the particular species differ in different places, there are similarities in general structure of the communities. These broadly similar communities are termed biomes.

Distribution of the biomes shows latitudinal and altitudinal zonation, as described in Chapter 6. The boundary between biomes (and individual communities within any biome) is very rarely distinct. The gradients in abiotic factors are gradual, and this is reflected by gradual changes in organisms over distance. There is usually a blurred boundary between two distinct communities, where some organisms from each community can be found. Six of these biomes are described below.

Tundra

The **tundra** is found in the most northern latitudes, which are characterised by low average temperature and low annual precipitation, usually in the form of snow. Even in the short summer period, the soil water more than a few metres from the surface remains frozen and this prevents the rooting of large plants. Low stunted shrubs, mosses and lichens are the only plants to grow successfully in this biome. During the summer months these plants support a variety of rodents (mice, lemmings and moles) as well as hares, caribou (a reindeer), bears, foxes and a variety of birds and insects. Since the plants have a shallow system, this is a fragile environment, susceptible to massive erosion with any disturbance of the vegetation.

Taiga

The coniferous forest areas found south of the tundra are termed **taiga**. Although the rainfall is not high (35–40 cm per year), the low temperatures inhibit evaporation and the soils are therefore very wet and acidic. Since the sub-surface soil water does not freeze, tall trees abound. These create shade, shelter and protection for many organisms. Thus species diversity of both plant and animal life is greater than that found in tundra.

Temperate deciduous forest

The trees of **temperate deciduous forest** characteristically lose their leaves during winter. These forests are found in warmer regions which encounter distinct seasons and have an annual rainfall of about 100 cm. All forests display **vertical stratification**. The leafy branches, or **canopy**, of the trees shade the ground below and provide food and shelter for a variety of animals. The small trees and shrubs that can grow beneath are limited by the amount of sunlight that can penetrate the canopy. If the trees are widely spaced, these will be relatively abundant.

The forest floor occupants are even more limited by available sunlight. The floor usually has a layer of leaf litter in which arthropods, snakes and rodents live. A wide variety of litter and soil microorganisms either decompose this dead matter or are predators of decomposers. Fallen logs provide microenvironments for other organisms which may form a subcommunity within the forest. The canopy also influences the humidity and effect of wind at various strata. Humidity in a closed forest increases from the top of the canopy to ground level, while the effects of wind decrease. Each stratum, or layer, of the forest has its own set of environmental conditions and thus will support different life forms.

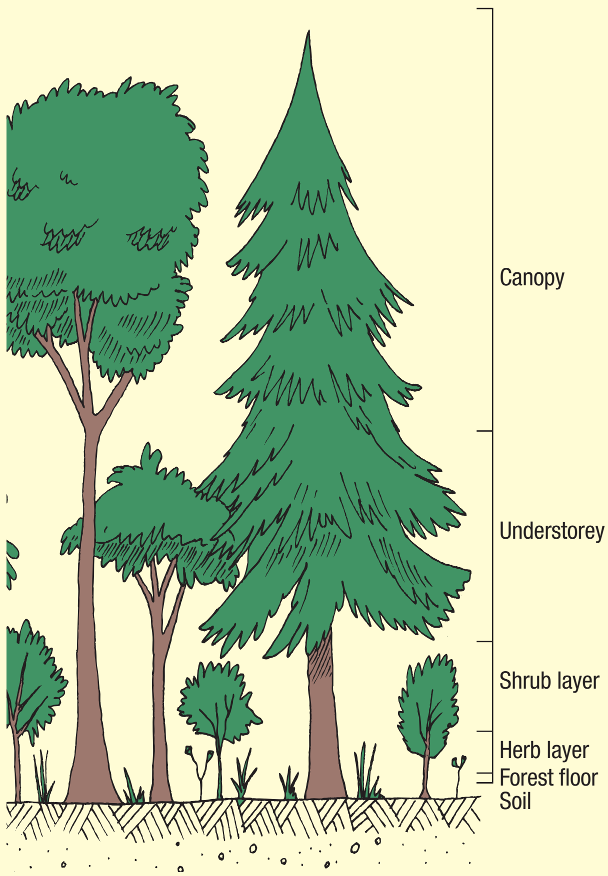


Figure 9.2 Forests show vertical stratification, with different life forms in each layer.

Rainforest

Rainforest is found in tropical, subtropical and temperate regions where the annual rainfall is high and there is a long growing season. The temperatures typically remain within a narrow range. This biome will be examined in greater detail later in the chapter.

Grassland and savannah

Grassland occurs in both temperate and tropical regions where there is unevenly distributed rainfall between 25 and 75 cm per year. Depending on the region, this biome may be termed steppe, prairie, plain, pampa or veldt. A **savannah** is a biome in which grasses predominate but in which there are also scattered trees. These areas have become the major agricultural regions of the world, both for grazing cattle and sheep and for growing cereal crops.

Deserts

Deserts exist where irregular rainfall is less than 25 cm per year and there is a high evaporation rate. Plants and animals find survival difficult in these areas and most adaptations are centred around maximising water uptake while reducing water loss. The rainfall relative to average temperature determines whether these desert biomes are hot, cold or temperate. Much of Australia displays desert or semi-desert conditions.

Case study 9.1: Kilimanjaro—terrestrial biomes in a nutshell

Mt Kilimanjaro, the seventh highest mountain on earth at 5896 m, is found on the border between Kenya and Tanzania in Africa. Massive movement of the fault line running 8000 km from Turkey to the mouth of the Zambezi River in Mozambique created the Great Rift Valley 20 million years ago. Between one and two million years ago, volcanic activity along the fault line resulted in the present form of the mountain.

The mountain has six distinct vegetation zones—the lower slopes, montane (mountain) forest, heather, moorland, alpine desert and the summit—each covering an altitude of approximately 1000 m. These zones correspond to variations in both the rainfall and the temperature. The forest receives the greatest rainfall (1800 mm a year). Generally the temperature decreases 1°C for every 200 m increase in altitude. Associated with this is a decrease in rainfall. Thus precipitation (invariably snow) at the summit is less than 100 mm a year.

Most of the vegetation of the lower slopes has been dramatically altered by human activities of cultivation (bananas and coffee) and cattle grazing. As a result of water percolating from the high-rainfall forest zone, and rich volcanic soils, this zone is highly productive and thus the area, between 800 and 1500 m altitude, is densely populated. Many exotic plants (including bougainvillea, lantana, eucalypts and grevilleas) have been introduced and there is some concern that these are infiltrating the forest zone.

The forest zone, between 1500 m and 2800 m altitude, can be divided into two distinct sub-areas. The lower region is typically rainforest. Large trees provide a dense canopy that decreases the level of evaporation of water from the ground. Previous activities by buffalo and elephants in this forest have produced semi-open glades. As a consequence the ground story has a fairly dense herbaceous cover, not seen in typical rainforest. Although poaching in recent years has resulted in the loss of these large herbivores, the glades are kept open by grazing antelope such as the bushbuck. Common trees of the rainforest include *Albizia schimperiana, Olea kilimandscharica* (an indigenous olive tree) and *Macaranga kilimandscharica*, with sycamore figs and palms being more predominant in the river gorges. In areas of high soil moisture tree ferns (*Cyathea*) grow as high as 6 m. In these areas the ground is covered by very large clubmosses (*Seliganella* and *Lycopodium*). Two species of herbaceous balsam are common, particularly near streams—the pink *Impatiens pseudoviola* and the scarlet and yellow *I. kilimanjari* which is only found growing on this mountain.

At about 2500 m altitude the structure of the forest changes. The dominant trees of the rainforest are replaced first by giant camphor-wood trees (*Ocotea usambarensis*) and then by the conifer *Podocarpus milanjianus*. The upper part of the forest zone is constantly shrouded in cloud that further reduces water evaporation. The trunks and lower branches of the trees are encrusted with mosses and epiphytic ferns, while the upper branches are festooned with the bearded lichen (*Usnea*).

The conifers are replaced by tall heather (*Erica arborea* and *Philippia excelsa*), both growing to 10 m tall and beribboned with bearded lichen as the temperature and ground water is further reduced at about 2800 m altitude. These plants have small leaves on short branches, an adaptation to prevent water loss. On the eastern side of the mountain, the cream-flowered *Protea kilimandscharica,* is commonly scattered among the heath plants. Where the ground is less rocky and dry, red-hot pokers (*Kniphofia thomsonii*) and red gladioli (*Gladiolus wastonioides*) are common. As the altitude increases the heath plants become shorter and shorter, and are replaced by low-growing shrubs that form dense clumps so that at 3200 m the vegetation zone is classified as moorland.

On Mt Kilimanjaro the most striking moorland plants are the tall groundsels (*Senecio*) and giant lobelias (*Lobelia deckenii*). Both of these plants have special adaptations to survive in the extremes of temperature at this altitude. Temperature at night is below 0ºC but may reach 40ºC during the day. Without the protection of tall forest trees, the winds blow across the

3200 m Zone 4 Heather

Erica arborea covered in bearded lichen (*Usnea*)

3000 m Zone 5 Forest Coniferous (*Podocarpus milanjianus*)

2800 m Rainforest

(a) Glade showing *Olea kilimandscharica* forming a loose canopy over grasses and red-hot pokers

(b) The two herbaceous balsam plants; *Impatiens pseudoviola* and *I. kilimanjari*

1500 m Zone 6 Lower slopes (cultivation)

900 m

Banana cultivation

Figure 9.3 (a) Altitudinal zonation on the lower slope of Mt Kilimanjaro.

6000 m

Zone 5 Summit

Kilimanjaro summit with glaciers

5000 m

Zone 4 Alpine desert

Alpine desert showing tussock grasses and stunted everlasting daisies

4000 m

Zone 3 Moorland

(a) Moorland with cloud rising from the valley below.

(b) Tree groundsel

(c) Giant lobelia (with flower; closed with ice covering in early morning)

(d) Grass zone at the lower edge of the moorland

Figure 9.3 (b) Altitudinal zonation on the upper slope of Mt Kilimanjaro.

moorland and the predominant species are low-growing everlasting daisies (*Heliochrysum*) and tussock grasses such as *Pentaschistis minor*. These two species, however, are tall. The endemic *Senecio kilimanjari* grows to a small tree up to 5 m tall with a woody trunk and a crown of thick, cabbage-like leaves. As the plant grows the dead leaves remain on the trunk, forming an insulating skirt. The living crown of dull green leaves have a hairy undersurface. At night the leaves close up and protect the central growing shoot. The lobelias, also endemic to the mountain, grow to 3 m tall. They have smaller and thinner leaves than the groundsels. At night the leaves of these plants also close around the central growing stem, somewhat like a turban. In addition, glands on the undersurface of the leaves secrete a slimy solution that freezes at night, preventing freezing of water in the leaf tissues.

Scattered throughout the moorland are small springs where water percolates through the porous volcanic rock from the summit. These bog areas are habitats for a number of different types of plants, including the fragile sedge (*Carax monostachya*) that forms thick clumps. Surface water from these springs freezes over at night, coating the sedges in ice.

The alpine desert is found at 4000–5000 m above sea level. This zone has little water, shallow soil and experiences extremes in diurnal temperature. Added to this is a phenomenon termed 'soliflucation'. As the ground freezes, soil water expands and moves soil particles. Few plants can grow under these conditions. Scattered tussock grasses with wiry, narrow leaves (e.g. *Pentaschistis minor*) and low-growing everlasting daisies are the dominant plants of this area. Lichen and a moss overcome the problem of the shifting soil. The lichen attach to rocks, while the moss grows around small packages of soil to form free-rolling balls.

Above 5000 m the temperature is too extreme and water too sparse to sustain much life. Slow-growing (less than 1 mm per year) red and grey lichen are still found on the rocks. Only one species of plant has been found in this zone—a very compact form of the everlasting daisy, *Heliochrysum newii*, which has a more prolific growth form in the moorlands.

SUMMARY

The biosphere is that part of the earth which supports life. It consists of two major divisions: aquatic (marine, estuarine and freshwater) and terrestrial environments. The terrestrial portion of the biosphere can be subdivided into biomes—vegetation groups with similar structural patterns which are adaptations to particular temperature ranges and water availability. Biomes reflect both latitudinal and altitudinal variations in abiotic conditions. From the North Pole to the equator there is a latitudinal zonation of terrestrial biomes from tundra, through taiga and temperate deciduous forests to rainforest. Grassland and desert occur in those areas where rainfall is low although temperatures are higher than those of the tundra and taiga.

? Review questions

9.1 What are the two major factors responsible for the distribution of the world biomes?

9.2 Compare and contrast the environments of the taiga and temperate deciduous forest.

9.3 In which terrestrial biome would you expect to find the greatest species diversity and species abundance? Explain your answer.

9.4 Explain how vertical stratification influences species diversity in a community.

9.2 The marine environment

9.2.1 The oceans

Approximately 71 per cent of the surface of the earth is covered by the sea. The oceans, by evaporation and condensation, provide the water that falls on land, indirectly sustaining the existence of all terrestrial life. They absorb solar radiation, store it as heat energy and exchange energy with the atmosphere, thus regulating the world's weather and determining the climates of the continents.

The oceans around the globe are constantly in motion, driven by winds, tugged by the tidal attraction of the sun and moon, and swirled in their basins by the rotation of the earth. Australia, being an island, is strongly influenced by the behaviour of the oceans around its shores (see Figure 9.4 on page 206).

Ocean currents

Two major ocean currents affect the Australian continent. One of these is driven across the southern Indian Ocean by prevailing winds (the 'roaring forties'), a combination of the West Australian Current and the West Wind Drift. This forms the northern edge of a vast circulation of water around the South Pole in an easterly direction. The combined current divides when it approaches the south-west corner of Australia, with one branch continuing eastward across the Great Australian Bight and the other turning up the west coast of the continent until it turns west at North West Cape.

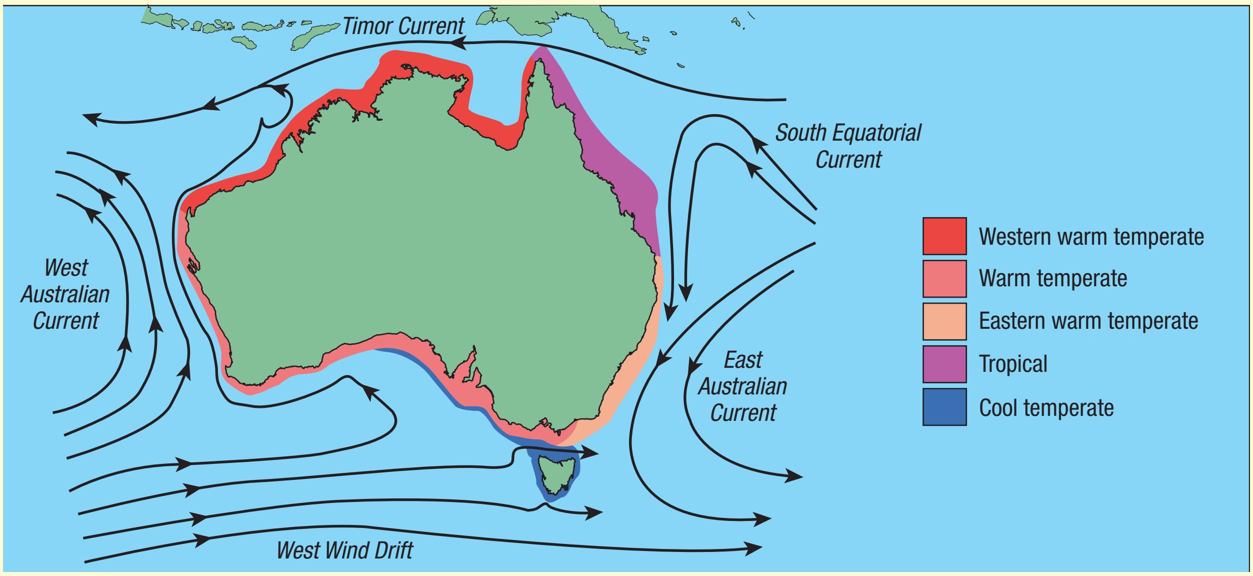


Figure 9.4 Major Australian marine biogeographical zones and winter ocean currents. In summer there is a reversal of the currents along the northern and southern coasts for a few months (Timor Current and West Wind Drift).

The other major ocean current to influence Australia comes from the Pacific and strikes the Queensland coast before turning south. This flow, the East Australian Current, is one result of the great subtropical westward circulation of wind and water, both north and south of the equatorial belt,

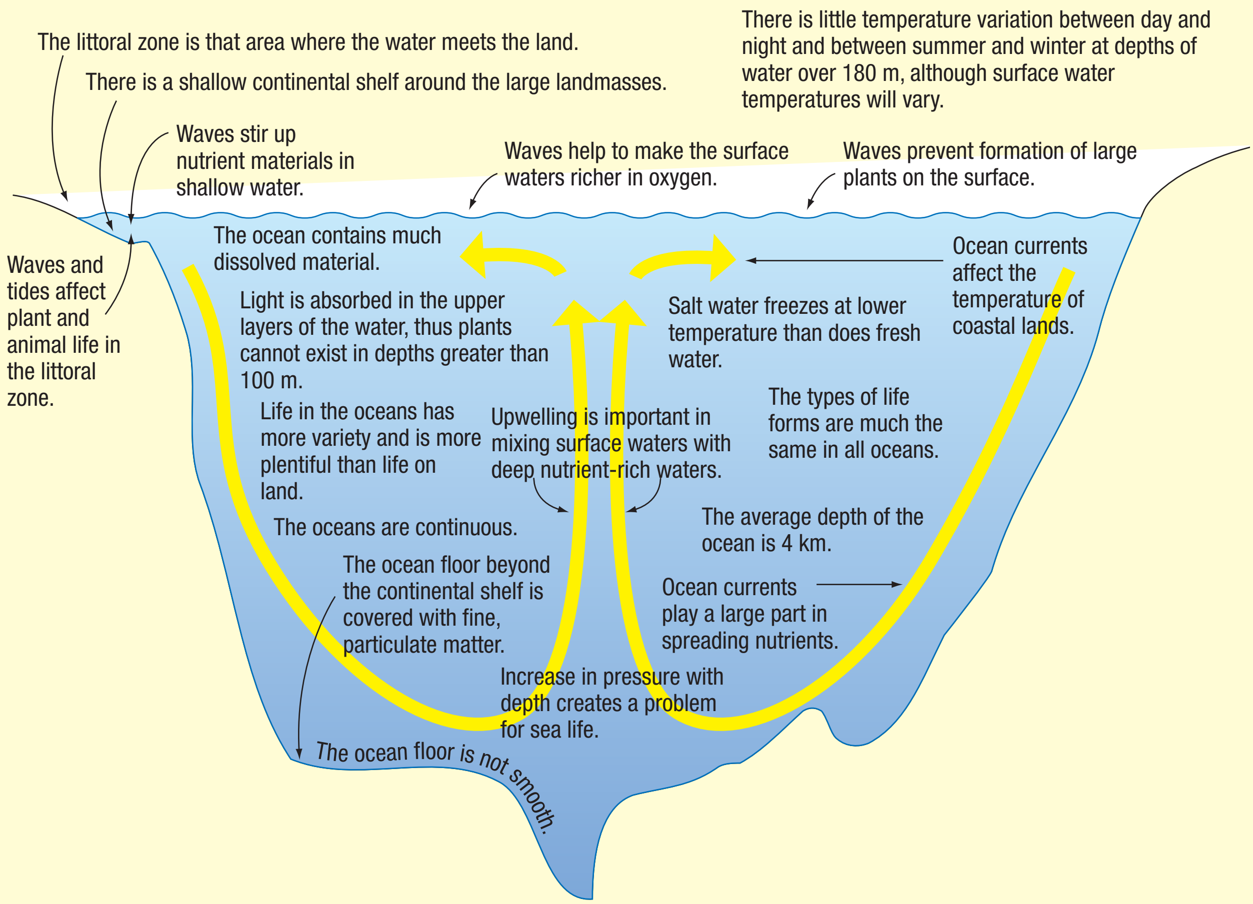


Figure 9.5 Cross-section through an ocean, showing major features

caused by the steady pressure of the east-to-west trade winds. Although the East Australian Current has a great influence on the climate of the east coast of Australia, the waters carry very little nutrient.

The surface currents overlie a series of very deep 'rivers' of cold, dense waters flowing northwards into the Pacific, Indian and Atlantic Oceans from the Antarctic. This bottom water is rich in nutrients and dissolved oxygen. In equatorial regions the deep water is 'pulled' to the surface to replace warmer surface water as it is moved by the prevailing winds. These upwellings bring rich nutrients to the surface and are therefore areas of high productivity.

Some species of marine organisms are common to the entire Australian coastline. However, studies of the distribution of molluscs, echinoderms and algae indicate that there are five distinct biogeographical zones which are, at least in part, determined by the ocean currents around the coast.

9.2.2 General features of the marine environment

Features of oceans that contribute to the great biodiversity of this environment are illustrated in Figure 9.5.

The majority of marine organisms have no problems controlling their water balance, because the salt concentrations of their cells and body fluids are similar to that of sea water. Bony fish, however, have an internal salt concentration that is lower than that of sea water and so water tends to be drawn from the fish's tissues to counteract this imbalance. To overcome this effect, the fish must use energy. Sea water is swallowed and passes into the bloodstream. The excess salts taken in are actively pumped out of the body through the gills. Turtles and marine birds must also secrete salt. The 'tears' of the turtle, seen when it comes to land to lay eggs, are in fact secreted salt.

The buoyancy provided by sea water allows marine organisms to attain a greater size than would be possible in a terrestrial environment, particularly in those organisms without a skeletal system. Floating organisms such as jellyfish and many larvae of larger animals are abundant. Rapid locomotion, however, is difficult in water and many vertebrates have evolved a very streamlined body shape which reduces resistance to movement in water.

Sea water absorbs a large percentage of the visible spectrum in the upper layers, which blocks photosynthesis beneath this zone and reduces visibility. Little use of vision is made, therefore, by marine animals and they rely more on touch, chemical and sound stimuli.

9.2.3 Marine ecosystems

The ocean can be divided broadly into two ecosystems—those of the surface and of the ocean floor.

The **plankton-nekton ecosystem** is the ecosystem of the surface. Nekton consists of free swimmers including fish, turtles and seals. Plankton consists of

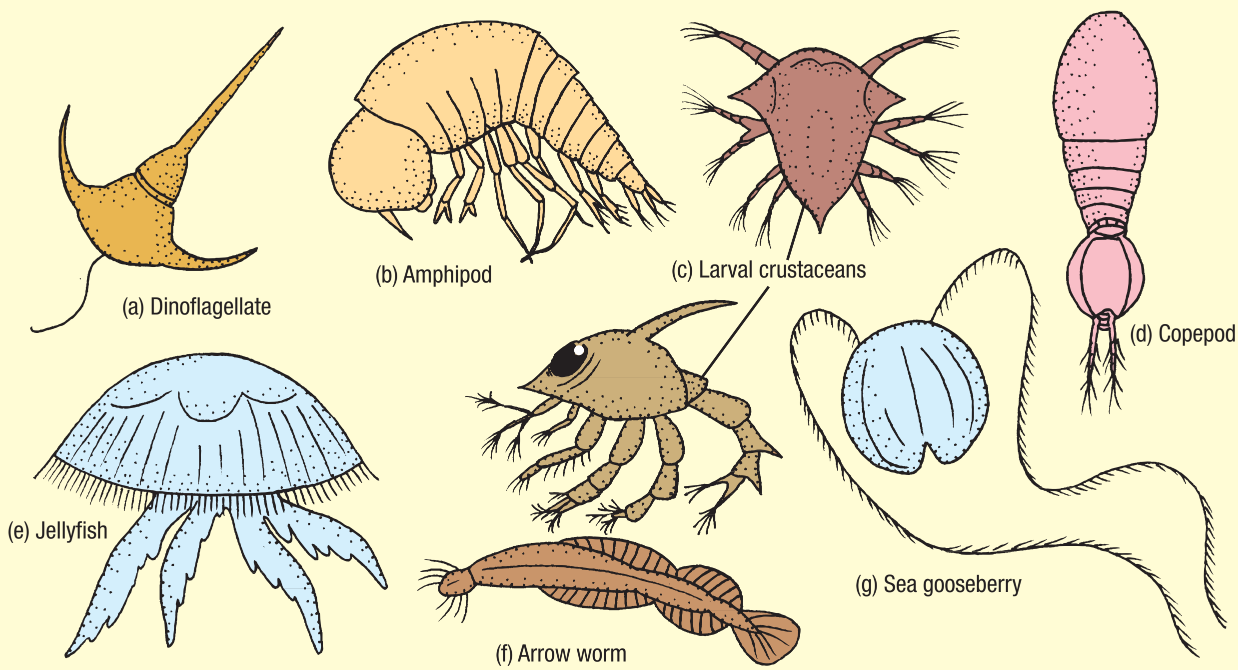


Figure 9.6 Plankton of the oceans (not to scale)

floating and drifting forms, most of which are microscopic in size. Phytoplankton refers to photosynthetic plankton; zooplankton to planktonic animals.

The **benthic** (noun *benthos*) **ecosystem** is the ecosystem of the ocean floor. The benthic ecosystem may be:

- **littoral**—where water meets land; or
- **neritic**—shallow coastal water (to a depth of approximately 180 m), which is associated with the continental shelf; or
- **abyssal**—deep water (depth greater than 180 m).

There is no light penetration in the abyssal zone and thus no photosynthetic organisms are found there. Consequently the oxygen content of the water is low. Most animals tend to be small, sluggish organisms which rely on odour to detect food. Some of these are detritus feeders, obtaining their food from dead organisms and organic matter drifting down from the upper surfaces. Others are carnivores which, like the angler fish, often have light-producing (bioluminescent) organs on the body surface to attract prey. The water pressure at these depths of the ocean is very great, so a hard outer surface protects the inner organs of most animals.

Deep rifts in the ocean floor support some communities at a water depth of 3000 m. In these regions molten magma seeps to the surface of the ocean floor. Geothermal energy from the radioactive material in the earth's mantle raises the temperature of the water. This hot water, reacting with minerals in rocks, produces hydrogen sulfide which is metabolised by chemosynthetic bacteria. Thus the producers of this community are bacteria which are eaten by a variety of mussels and clams. These become the food for crabs, starfish, octopuses, fish and giant tube worms.

At the surface of these deep oceans there is an abundant supply of phytoplankton. Zooplankton feed on these organisms and in turn provide food for a variety of **pelagic** organisms (free-swimming nekton of the open sea). Tuna and whales, which are adapted to swimming large distances, are examples of pelagic organisms.

In the neritic zone phytoplankton and zooplankton are plentiful. The temperature range is great, because of the relatively shallow depth of the water and the action of waves and currents. Evaporation in shallow waters and freshwater run-off from land both cause salinity to vary. Tides and currents can have a profound effect on organisms.

Benthic forms are found from the littoral zone through the neritic zone right down to the ocean depths. Life is plentiful in the first 50–100 m of the ocean because this region contains light and oxygen; it is also subject to wave action which circulates both oxygen and food. Life is not so abundant in the ocean depths because light, oxygen and food are scarce.

The littoral zone is wide along shorelines because of tidal action. Tides are associated with the

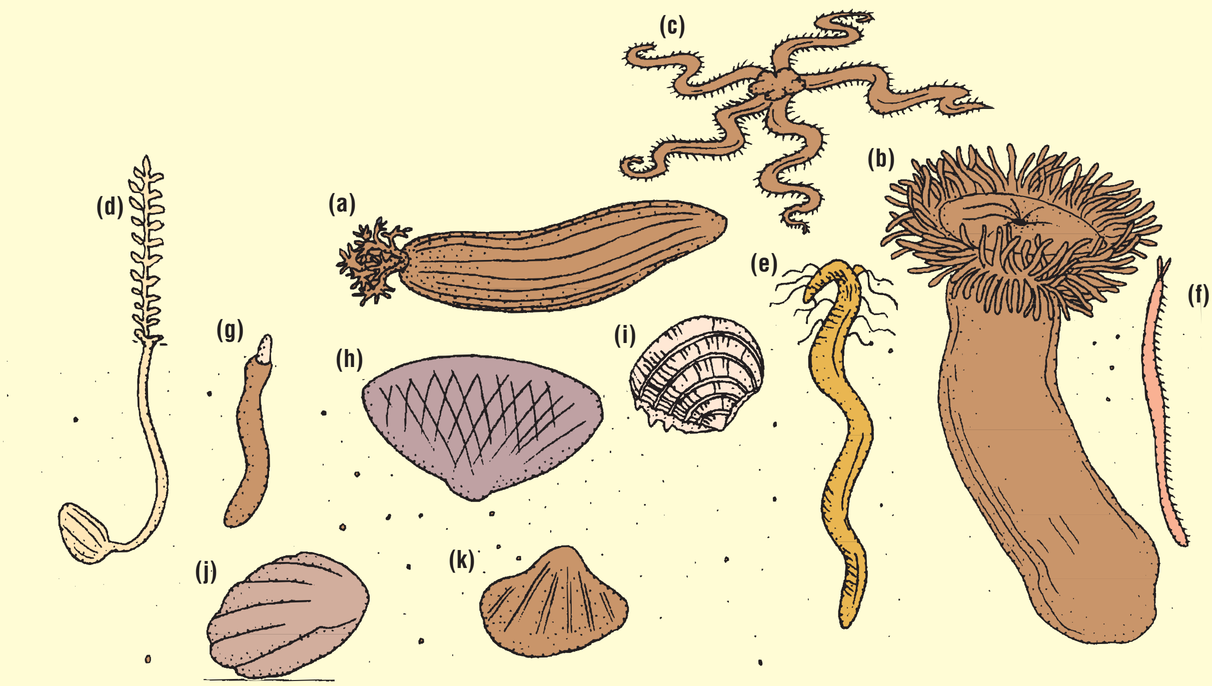


Figure 9.7 Benthic organisms: (a) sea cucumber; (b) burrowing sea anemone; (c) brittle-star; (d) sea pen; (e), (f) bristleworms; (g) echiuroid; (h), (i), (j), (k) various bivalves

gravitational pull of both the moon and the sun, but the moon has more than twice the effect of the sun since it is closer to earth. The earth rotates on its axis once every 24 hours, but the lunar day is approximately fifty minutes longer. Thus during every 24 hours and 50 minutes, any particular location on earth will experience two tidal cycles. A high tide occurs both when the moon is situated directly facing the locality and when it is located at the 'opposite' side of the earth. At these times the moon exerts its greatest gravitational pull.

The solar day is also 24 hours. Thus the gravitational effects of the sun on the surface waters of the earth coincide with that of the moon at full and new moon. When the gravitational pulls of the sun and moon add together they produce a **spring tide**. Between these periods, when the sun and moon are out of phase, the moon's effect is diminished slightly by the opposing smaller pull of the sun, and a **neap tide** results. These effects are illustrated in Figure 9.8.

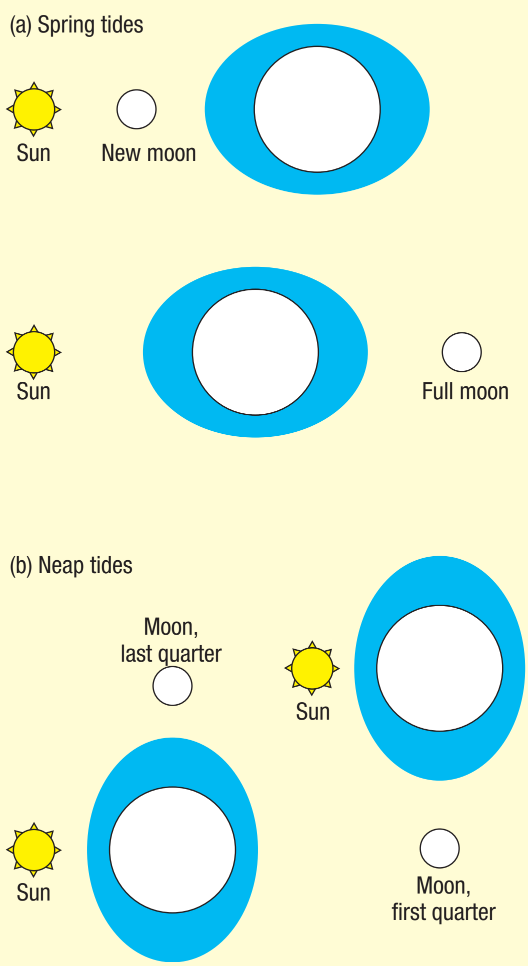


Figure 9.8 Positions of the earth and moon producing high tides

This tidal action means that the littoral zone is covered with water only for part of the daily tidal cycle. Organisms living in this zone, therefore, must:

- be restricted to rock pools where temperature variations may be great; or
- be capable of existing both in water and on land, and thus overcome the problems of desiccation, breathing in two different media, locomotion and reproduction; or
- move in and out of the area with the tide.

There are many different environments in the littoral zone, each having a distinctive community, such as rocky shore, muddy flat, sandy beach or estuarine. Life in this area can be very difficult because: of the sun, wind, waves and variable water level. On the other hand, it is a very fertile area because:

- much nutrient is swept down from the land
- tides and waves circulate these nutrients
- tides and waves dissolve oxygen in the water
- light can penetrate all depths
- abundant algal and plant life is present, due to ideal conditions for photosynthesis, and is readily available to the consumers
- high water temperatures cause rapid decomposition of dead organisms.

Case study 9.2: Rocky shore communities

Rocky shores are areas rich in marine flora and fauna as a result of the high nutrient and oxygen content of the water and the large range of habitats.

Table 9.1 Summary of habitat conditions on a rocky shore

Favourable factor	**Adaptation/effect**
Plentiful supply of food each tide	Filtering devices to trap food
Regular supply of water twice daily	Adaptations for fast feeding
Variety of habitats	Adaptations to a variety of places to live
Unfavourable factor	**Adaptation/effect**
Mechanical battering by waves	Strong holdfasts and muscular feet or cemented to rocks; hide in crevices; streamlined, flattened or rounded shape
Hot, dry environment	Waterproof 'houses' or skins (tubes, shells etc.); gastropods may have operculum to close opening of shell
Open to predation at low tide	High reproductive rate, ensuring survival of the species

Table 9.2 Horizontal zonation of rocky shore organisms

Zone	Organisms	
	Dominant	**Other common organisms**
Supralittoral		
Extreme limit of spray to HWS	*Nodilittorina* (snail)	lichen; encrusting algae
HWS to HWN	*Melaraphe* (periwinkle)	crabs; encrusting algae
Littoral		
Upper zone, HWN	*Chthamatus* (6-shelled barnacle)	limpets, gastropods; *Austrocochlea* (periwinkle) and *Bembicium* (nodiwink); green algae and a few small red and brown algae
HWN to MTL	*Tetraclita* (4-shelled barnacle)	chiton; oysters; algae
MTL to LWN	*Galeolaria* (tube worm)—replaced in waters north of Brisbane by a red algal zone	large brown algae; red and encrusting algae; barnacles
LWN to LWS	*Pyura* (sea squirt/cunjevoi)	shield shells; larger predatory gastropods, e.g. *Dicathais* (cartrut shell) and *Dinaessovica* (cat's eye); sea anemones; sea urchins
Sublittoral	red and brown algae	variety of algae; large gastropods; sea urchins; sea anemones; octopus

Key: HWS = high water spring tide; HWN = high water neap; MTL = mean tide level; LWN = low water neap; LWS = low water spring

Table 9.3 Vertical zonation on a rocky shore

Habitat	Organisms
Exposed to air on rock surface	Barnacles; periwinkles; limpets; chitons; tube worms; sponges; tunicates
In crevices and under rocks	Purple barnacle; red sea anemone; cap limpet; crabs; sea urchins; tent shells; purple sea cucumber; brittle-star; hermit crabs; worms
In rock pools	Small fish; brown sea cucumber; red-mouthed shell; sea hare; pear oyster; sea urchin; lace and parchment tube worms; sea anemones; soft and hard corals; sponges; octopus

Rocky shores are characterised by quite distinctive **horizontal zonation**, in which plants and animals are distributed in zones corresponding to various tidal and wave spray levels. These zones are named after the dominant (i.e. most abundant) organism found in the area. An additional **vertical zonation** is superimposed on this horizontal zonation. The type of organism found in each zone is related to its ability to withstand exposure to terrestrial conditions during low tide. Many of the shore organisms are very strict in their requirements and so are limited narrowly to certain conditions. Others are less particular.

Three strategies are available for littoral zone organisms:

- to remain marine (e.g. barnacles and limpets)
- to become amphibious (e.g. snails and crabs)
- to adapt to dry-land conditions (certain snails, e.g. *Nodilittorina*), although they still have to periodically return to the water to reproduce and moisten their gills.

The most common algae found in the littoral zone are the green filamentous *Enteromorpha* at high tide level, the brown Neptune's necklace (*Hormosira*) at mean tide level, and the green sea lettuce (*Ulva*) in the lower regions. The larger brown and red seaweeds are found only where there is minimal length of exposure to air. Although many gastropods in the littoral zone are browsers, the only other herbivores are the sea hare and a few sea urchins. The algae play an important part in the protection, support and shelter of many other animals in this community.

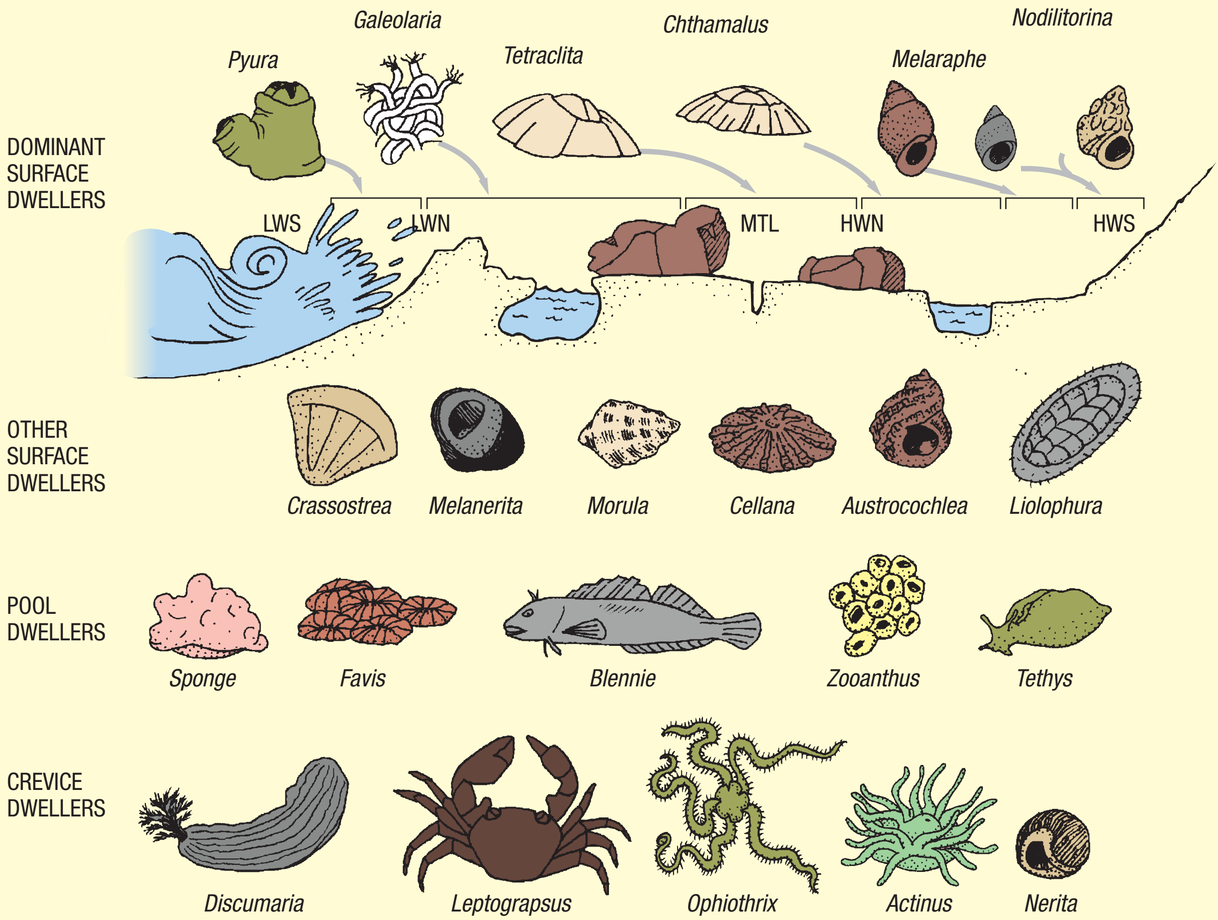


Figure 9.9 Cross-section of a rocky shore typical of southern Queensland and northern New South Wales, showing vertical zonations and their dominant animals

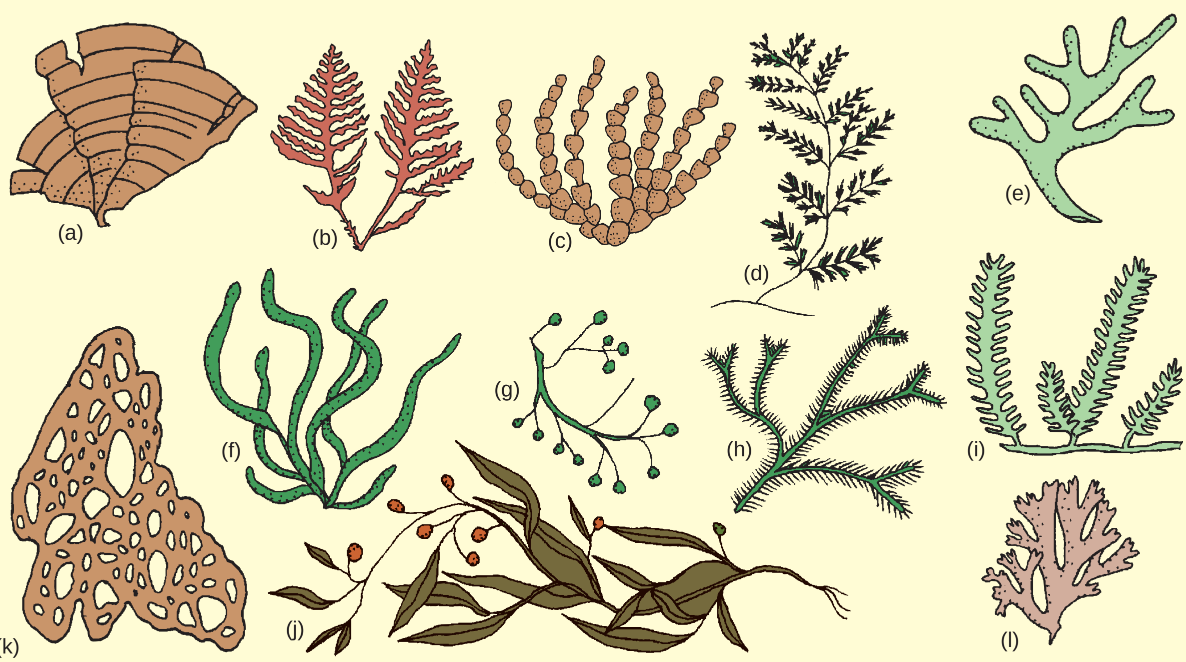


Figure 9.10 Common tropical marine algae (not to scale): (a) *Padina*; (b) *Laurencia*; (c) *Hormosira*; (d) *Asparogopsis*; (e) *Codium*; (f) *Enteromorpha*; (g), (h), (i) different species of *Caulerpa*; (j) *Sargassum*; (k) *Hydroclathrus*; (l) *Dictyota*

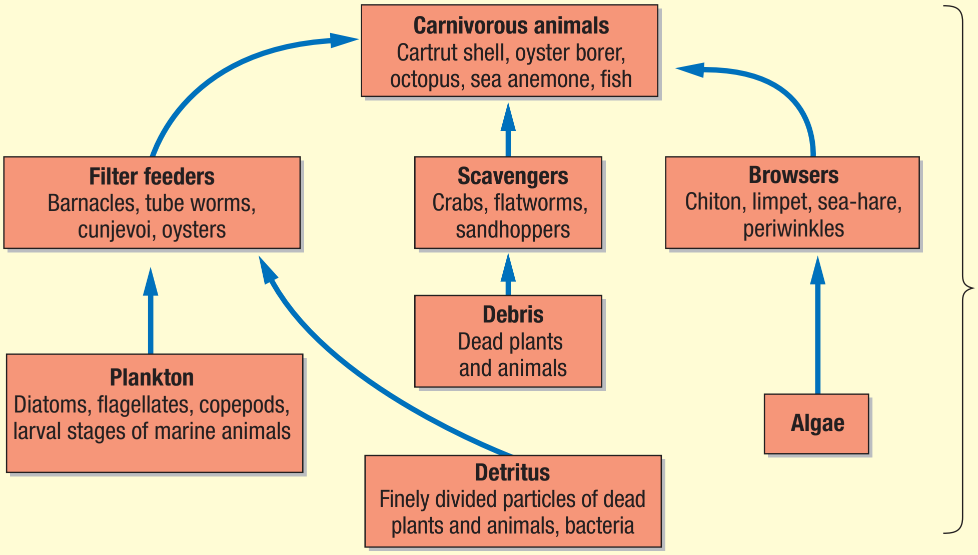


Figure 9.11 Feeding relationships of a rocky shore community (The arrows show the direction of flow of food.)

SUMMARY

Marine biogeographical zones around continents are strongly influenced by water currents.

Physical and chemical features of the oceans make them very stable habitats which can support a wide variety of different types of organisms.

Different marine zones are based on water depth and thus light penetration. The boundary of each zone is continuous with the next, so there is a gradual merging of life forms typical of a particular habitat.

Review questions

9.5 What factors are responsible for ocean currents?

9.6 Name the marine biogeographical zones around Australia and describe how they differ.

9.7 Internal water balance is not a problem for most marine plants and animals. Land animals which have returned to the sea (e.g. the turtle) or utilise marine resources (e.g. birds) do have problems maintaining the correct concentration of their cell and tissue fluids. How have they become adapted to this factor in the habitat?

9.8 Why can marine organisms grow to very large sizes?

9.9 Explain why marine organisms do not rely on the visual sense.

9.10 What is an upwelling? How and where is it formed?

9.11 Distinguish between plankton, nekton and benthos.

9.12 List the three benthic ecosystems and briefly note the environmental conditions which distinguish them.

9.13 What is meant by vertical and horizontal zonation of a habitat? Describe adaptations to the different environmental conditions encountered in each of these zonations by organisms of a rocky shore community.

9.3 Freshwater environments

The freshwater environment is discontinuous, and therefore different ecosystems are isolated from each other, often by vast tracts of land. Due to the non-permanence of many freshwater ecosystems, the variety of organisms living in them is much less than in marine ecosystems. One of the major differences between the two environments is associated with the depth and volume of water. The relative shallowness of freshwater ecosystems has both positive and negative effects.

Table 9.4 The effects of shallowness of water in freshwater environments

Positive effects	Negative effects
• Surface nutrients readily available • Upwellings of nutrients common • No problems of high water pressure	• Seasonal variations in depth, which may be very dramatic • Variable freshness of water • Variations in salt and ion concentrations with locality • Temperature variations between day and night and between seasons can be great. • Oxygen comes out of solution as water temperature increases. • Waters tend to be turbid and thus reduce light penetration to bottom.

A vital problem facing freshwater organisms arises from the fact that the salt concentration of the medium is less than that of the cells and body fluids of the organisms. There will be a tendency for water to pass into the organism and salts to pass out. For the organism to survive, this tendency must be counteracted. Various mechanisms are used:

- In some organisms (insects, lobbies and shrimp) the outer cuticle is impermeable to water.
- The outer surfaces of fish are protected by scales and a thin layer of mucus which reduces permeability.
- The shell of molluscs helps conserve body salts.
- The thin-walled gills of aquatic animals actively absorb salts from the surrounding water.
- Many aquatic animals have complex excretory systems which retain considerable amounts of salts and produce a large volume of very dilute urine.

Freshwater environments may be classified as either standing water (lakes, ponds and swamps) or running water (streams, creeks, dams and rivers). Isolated permanent ponds approach a closed community where inputs and outputs are fairly balanced.

Table 9.5 Characteristics of freshwater ecosystems

Environment	Characteristics of environment	Typical organisms
Rapid streams	• Rapid flow of water producing a firm bottom • Rocks with crevices for protection of organism • Often shallow with good light penetration and high oxygen concentration	• Larvae of insects with high oxygen requirement, e.g. mayfly, stonefly, caddis fly; bloodworms, snails and bivalves; fish • Minimal vegetation and plankton
Pools (quiet parts of streams)	• Slow movement of water • Bottom usually soft, of mud or sand; suitable for burrowing organisms	• Larvae of insects, e.g. dragonflies and damsel flies, beetles, bugs, bloodworms; mussels, fish, water snakes, turtles, frogs • Vegetation more plentiful
Ponds	• Slow movement due to wind or convection • Soft, muddy bottom	• Larvae of insects, e.g. dragonflies and caddis flies; mussels, snails, shrimp, amphipods, copepods, fish, water snakes, turtles, frogs • Vegetation and plankton plentiful
Lakes	• Wave action depending on size, depth and wind strength • Bottom mud or sand and gravel, or rocks • Lakes larger and deeper than ponds	• Animals vary greatly according to the nature of the bottom • Vegetation limited to region of light penetration

Case study 9.3: Standing water communities

Standing water communities are found where there is little movement of water. They are therefore characterised by low oxygen concentration, great temperature variation and changes in salinity as well as water level. Organisms include benthos, nekton and plankton and the individuals in each community fill the major niches as producers, consumers and decomposers.

Plants and algae which live in water are called **hydrophytes**. They may be:

- floating (plankton, green algae, duckweed, *Salvinia* and *Eichhornia crassipes*—water hyacinth)
- submerged (pondweeds whose leaves are thin and finely divided, reducing resistance to water movements)
- rooted, with floating leaves (waterlily)
- emergents (the edge-dwelling sedges, reeds and aquatic grasses whose photosynthetic surfaces are mainly projecting from the surface).

Representatives of most animal phyla (except echinoderms) are found among the consumer organisms.

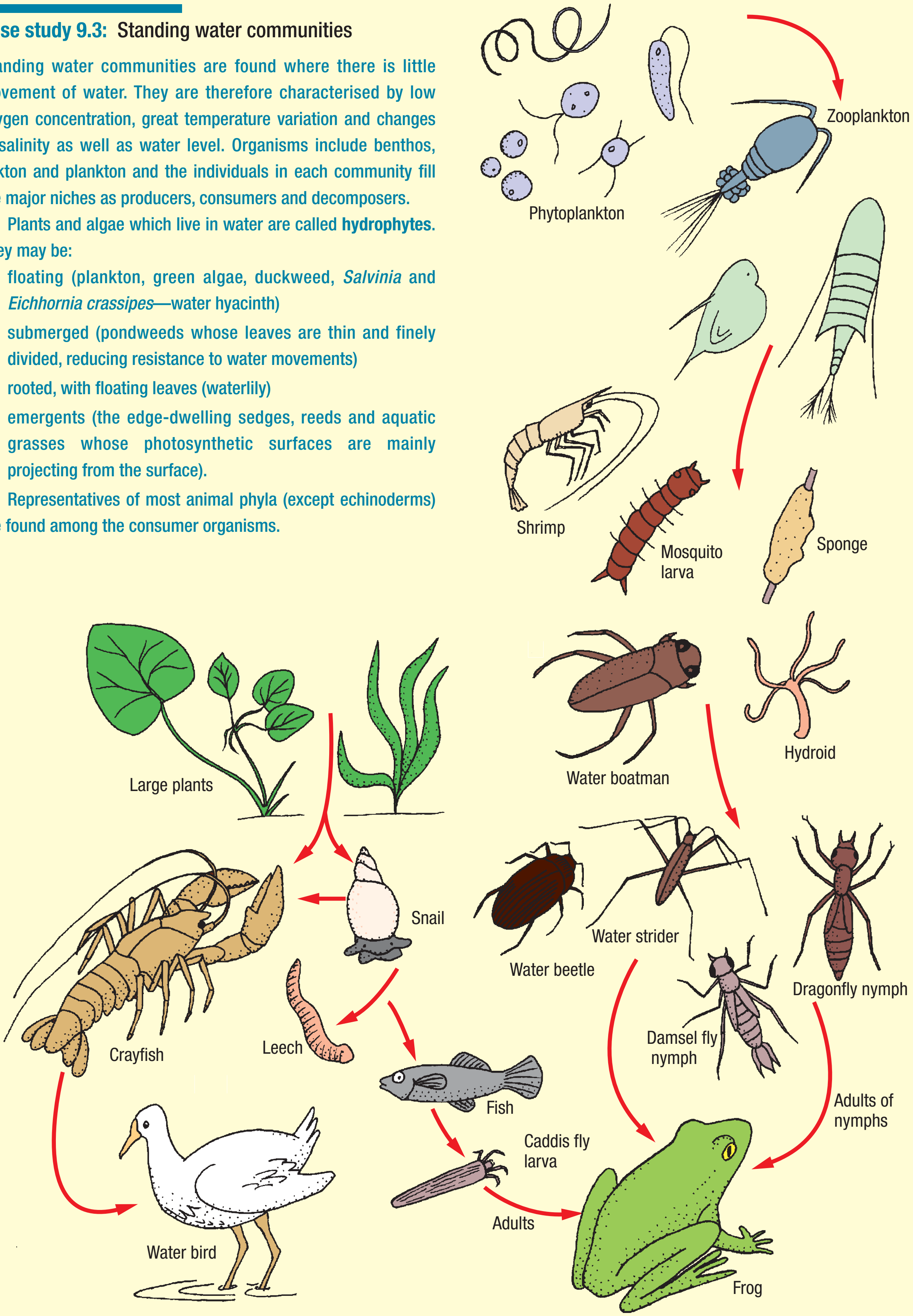


Figure 9.12 Feeding relationships of a permanent pond

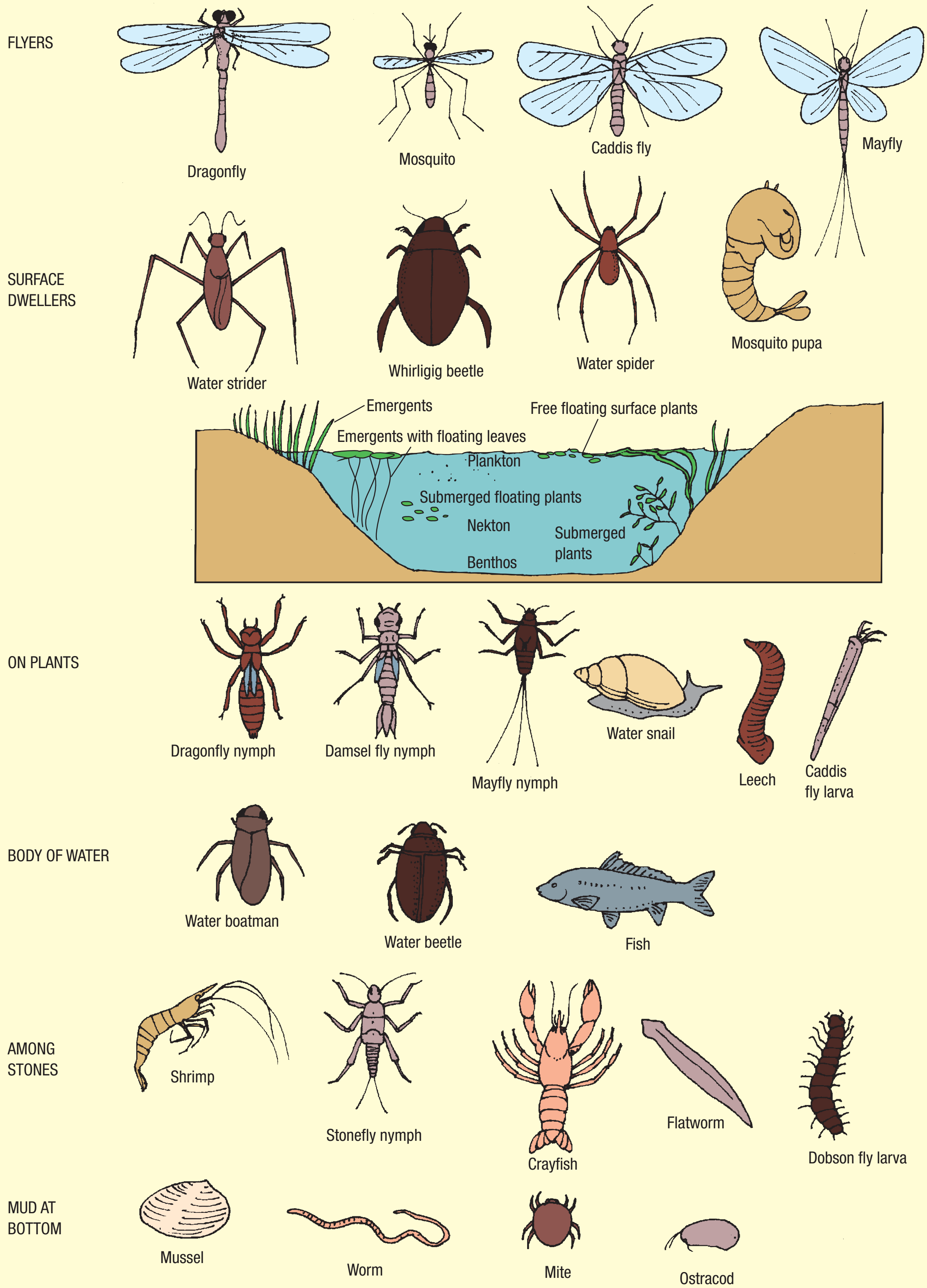


Figure 9.13 Cross-section of a permanent pond showing the dominant organisms

SUMMARY

Freshwater environments share many of the properties of the marine environment, but they:

- are discontinuous, so there is greater species variation between different areas
- are relatively shallow, so have greater light penetration and nutrient upwellings; less pressure problems, but greater temperature variations
- have a very low concentration of dissolved salts (which varies with soil composition), so organisms need adaptations which counteract the tendency for water to enter the body and allow them to absorb salts.

Plants that live in water are called hydrophytes and may be floating, submerged, rooting or emergent. Freshwater ecosystems are associated with either running or standing water.

Review questions

9.14 List some adaptations of organisms that make it possible for them to maintain their correct water balance in a freshwater habitat.

9.15 Compare and contrast abiotic features of a rapid stream and a large permanent pond.

9.16 The boundaries of a pond community are more defined than those of most other communities. Explain why ponds are considered virtually closed communities.

9.4 Terrestrial ecosystems

9.4.1 General features

Land environments are controlled by a wide range of factors which make conditions more variable than in water environments. These can be grouped into four main categories:

- chemical (e.g. nature of the soil)
- geographical (e.g. topography and altitude)
- physical and climatic (e.g. transparency of air, lack of buoyancy)
- biological.

Some of these factors and their effects are listed in Table 9.6.

All terrestrial communities depend ultimately on the vegetation, whether this be trees, bushes or grasses, or a combination of all three forms. Since plants are immobile, they are completely controlled by their environment and therefore strongly reflect it. As environmental conditions (landform, soils, animal life, human activities and climate) change from region to region, so does the type of vegetation cover.

The general pattern of vegetation in Australia reflects four important environmental influences:

- The aridity of the Australian continent has resulted in a large number of xerophytic (drought-adapted) plants.
- Zones of decreasing moisture from the coast to the dry interior have produced a roughly concentric pattern of vegetation, graded from forest associations along the coasts through woodlands and grassland to desert associations in the interior.

Table 9.6 Factors affecting terrestrial communities

Unfavourable factor	Effect	Favourable factor	Effect
Very variable temperatures	Adaptations to specific temperature ranges	Plentiful oxygen supply	Animals can have high metabolic rate and thus be very active
Air not buoyant	Few floating forms; plants and animals need supporting structures; animals need structures for locomotion	Air transparent	Sunlight readily penetrates air; therefore high rate of photosynthesis; visual perception
Scarcity of water	Paucity of life in areas; concentrated excretory products; respiratory surfaces internal; internal fertilisation; seeds hard and dry; external surfaces prevent water loss	Air has low viscosity	Greater variation of animal shapes; sound production by a great variety of animals
		Greater variety of habitats	Diversity of form and requirements

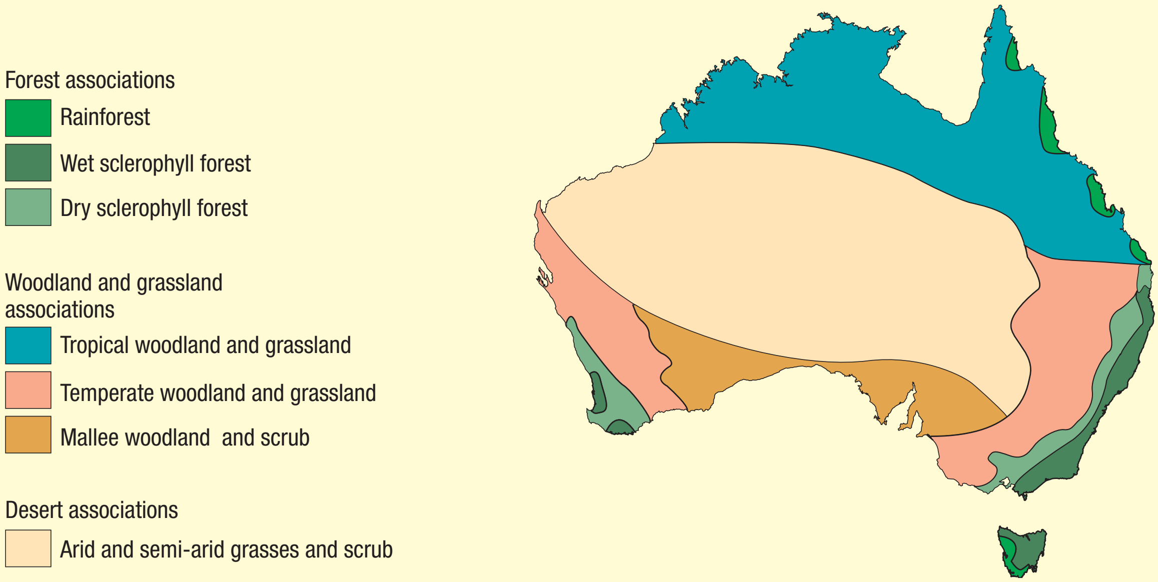


Figure 9.14 Australian vegetation zones

- The isolation of the Australian continent has resulted in the dominance of typically Australian plants.
- The low-fertility soils are depleted of nitrates and phosphates.

Although climate is the major influence on Australian vegetation patterns, many parts of the continent do not support plant communities that are typical of the climate, due to the overriding influence of local soils and topography. Thus many coastal areas, instead of supporting forest communities, have heath vegetation. This is due to the high permeability and low water retention of the low-nutrient, sandy soils as seen in the Hawkesbury Sandstone communities of New South Wales.

9.4.2 Characteristics of Australian vegetation zones

Rainforests

- Found in high-rainfall regions near the coast.
- Require fertile soils, or soils in which there is a rapid rate of decomposition and recycling of nutrients.
- Trees grow close together and display species diversity.
- The canopy forms a cover which excludes light from the forest floor.
- Grasses and herbs tend to be absent from the forest floor.
- Epiphytes (plants which use other plants for support) are present.
- Mosses and ferns survive well in the limited light and high humidity of the forest floor.

Wet sclerophyll (= hard-leafed) forest

- Found in high-rainfall coastal regions.
- Large number of eucalypts present.
- Shrubs and ferns present on the forest floor due to the less dense canopy.
- Broadleaved creepers present.

Dry sclerophyll forest

- Found on drier soils than wet sclerophyll forests.
- Eucalypts are the main trees.
- Trees are not as tall as those of the wet sclerophyll and the canopy is more open.
- Trees are widely spaced.
- Fewer shrubs and ferns than in wet sclerophyll.

Woodland

- Trees are more scattered than in forests and thus the canopy is very open.
- Grasses and shrubs cover the ground.
- In savannah woodland, grasses more numerous than shrubs.
- In shrub woodland, shrubs more numerous than grasses.

Scrub

- Trees not present.
- Main plants are tall shrubs.
- Perennial grasses (those in which growth continues for many years) are usually found.

Saltbush

- Short, widely spaced shrubs only.
- Grasses occupy the areas between the shrubs.
- Leaves of the shrubs are semi-succulent.

Desert

- Very little moisture available.
- Sparse covering of bunch grasses such as spinifex.
- Flowering ephemerals (able to go through their life cycle extremely quickly) grow after rain.

Case study 9.4: The rainforest community

Characteristics of a rainforest community

Rainforests are dense forest communities dominated by a very large number of tall moisture-loving trees of different species, growing very close together. The tree trunk diameters range from very large to small. The canopy is layered. Some trees emerge high above the closed canopy of a middle layer which virtually eliminates sunlight from the forest floor. The forest floor, therefore, is usually covered with leaf litter but very few grasses or herbs. Characteristic plant forms include:

- trees, displaying either buttress or prop roots
- epiphytes—plants such as lichens, mosses, ferns and orchids which adhere to other plants; like aerial gardens in the treetops
- tree ferns
- palms
- lianes—woody plants rooted in the ground but using other plants for support so that they can reach the light
- scramblers such as the lawyer vine or rattan, which are assisted by thorns or prickles on long flexible stems and which cling to trees
- root climbers (e.g. members of the family Araceae). In these species adventitious roots from the stems attach to the bark of the supporting tree.
- twiners, which grow spirally around the stems of saplings.

All of these plants show adaptations to growing in low light intensities, or to finding their way high in the dense canopy in order to reach the light.

Factors necessary for the existence of rainforest

Climate is a significant factor in the distribution of rainforest. Usually a rainfall of more than 127 cm per year, with no seasonal droughts, is required. Rainforest can exist in areas of lower rainfall provided there is a low evaporation rate, persistent cloud cover or high humidity.

Soils on which existing rainforests occur are usually shallow and derived from eroded basalt rock. Many deep-soil rainforest areas have been cleared for agricultural purposes; for example, on the Atherton Tableland and the coastal sugarcane areas of Queensland. In tropical regions where decomposition of dead material is rapid, soil nutrients are not critical, but in subtropical regions soil fertility is a significant factor in rainforest distribution. Soil mineral reserves in rainforests are generally low and the maintenance of large and vigorous vegetation is dependent upon internally cycled elements through the action of decomposers. Rainforest species are intolerant of fire, and areas destroyed by fire tend not to regenerate.

Mineral cycling

Most of the minerals and nutrients of a rainforest area are locked in the chemicals of the plants themselves. In order to maintain such large trees, these chemicals must be rapidly broken down to a form which can be utilised by the plants as soon as organisms die. Thus there is a large decomposer population in the rainforest. Fungi and bacteria thrive in the high humidity maintained by the closed canopy of the forest. Mycorrhizae are prevalent on the roots of rainforest trees, making nutrients contained in detritus readily available to the trees. Buttress roots support the larger trees; they also aid in the rapid resorption of mineral nutrients as decomposers make them available, and serve as aerating organs.

Types of rainforest

There are several types of rainforest, each associated with particular climatic conditions. Biodiversity is greatest in forests near to the equator. Characteristics of the various types of rainforest are given below.

Tropical rainforest

- This is the most complex of all ecosystems, due to the large number of plant and animal species.
- Trees tend to be straight-stemmed and slender.
- Plank buttresses are common on the larger species.
- Leaves tend to be large, thin and smooth-edged, many displaying a ‘drip tip’ which is an adaptation for rapid removal of water.
- Cauliflory (the bearing of the flower buds directly on the branchless sections of the tree stems) is common.
- Lianes and epiphytes are abundant.
- Strangler figs are present. These begin life as an epiphyte on the stem of a ‘host’ tree, and send down long aerial roots to the ground, the network of which gradually enmeshes the host, ultimately killing it by strangulation.

Figure 9.15 Some of the life forms of a tropical rainforest

Subtropical rainforest

- The range of plant species is reduced in comparison with tropical rainforest.
- Leaves are smaller.
- There are fewer lianes and epiphytes.
- Buttress and stilt-rooted species are fewer.
- Cauliflory is absent.

Temperate rainforest

- Buttressing, cauliflory and lianes are absent.
- There are fewer tree species.
- Leaves are smaller and frequently have serrated edges.
- Mosses and lichens are prominent.

Animals of the rainforest

Due to the complexity of the rainforest and the myriad of habitats within this ecosystem, there is great diversity of animal life and feeding relationships are intricately cross-linked. Animal relationships within the rainforest can probably best be interpreted on the basis of the strata within it.

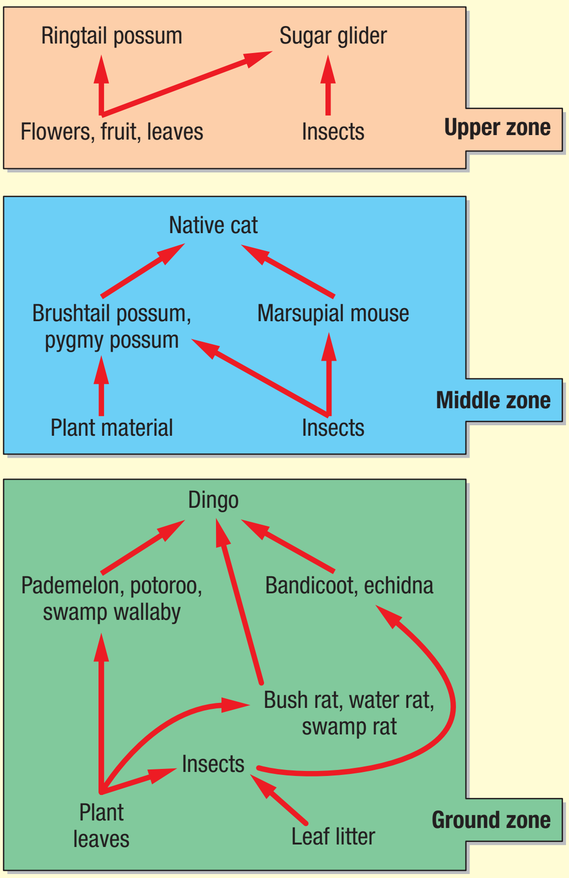


Figure 9.16 Feeding relationships of mammals found in the Lamington National Park (south-east Queensland)

The humidity of the forest, with its moist layer of leaf litter, provides a perfect environment for detritus feeders such as insects, snails, slugs and earthworms. These ground-living organisms provide food for a variety of frogs, skinks, birds and mice, bandicoots and wallabies, which in turn are preyed upon by carnivores such as snakes, water rats and dingoes. The middle and upper layers of the forest have their own distinctive fauna, with the leaves, flowers and fruit of the trees, and the algae and lichens encrusted on them forming the basis of their feeding interrelationships.

Figure 9.16 shows some of the feeding relationships of mammals in a rainforest area of south-east Queensland.

SUMMARY

The terrestrial habitat consists of the soil, its surface and the layer of air surrounding it. There are great differences in abiotic features from place to place, which depend on climate, topography, soil type and water availability. These features influence the types of vegetation and thus the fauna present in any area. Australian vegetation patterns reflect world biomes, and are strongly influenced by the zones of increasing moisture from an arid interior to the coast, and by soils that are poor in nitrates and phosphates.

Review questions

9.17 List favourable and unfavourable factors and their effects on organisms in a terrestrial environment.

9.18 What major factors influence the distribution of plants in Australia?

9.19 What factors (biotic and abiotic) contribute to the great biodiversity of rainforests?

9.20 Rainforests are often termed ‘closed forests’. To what feature does this refer? How does this influence the types of vegetation found in these communities?

9.21 Describe features of the different types of rainforest. Where in Australia would you expect to find each type?

9.22 Distinguish between a dry sclerophyll forest, a savannah woodland and a desert.

9.5 Interactions between communities

The boundaries between communities are rarely distinct; they usually merge into each other. A mangrove community forms a buffer between an estuary and the land, with species from both areas intermingling in this area.

Case study 9.5: The mangrove community

Mangrove is the name applied either to an individual species or to a whole community of plants. These plants grow together in habitats along tropical and subtropical coasts where there are quiet tidal waters, areas of silt around the mouths of rivers, tidal river reaches or swampy areas inundated by tides. All these areas are usually protected from strong wave action and currents.

The plants occupy the areas between the low and high tide levels, rarely extending beyond the limit of high tide because they rely on the water for seed dispersal. Their roots and trunk bases are covered by sea water at high tide, and at low tide the roots are subjected to rain and freshwater seepage.

A number of plant families are found in these habitats. Each species is found in fairly well defined zones according to the ability of its roots and trunk to withstand one or more of the following factors:

- salt water
- the degree of submersion
- the frequency of submersion
- the soil conditions.

Soils in this zone are poorly drained, saline, anoxic (oxygen-depleted) and usually consist of fine-grained sediments. They are poorly consolidated and can range from coarse shell fragments through sands to clayey muds. The soils are rich in organic materials that originate from the deposition of plant debris from the mangroves. This organic debris is broken down by microorganisms such as bacteria, moulds and cyanobacteria. The anaerobic conditions below the soil surface provide a home for sulfate-reducing bacteria which convert the organic sulfates from debris and soil water to hydrogen sulfide gas, giving mangroves their pungent odour.

Mangrove species are facultative **halophytes**. A halophyte is a plant adapted to grow in salt and brackish water. Mangroves grow best in saline conditions but do not need salt to grow: they are not obligate halophytes. Many adaptations are required for survival in this unstable, anaerobic, saline habitat.

General physiological adaptations

Mangroves have many ways of coping with the high salt content in their environment.

In general, they have relatively higher internal salt concentrations in their sap than most other land plants can tolerate. Mangroves may remove salt by storing it in older leaves before they fall. It is the higher salt concentration that gives the older leaves their succulence.

Mangroves reduce the accumulation of internal salt by actively excluding and/or secreting salt from roots and leaves. These processes have the effect of reducing the concentration of salt in actively growing shoots. Mangroves can be divided into two major groups on the basis of these processes: **salt secreters** and **salt excluders**.

Salt secreters absorb salt and water into their roots. The salt is concentrated and then actively removed by special leaf glands, using energy supplied by the plant. Examples of salt-secreting mangroves include species of *Avicennia*, *Aegiolitis* and *Aegiceras*.

Salt excluders allow less salt to enter their root systems. Very little salt is secreted, therefore, and excess salt is dealt with by leaf storage. This also involves a mechanism whereby salt is removed from the root, leaving the water behind. Again, energy for this active transport is provided by the plant. Examples include the genera *Rhizophora*, *Sonneratia*, *Lumnitzera* and *Bruguiera*.

Root system adaptations

Aerial roots give the plants nutrition, water absorption, gas exchange, support and anchorage in oxygen-deficient, often fluid soils. The roots are often extensive and shallow, and lack taproots. There are four main root types seen in mangroves: **prop** or **stilt roots**, **'knees'**, **peg roots** and **meandering buttresses** (see Figure 9.17 on page 222).

Prop or stilt roots arch from the main trunk and end in clusters of support roots. Looping **pneumatophores** ('breathing' roots that facilitate aeration) may develop from the prop roots. Aerial (adventitious) roots may originate from lower branches. All these roots have lenticels that allow gas exchange, particularly uptake of oxygen at high tide (e.g. *Rhizophora*).

Lateral roots may send up 'knees' above the soil surface (e.g. species of *Bruguiera* and *Ceriops*, which grow in more consolidated soils); these provide oxygen for root activities.

Peg roots are slender conical aerial pneumatophores which emerge upwards through the soil surface from an extensive system of shallow lateral roots. These pegs have the ability to trap oxygen in spongy tissue when the root lenticels are exposed at low tide. This oxygen is then available for respiration by the roots when they are submerged. Peg roots are found in the genera *Sonneratia*, *Avicennia* and *Xylocarpus*.

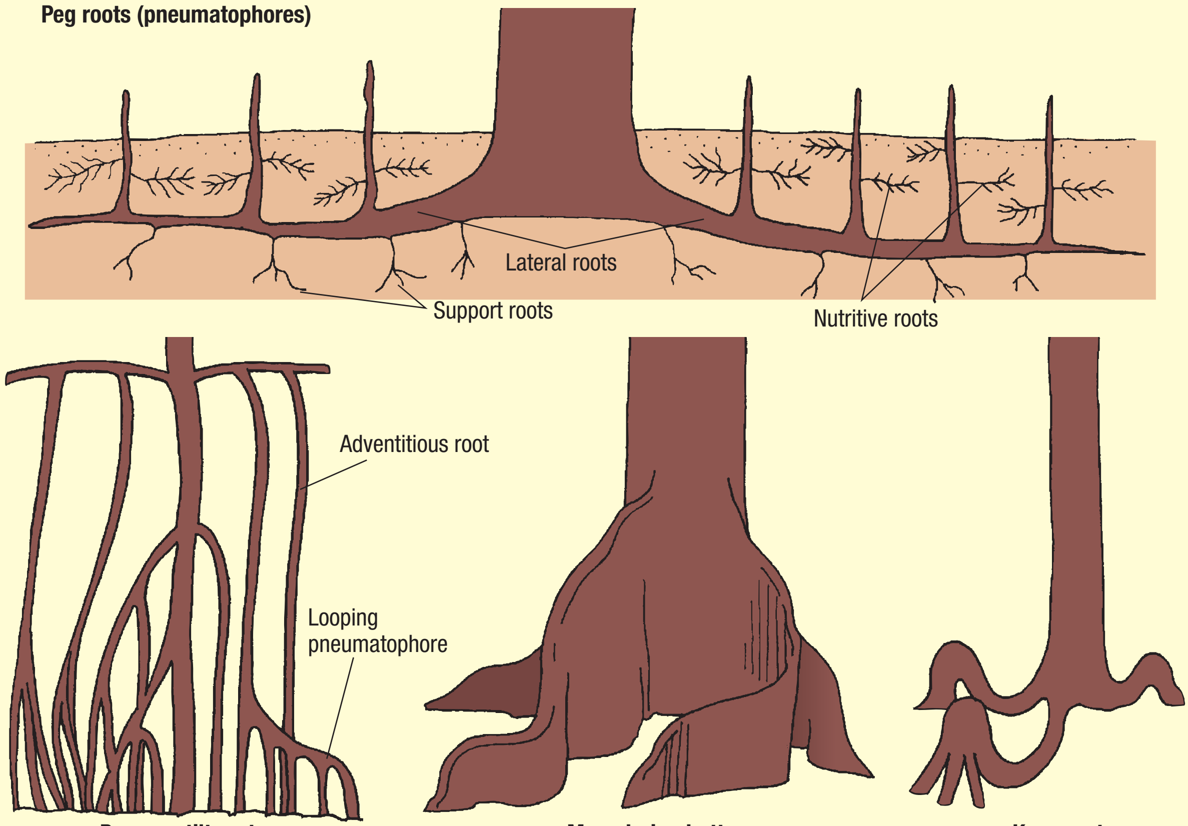


Figure 9.17 Adaptations of mangrove roots

Meandering buttresses are triangular, upwardly projecting ridges of the main lateral roots. They contain lenticels which aid in the aeration of the underwater and underground sections. These may be seen in *Xylocarpus* and *Heritiera*.

Leaf adaptations

The leaves are all very much alike: smooth, of medium size, and succulent. The environment in which mangroves survive is saline, with high light intensity and high temperatures, and is often windy. These conditions result in physiologically drying conditions. To prevent water loss, the leaves have a thick-walled waxy epidermis, sunken stomata, well-developed water storage which gives them their succulent characteristics, and some have salt glands that remove excess salt. They are thick and toughened, preventing collapse of the leaf's photosynthetic tissue in this harsh environment.

Flowers, fruits, seeds and seedlings

Flowers are small. They are pollinated by wind, bees, nectar-eating bats and birds, and nocturnal moths. Most flowering and fruiting occurs in the summer months.

Fruits are variable, but many are **viviparous:** seedlings are produced from the fruit while it is still attached to the parent tree. This practice is unique to mangroves and is an adaptation to the environment which allows seedlings to grow rapidly once they settle. The seedlings are dropped at an advanced stage and their roots can develop within a few hours of being shed from the parent tree. They are light, for water dispersal, and are structured so that they float with the root section downwards. Some examples are shown in Figure 9.18.

Seeds and viviparous seedlings are all dispersed by water only, and are able to survive for some months floating in the sea water.

Because the estuarine waters are so silt-laden and the mangrove trees themselves cast considerable shade on the water, light penetration through them is very poor. As a consequence, the mangroves are the only conspicuous producers of the littoral zone. Planktonic diatoms are, however, found on the surface of the mud and smaller algae grow on the trunks of the trees.

Where the trees are spaced out, some clumps of eelgrass, *Zostera capricorni*, are found. Eelgrass (a marine angiosperm) becomes more dominant seaward of the mangrove zone and into the shallow waters of the sublittoral zone in areas where there are no soldier crabs present.

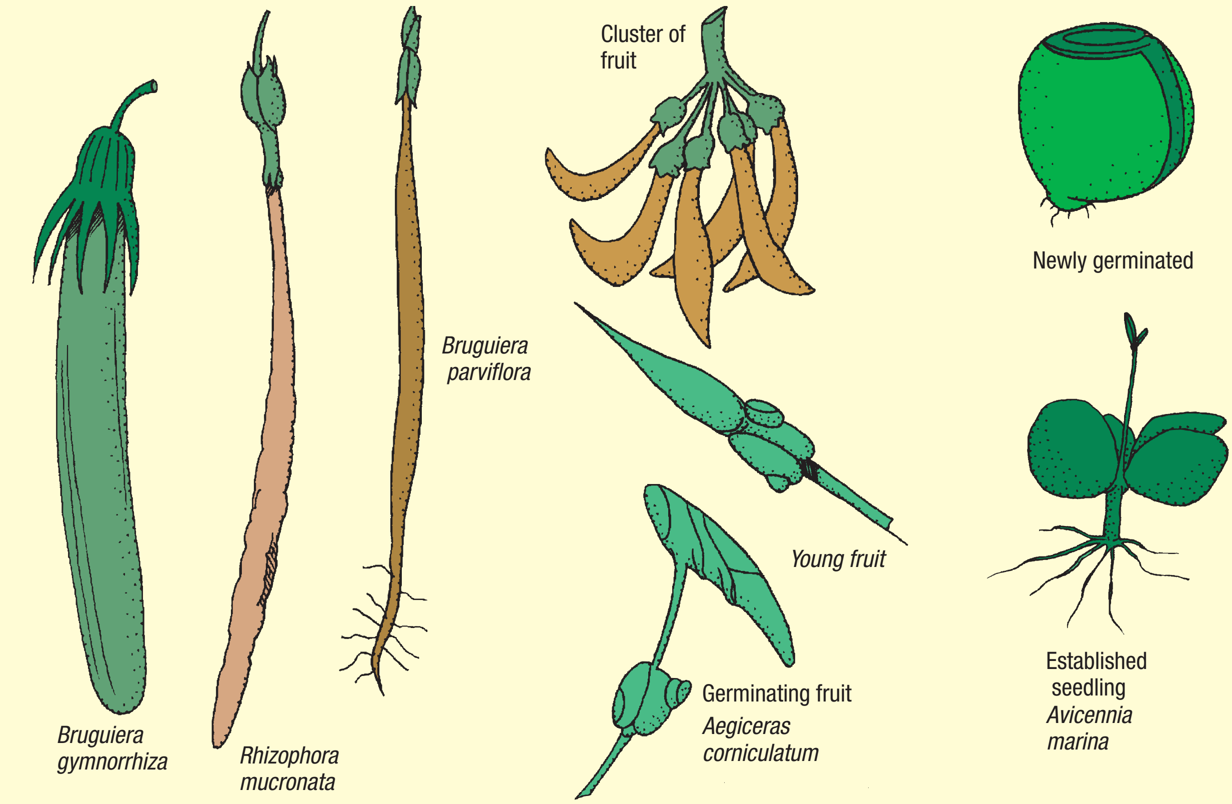


Figure 9.18 Fruits of common mangrove species

Table 9.7 A mangrove-mudflat community in south-east Queensland

Zonation	Habitat	Dominant species	Other species
Supralittoral			
	mud	grey mangrove (*Avicennia marina*), snails (*Salinator solida*), semaphore crab (*Sesarma*)	bubble shell (*Haminoea*), fiddler crab (*Uca*), snail (*Ophiocardilis*)
	on trees	*Melaraphe scabra*	
Littoral			
	mud	*Ceriops tagal*, *Bruguiera gymnorrhiza*, semaphore crab	nodiwink (*Bembicium auratum*) periwinkle (*Austrocochlea obtusa*) mudwhelk (*Pyrazus ebenius*) fiddler crab mud crab (*Scylla serata*)
	on trees	encrusting barnacles (*Balanus amphitrite*)	shells (*Nerita, Melanerita*, *Bembicium*) oyster (*Saccostrea commercialis*) mussel (*Trichoma hirsutus*)
	mud	*Rhizophora stylosa*, fiddler crab	stalk-eyed crab (*Macrophthalmus crassipes*) hermit crab (*Paguristes*)
	on trees		oyster, mussel
	mud	*Avicennia marina*, mudskipper (*Periopthalminae*)	soldier crab (*Mictyris*)
Below mangroves			
	mud	*Zostera* beds mudskipper, yabby	other crabs, polychaete worms, sea anemone (*Edwardia*), sea cucumber, sea slug (*Dolobella*), sponges

Mangrove animals

Mangrove animals live in a variety of quite different habitats: creeks and channels, semi-permanent pools, on the soil surface, within the soil, on tree trunks and root systems and in the tree canopy. A large number of essentially terrestrial animals utilise the mangrove area.

Wetland birds (e.g. sea eagle, pelican, heron, mangrove kingfisher and rainbow bird) use the canopies of the trees for roosts and prey on organisms below. The water rat (*Hydromys chrysogaster*) builds a twig nest above the high water level and fruit bats roost in the canopy. The mangrove snake (*Fordania leucobalia*) is believed to enter burrows, seeking crabs which are probably also preyed upon by the mangrove monitor lizard (*Varanus semiremex*). Numerous insects (sandflies, mosquitoes), ants and spiders abound in this area.

The mangrove area is second only to coral reefs in terms of productivity, due to the large amounts of debris falling from the mangrove trees and nutrient run-off from land. The debris is rapidly broken down into smaller particles by microorganisms which abound in the warm, humid conditions. Thus detritus feeders are plentiful and these attract estuarine fish into the area at high tide to feed. For many commercially fished species (e.g. mullet, mud crab, flathead and prawns), the mangrove acts as an important breeding ground where the planktonic larvae

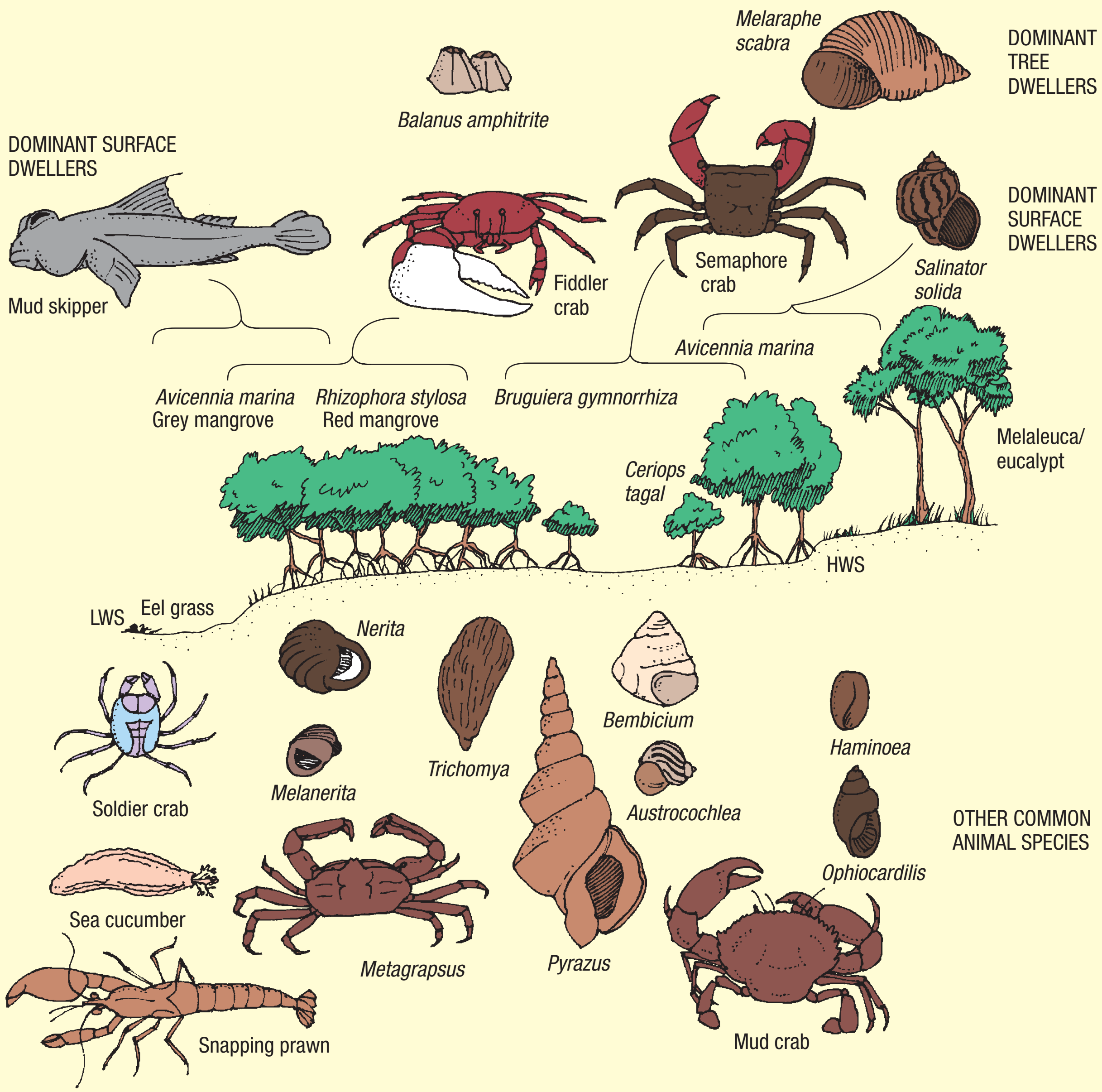


Figure 9.19 Cross-section through a mangrove community in south-east Queensland, showing dominant species. In northern Australia, where climatic conditions are more suitable for mangrove plants, the trees are generally taller, with a closed canopy. There is greater species diversity, making the zones more complex.

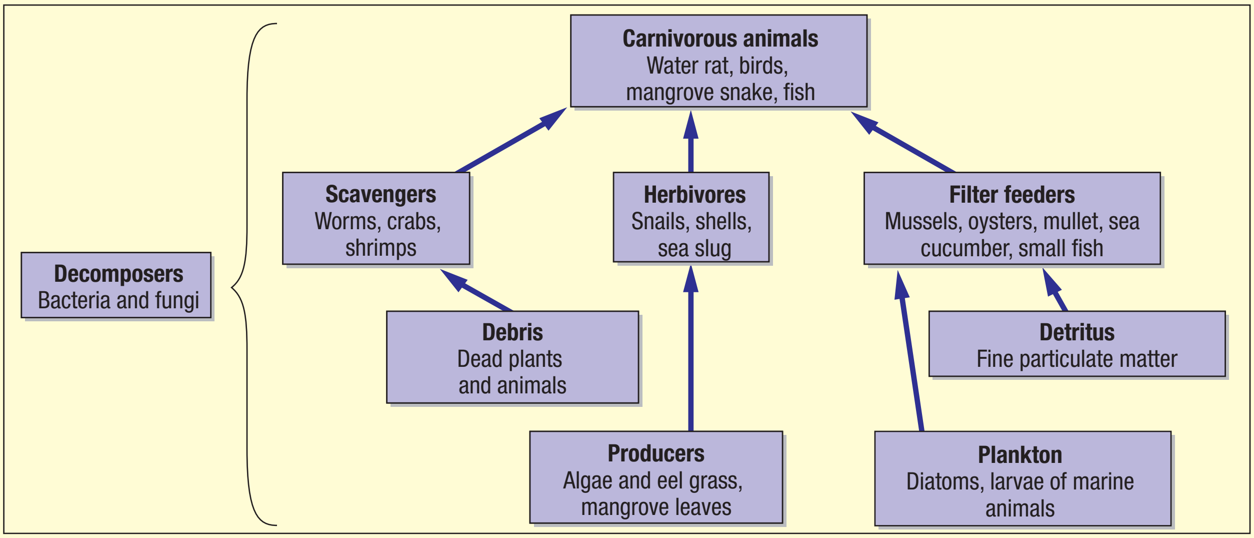


Figure 9.20 Feeding relationships in a mangrove community

and young fish are able to develop in a nutrient-rich environment.

Although mangrove is a predominantly littoral zone community, it forms an important buffer zone between the marine estuarine community (which merges with the oceanic community) and the woodlands directly adjacent on the landward side. Above the high water level there is a marked transition from the halophytic vegetation to the paperbarks (*Melaleuca*) which are adapted to wet, swampy freshwater soils, or woodlands and forests in areas where no swamps exist. Many terrestrial animals utilise both zones. Thus the fruit bats, which 'camp' in the mangrove, forage widely in the adjoining forests.

SUMMARY

Within each biome, communities exist with specific adaptations to local conditions. Boundaries of communities are rarely distinct, because abiotic conditions do not change abruptly. Thus the ocean biome merges, through the littoral zone, with terrestrial environments. Some members of both communities will be common to both environments, utilising resources on their edges.

Review questions

9.23 Mangroves are usually included among marine communities. Trees—the dominant life form of mangroves—are, however, specifically terrestrial organisms. Mangroves occur many kilometres inland along rivers and tributaries which are under tidal influence (e.g. Oxley Creek and the Indooroopilly Reach of the Brisbane River). The estuarine flats, where mangroves are more commonly found, overlap with freshwater environments. What does this information indicate about community boundaries?

9.24 List the abiotic conditions of mangrove communities.

9.25 Discuss adaptations of mangrove plants to:
(a) high salt content; (b) low-oxygen soils;
(c) unstable soils.

9.6 Studying communities in the field

9.6.1 Types of assessment

There are few situations where it is possible to count all members of a population, let alone those of a community and the abiotic components significant to that community. Biologists therefore sample the particular features they wish to measure and apply statistical tests to the data obtained in order to come to a conclusion about the whole.

The first step in any sampling is to define precisely what is to be sampled—for example, the distribution of spotted gums on the western slope of Mt Coot-tha. Then it must be determined from where the samples will be obtained within the total area. Normally, samples should be taken at random.

Sampling is biased if:

- some members of the population are more likely to be recorded than others

- the recording of some affects the recording of others
- the investigator selects particular sample sites that
  — are easy to reach
  — are not unpleasant to work in
  — give the results they are expecting, and so on.

Random sampling implies that each measurement in the study has an equal chance of being selected as part of the sample. Biologists often use a table of random numbers from which to select map coordinates or numbered sample sites.

The area under investigation might be mapped as a grid pattern, as illustrated in Figure 9.21. Each square of the grid is allocated a number. A systematic approach would be to sample predetermined squares.

Random and systematic sampling minimise bias by deliberately ignoring features of the habitat. Legitimate conclusions can be drawn from data obtained from these types of sampling.

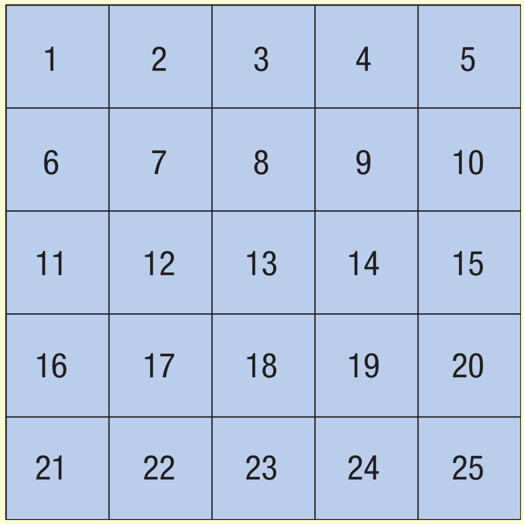


Figure 9.21 An area mapped into a grid. Systematic sampling would involve sampling a set sequence of squares: for example, 1, 4, 7, 10, 13, 16, 19, 22, 25. In random sampling, the grid squares to be sampled would be selected using a table of random numbers.

Table 9.8 Some commonly used assessment factors

Ecological factors		
Physical and chemical environment	**Biotic environment**	**Biological indicators**
Habitat area	Habitat diversity	Species diversity
Soil factors	Vegetation cover	Productivity
Atmospheric factors	Breeding sites	Biomass
Hydrological factors	Protective cover	Density
Geological factors	Stratification	Dominant species
Chemical factors	Plant distribution	Indicator species
Water currents etc.	Habitat type	Sensitive species
The ranges of migrating species	Zonation	Rare species
	Plant form	Eutrophication species
		Food chains
		Disease vectors
		Pest species
		Stage in succession
Human factors		
Economic	**Legal**	**Aesthetic**
Timber value	Endangered species	Unique species
Commercial fisheries	Protected species	Beautiful species
Crop production	Wetland regulations	Scenic environments
Fur production	Regulated game species	Pristine or virgin habitat
Domestic animal production	Wildlife refuge	Unique habitat features
Mineral resources	Air quality standards	Degraded habitat
Soil conservation	Water quality standards	Wilderness or open space
Water conservation	Solid waste regulations	Historical or archeological sites
Land value	Zoning laws	
Hazards to human health	Toxic materials regulation	

A single measurement is generally insufficient for conclusions to be drawn about a characteristic. Repeated measurements may vary greatly. A single value could be far from the average value. Therefore a series of repeated, or replicated, measurements should be taken to work out the mean of the characteristic.

The most common student field study is an environmental analysis which describes the geographical, physical, chemical and biotic characteristics of an area. The community is the aggregate of interacting species in that area. These studies have many practical applications. Examples include: assessment of environmental impacts; land use planning; management of fish, wildlife and vegetation habitats for the benefit of desired species; and habitat reclamation. The principal objective is often one of the following.

- *Basic ecological research:* proposing and testing hypotheses relating to ecological theories and principles
- *Ecological inventories:* collection of data and samples to be used for reference
- *Environmental planning:* use of ecological information for proposing potential sites for preservation, management, or other environmentally sound uses
- *Environmental impact assessment:* collection of information for assessing present or potential impacts of human activities
- *Ecological resource management:* collection of information needed for management of populations and for reclamation of disturbed habitats.

The prime objective of the study determines what is to be measured and the sampling techniques to be used.

9.6.2 Measurement of the abiotic environment

The distribution and abundance of any specific species in a community is linked to both the physical and chemical features of the habitat and to the other species present. Physical and chemical factors may be measured using a variety of techniques, as listed in Table 9.9.

The slope and aspect of the study area affect factors such as light, temperature and soil moisture. The difference in elevation between two points may be expressed as the distance relative to the horizontal distance between them (e.g. a slope of 15 m per 100 m) or as an angle.

Table 9.9 Measuring some physical and chemical factors in the abiotic environment

Factor	Method of measurement
1. Light intensity	Light meter
2. Temperature	Thermometer
3. Topography and altitude	Measure slope; draw profile and transects to scale
4. Pressure	Barometer
5. Depth of soil	Soil profile cut down and measured; or soil corer
6. Soil moisture	Sample weighed, water evaporated and soil reweighed
7. Soil or water pH	pH meter or pH indicators
8. Organic matter (humus)	Sample weighed, burned then reweighed
9. Soil or water nutrients	Soil-testing kits
10. Dissolved oxygen	Oxygen meter
11. Rainfall	Collection and measurement
12. Humidity	Hygrometer; or measure evaporation rate over time
13. Wind	Rotating vane anemometer; or wind speed meter and compass

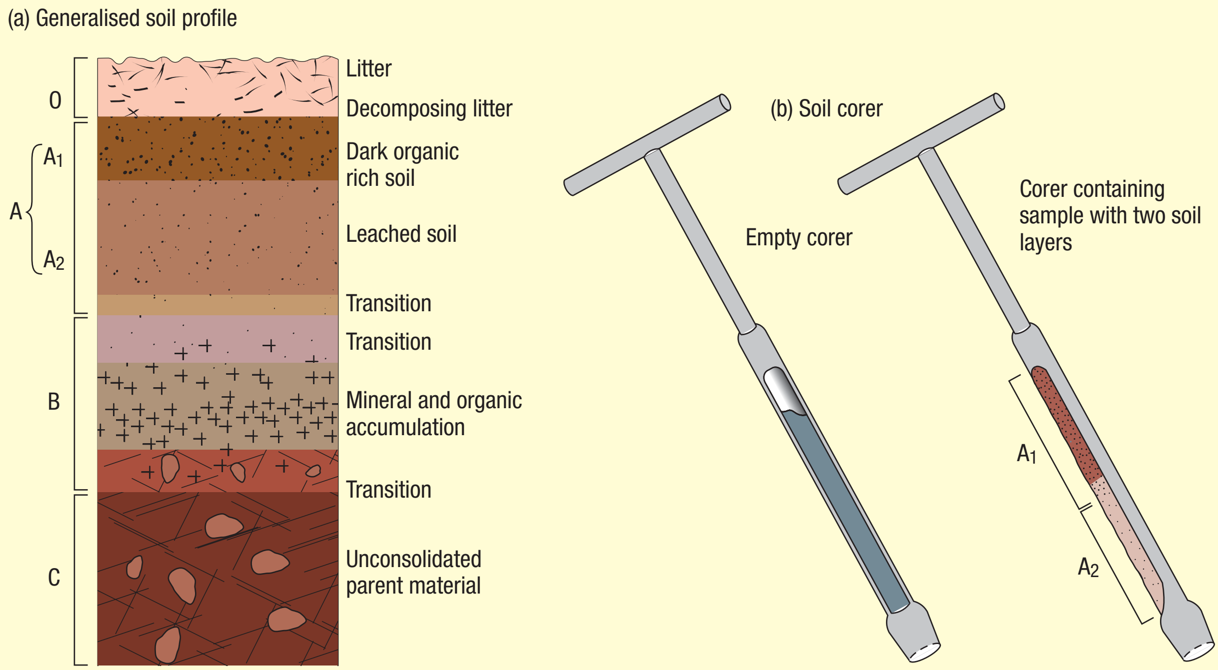


Figure 9.22 Generalised soil profile, and soil corer used to take a core sample from it

Measurement of slope may be calculated using simple equipment: a protractor, ruler, plumb-bob, tape measure and string.

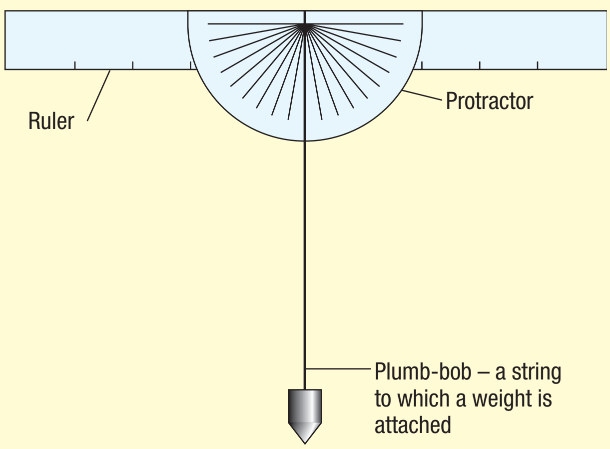


Figure 9.23 Construction of a simple device to measure slope

Two people hold a known length of string taut, one metre above ground level. The string is thus parallel to the slope. The rule, with its protractor and plumb-bob attached, is lined up along the string at the upper end of the slope as shown in Figure 9.24(a).

The angle inscribed by the plumb-bob is measured as shown in Figure 9.24(b). The vertical height between the two measuring points can then be calculated using trigonometry:

$$\cos \theta = \frac{v}{l}$$

$$v = \cos \theta . l$$

where θ is the angle inscribed by the plumb-bob, l is the length of the string, and v is the difference in height between the two ends of the string.

A similar method can be used to estimate the height of objects whose base can be seen: for example, a cliff or tree. A right-angle isosceles triangle can be constructed out of heavy cardboard or plywood. One 45° corner is held at eye level and the object is viewed 'through' the triangle. The observer walks backwards until the whole object just 'fits' the triangle, as shown in Figure 9.25. The horizontal distance from the observer to the object will be roughly equivalent to its height, since:

$$\tan 45° = 1 = \frac{\text{side opposite (height)}}{\text{side adjacent (horizontal distance)}} + \begin{array}{l}\text{height of}\\ \text{observer}\end{array}$$

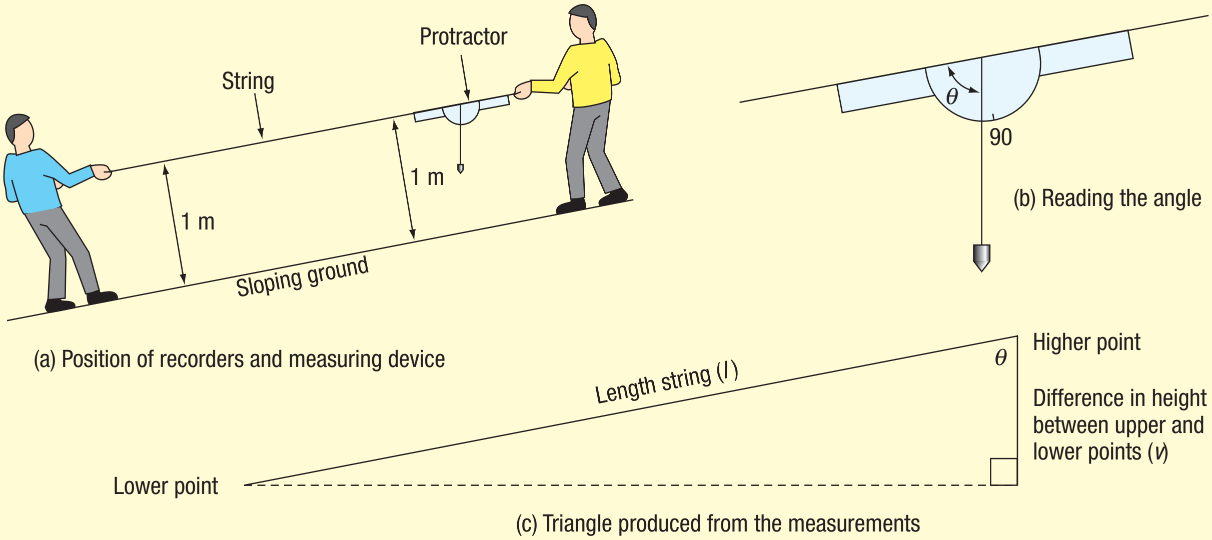


Figure 9.24 Using the protractor to measure slope

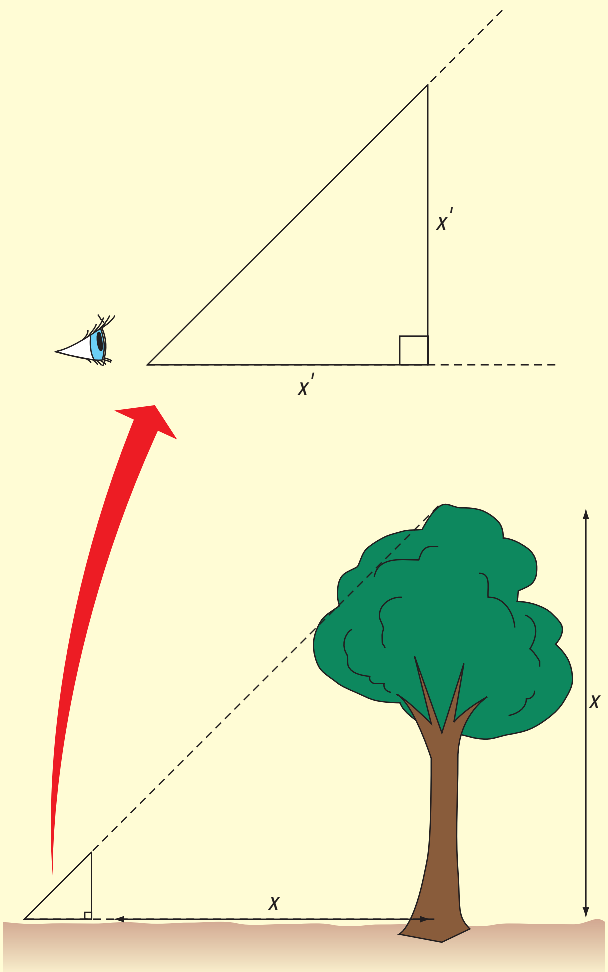


Figure 9.25 Estimating the height of an object using triangulation

9.6.3 Measurement of biotic factors

The vegetation type of a particular area can be determined in a variety of ways. The dominant species may be identified, or a more generalised description used. One method, using specific features of the plant life, is given in Table 9.10.

Foliage cover can be determined by taking several sightings (either along a predetermined line at set distances apart, or randomly) using crosswire sighting tubes. The tube is held to the eye vertically upwards towards the sky. What is seen exactly where the two wires cross—sky, green foliage etc.—is recorded and the percentage foliage cover is calculated from the following formula:

$$\text{\% foliage cover} = \frac{\text{number of foliage sites recorded}}{\text{number of observation sites}} \times 100$$

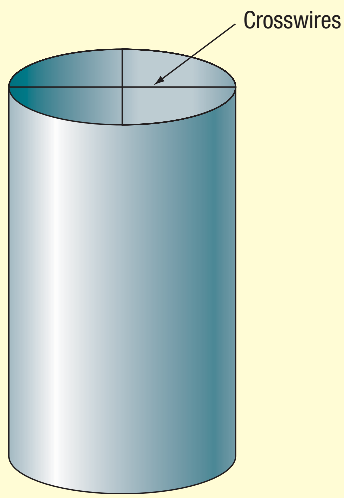


Figure 9.26 A crosswire tube

Table 9.10 Structural classification of Australian vegetation (after Specht)

Growth form of tallest stratum	Foliage cover by the tallest stratum			
	>70%	30–70%	10–30%	<10%
Tall trees (>30 m)	tall closed forest	tall open forest	tall woodland	
Medium trees (10–30 m)	closed forest	open forest	woodland	open woodland
Low trees (<10 m)	low closed forest	low open forest	low woodland	low open woodland
Tall shrubs (>2 m)	closed scrub	open scrub	tall shrubland	tall open shrubland
Low shrubs (<2 m)	closed heath	open heath	low shrubland	low open shrubland
Hummock grasses			hummock grassland	
Tufted/tussock grasses	closed tussock grassland	tussock grassland	open tussock grassland	dense open grassland
Graminoids	closed sedgeland	sedgeland	open sedgeland	
Other herbaceous species	dense sown pasture	sown pasture	open herb field	sparse open herb field

The **plot** method is a basic and commonly used procedure for sampling many types of organisms. A plot is generally a rectangle or a square (= quadrat), but circles or other shapes can be used. Within this plot of known size, individuals can be identified, counted and measured. Random or systematic sampling of the total area of the plot can give indications of abundance and distribution over a much larger area.

In sampling soil or aquatic organisms a volume of the habitat is often sampled and analysed. The plot method is most widely used for sampling land plants but may also be used for sampling relatively sessile or slow-moving animals, or for burrowing animals such as trapdoor spiders.

Plot methods of sampling are often very laborious and time-consuming, and their results depend on the size, shape and number of plots used. Plotless methods are useful for plants or sessile animals and have the advantage of not requiring sampling areas of a certain size or shape to be marked out.

The most popular plotless method is quarter-point sampling. This should only be used for populations with highly aggregated or uniformly spaced individuals. Randomly determined points are marked out in the study area. Each point represents the centre of four compass directions which divide the sampling site into four quarters or quadrants.

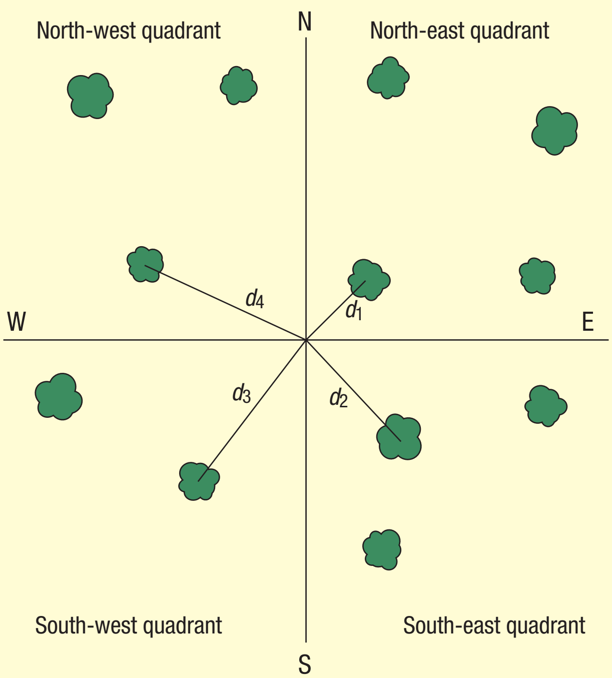


Figure 9.27 In quarter-point sampling the shortest point-to-point distance is calculated in each of four quadrants.

Measurements are made within each quadrant of the distance from the centre point to the centre of the nearest individual, regardless of species. Only one plant (or sessile animal) per quadrant is measured, so a total of four individuals are recorded for each point sampled. Each species encountered is identified. Statistical tests can then be applied to determine density and distributions of the various species.

In some types of vegetation, the use of plots may be impractical. **Transects** often give better information over large areas and also show up non-random distributions of some species. There are three main types of transect: belt transect, line intercept and strip census or line transect.

A **belt transect** is a long strip of terrain in which all organisms are counted and/or measured (Figure 9.28). Knowing the width and length of the transect makes it possible to estimate species diversity and abundance for the total area. Vegetation transects are often represented by a profile (showing slope of the terrain, position and height of vegetation types, and canopy cover) or a plan sketch (an aerial view showing position and canopy cover of species). Profiles can also be constructed for many types of habitat: for example, rocky shore (see Figure 9.9 on page 211) or a freshwater pond (see Figure 9.13 on page 215).

Line intercepts are used to estimate relative densities of species and involve counting the numbers of a particular species that lie on a straight line cutting across the community under study. Line intercepts are often used in grassland community studies where estimates of absolute density either cannot be made or are difficult to interpret because of the difficulty in distinguishing individual plants.

A strip census or line transect involves walking a line established through an area and recording individuals observed from that line. As for line intercepts, the data recorded are only an index of density. This method can be used in vertebrate population studies such as road kill censuses, bird counts and small mammal trapping. A strip census is very useful in studies of animals which are highly mobile.

Soil and litter organisms may be sampled by extracting them from a known volume of material. The equipment generally used is a Berlese-Tullgren funnel (Figure 9.29 on page 232). This method is limited, however, because it favours those species that do not desiccate easily and which can move through the soil easily.

A pit-fall trap is another piece of equipment used to sample soil and litter organisms. These can be set randomly along a transect or in a grid. An individual

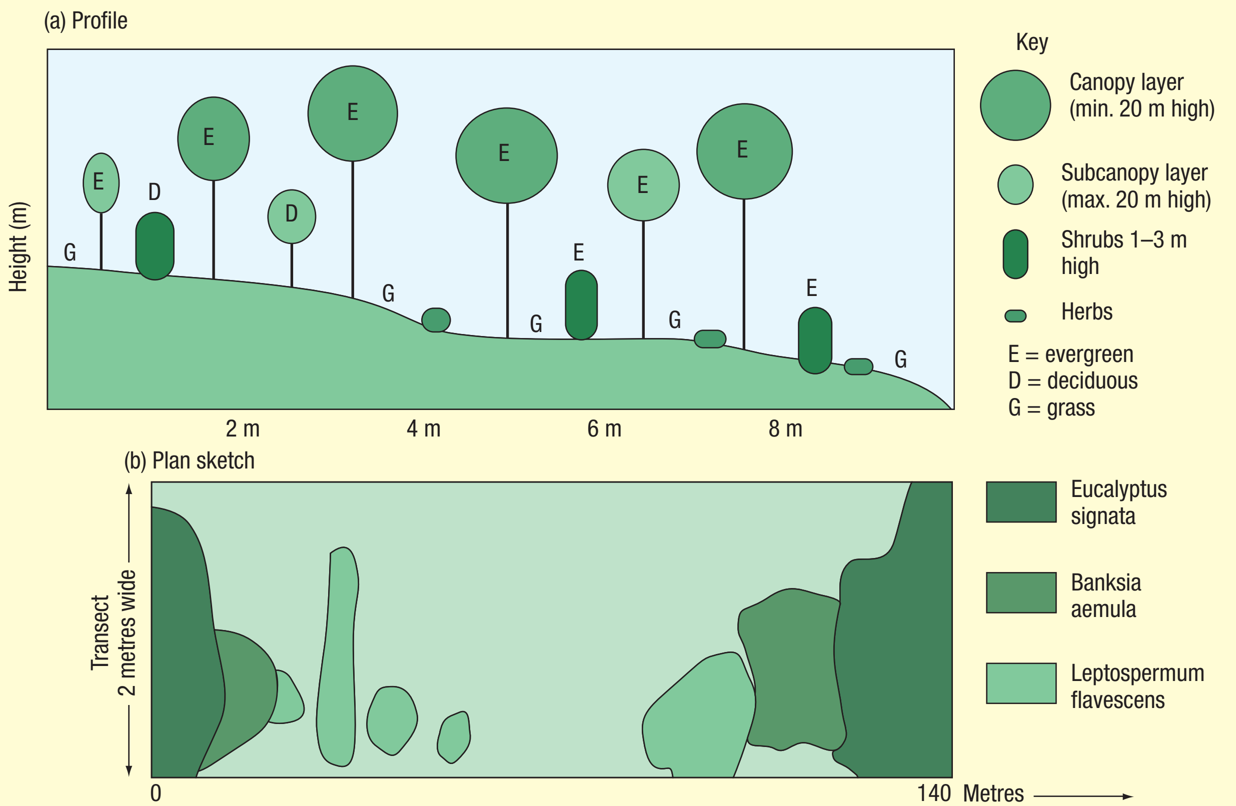
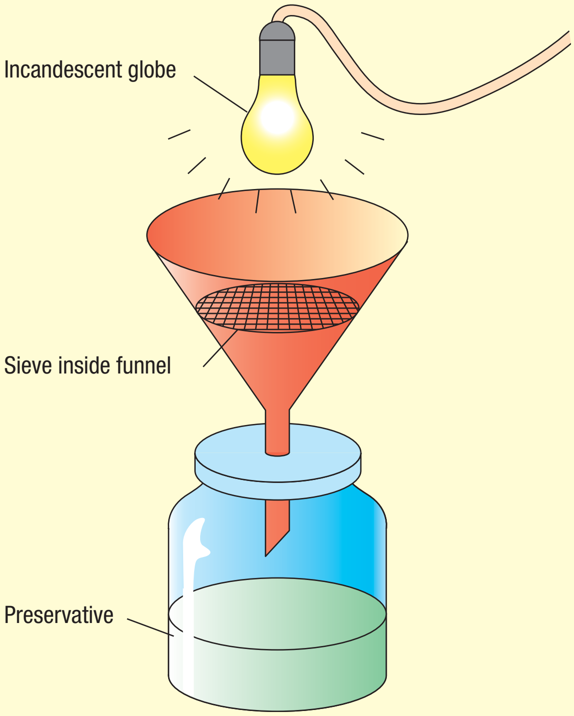


Figure 9.28 Representations of a belt transect



A known volume of soil or litter is placed on the sieve in the funnel. When the light above the funnel is switched on, the organisms move downwards to avoid the light, heat and drying effects of the globe. In doing so they fall into the jar containing preservative.

Figure 9.29 A simplified Berlese-Tullgren funnel

trap, consisting of a large can or jar, is set into the ground with its rim at the level of the soil surface, and is either baited or contains a few centimetres of water. Many animals traversing the area fall into the can and cannot escape up the smooth sides.

Population estimates of larger or more motile animals can be made using the **capture–recapture** method. A number of individuals from a population are captured, marked by some identifying means, and released within a short period of time. At a later date a second sample is taken from the population. Some of the individuals in this second sample may be identified as being members of the first sample because they were previously marked. If the population is large, the marked individuals will have become 'diluted' within it and only a few would be expected to appear in the second sample. But if the population is relatively small, the proportion of marked animals in the second sample will be larger.

Theoretically the proportion of marked individuals in the second sample is the same as that in the entire population, and the total population can thus be estimated:

$$\text{size of the population} = \frac{Mn}{R}$$

where M = number originally marked; n = total number captured in the second sample and R = number of recaptured (marked) individuals in the second sample.

This method does, however, have some inherent problems:

- Weather conditions may vary at the times of sampling and this may affect the activity of the particular organism under study. Wet or dry conditions, for example, would affect sampling of amphibians.
- The method of collection can be a contributing factor. Small mammals are usually collected using live traps which are baited with a specific food. If natural food resources are scarce, individuals may learn that traps are a ready supply of food. They become 'trap happy', with the result that proportionately more marked animals are recaptured than unmarked, making the population estimate lower than reality.
- Other individuals may associate the traps with an unpleasant experience (shock of handling and marking) and learn to avoid the traps. They become 'trap shy'. This would result in proportionately fewer marked individuals, giving a population estimate higher than reality.
- The method of marking may be unreliable. Tags may be torn off, and colour marking may be lost in feather moulting of birds. In a study of sea snake populations off the Queensland coast, tagged snakes had their tails nipped off by predatory fish, because the silver metal tags looked like the small fish upon which they prey.
- The length of time between sampling is also significant. If animals are highly motile, they distribute themselves randomly in a population more quickly than if they were slow moving.

A variety of nets, sieves and other devices are used to sample a community. The relative abundance of particular species can be determined from such collections. Some of these devices are illustrated in Figure 9.30.

SUMMARY

The type of data collected in the field depends upon the purpose of the study. Random or systematic sampling of an area, involving measuring and recording various biotic and abiotic features, gives an overview of the community's structure.

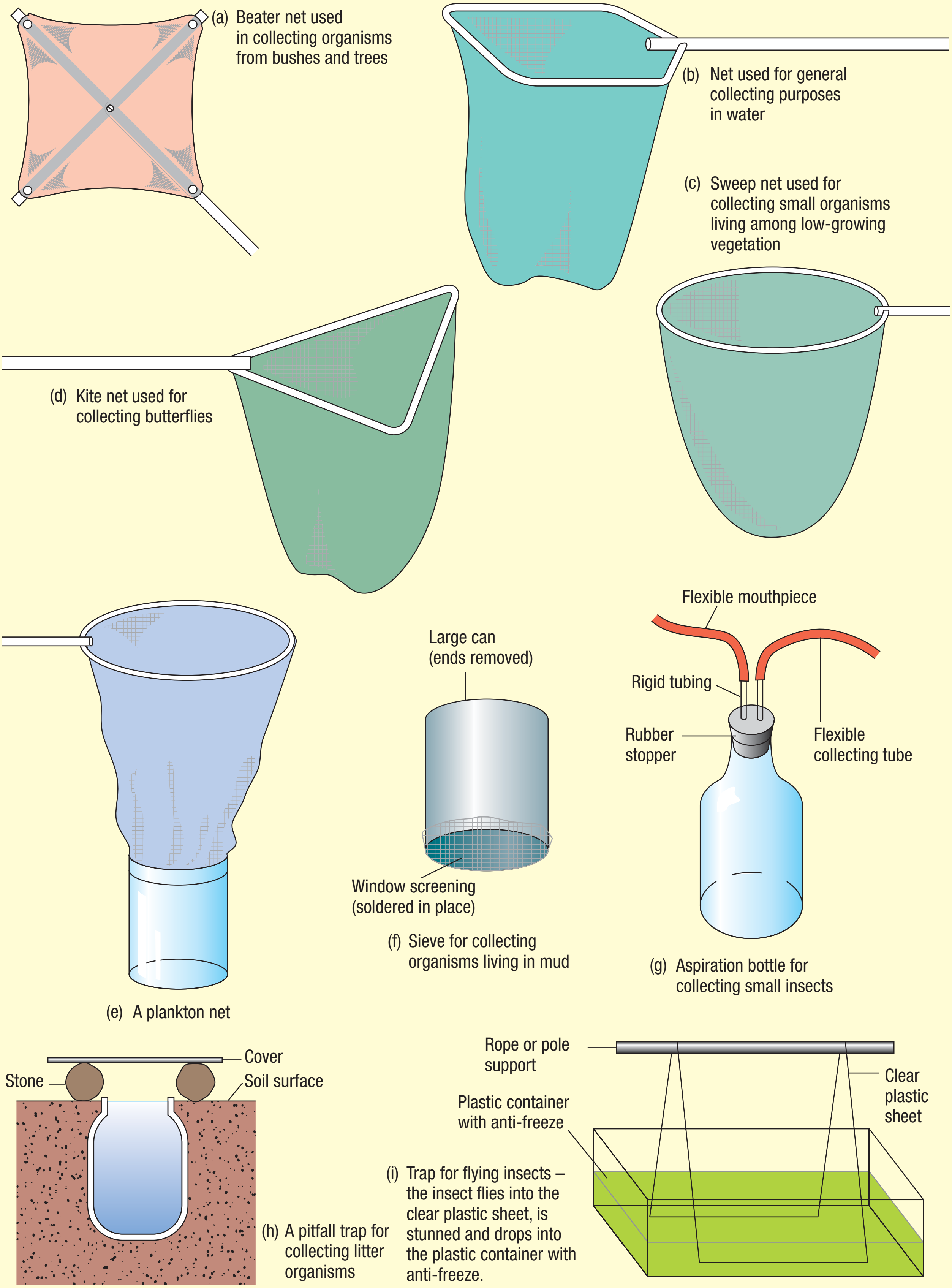


Figure 9.30 Some methods used to collect animals in the field

Review questions

9.26 What is meant by random sampling?

9.27 Why are observations replicated?

9.28 In a given area, how would you measure:

(a) depth of soil

(b) pH

(c) humus content of soil

(d) light intensity?

9.29 Distinguish between a belt transect and a line transect.

9.30 One evening fifty-five mice in an area were captured, marked and released. The following evening seventy mice were captured in the same area, of which thirty-five were marked.

(a) Estimate the mouse population for that area.

(b) If all the traps were within a 100 x 100 m area, what is the population density?

9.31 Describe methods which could be used to collect insects from various strata of a forest: for example, from shrubs, flying, in grass, in litter.

EXTENDING YOUR IDEAS

1. UB Rainforest soils retain few nutrients since they are utilised as soon as they become available from decomposer activity, to support the large mass of plants in the community. Predict the viability of an agricultural enterprise based on cleared rainforest soil.

2. UB 'Soil moisture, temperature and nutrients have a direct influence on plant distribution and abundance, whereas altitude, rainfall and soil type affect these parameters indirectly.' Discuss this statement.

3. UB A variety of animals can survive in the Simpson Desert. Predict:

   (a) structural,

   (b) physiological, and

   (c) behavioural adaptations

   of animals which would have survival value in this habitat.

4. UB Over the past 140 years there has been an increase in the average global temperature and the concentration of carbon dioxide in the atmosphere. Many people have associated this with an increase in the clearing of forests for agricultural and urban development over this period of time. They argue that forest communities 'suck up' vast quantities of carbon dioxide and release only oxygen. Others state that this is a spurious argument—only dynamic communities (i.e. actively 'growing' after a disturbance such as a fire or flood), use more carbon dioxide than they release. Stable forests release as much carbon dioxide, through decomposition of leaf fall, flowers, fruit and dead plants, as they take in.

   On the basis of your knowledge of community interactions, justify which argument is the most valid. What other factors could be responsible for global warming?

5. IB Figure 9.31 is a log–log graph showing the salt secretion from leaf glands of various mangroves (over 9 daylight hours), plotted against the salt concentration of the sap.

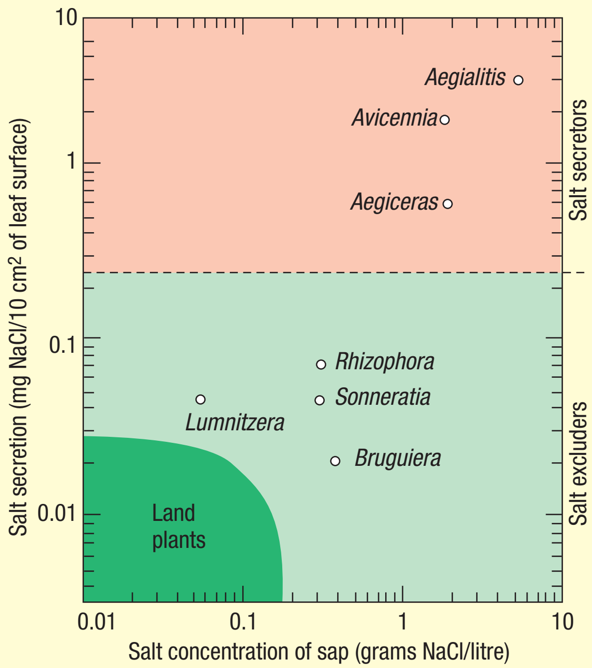


Figure 9.31

   (a) What values of salt secretion (mg NaCl per 10 cm^2 of leaf surface) and sap salt concentration (g NaCl per litre) are found in:

   (i) *Avicennia*

   (ii) *Lumnitzera?*

   (b) Using the plant genera shown in this graph, estimate the factors that determine whether a mangrove plant is a salt excretor or a salt excluder.

6. Soil types can be determined using a grid of percentage composition of sand, silt and clay as shown in Figure 9.32.

IB

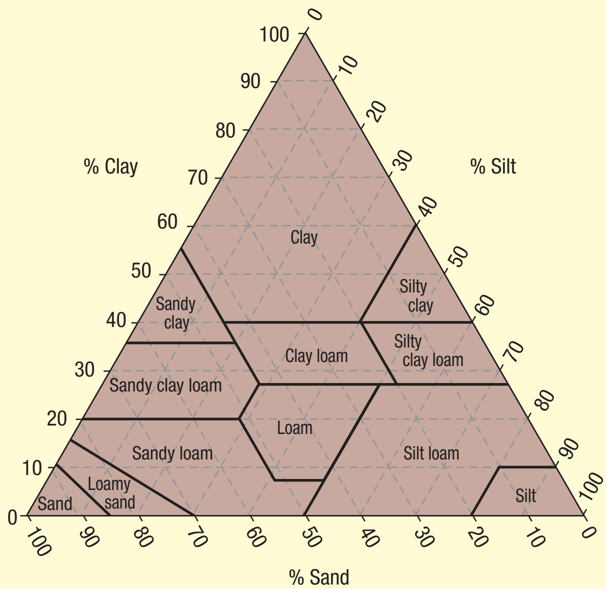


Figure 9.32

(a) A soil has been identified as a clay loam. It has a composition of 40 per cent silt, 30 per cent clay and 30 per cent sand. Where, within the clay loam dimensions of the grid, would you place this soil?

(b) A soil has a composition of 25 per cent silt, 8 per cent clay and 67 per cent sand. Using the grid, classify this soil.

7. CSIRO scientists collected cassowary dung around Mt Bartle Frere in North Queensland over a 2-year period. When seeds found in the dung were tested for viability, 89 per cent germinated. These seeds tended to be of trees with large fruits that fall to the ground, and particularly those which are red, green and yellow in colour. Cassowaries are large flightless birds, each pair of which occupies and defends an area of approximately 5 km^2.

EBI

(a) Evaluate the significance of the cassowary to the rainforest community in North Queensland.

(b) Increased pressure for land development in the Cairns area has seen disruption of large areas of rainforest. Predict, with reasons, the effect of this on the maintenance and regeneration of the forests.

8. A student throws a 0.25 m2 quadrat onto the school lawn. Figure 9.33 shows what was found.

IB

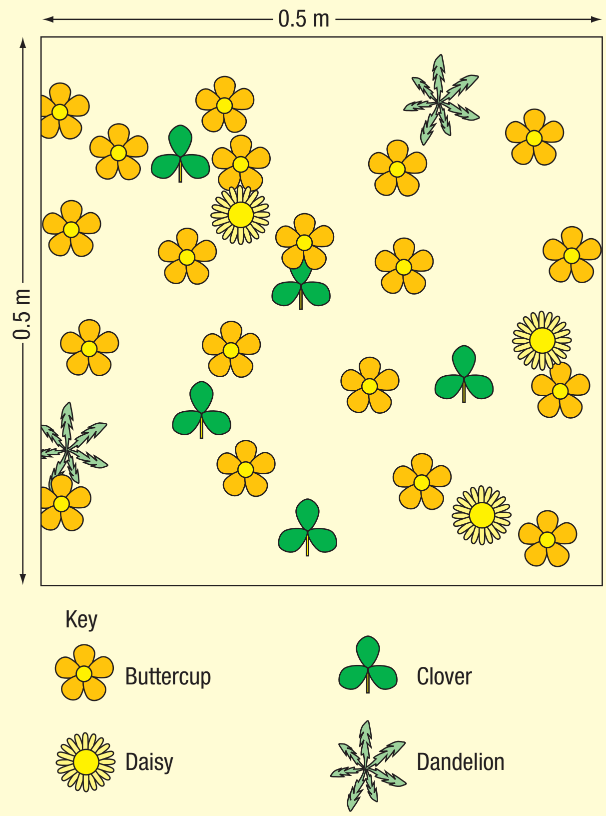


Figure 9.33

(a) Estimate the number of dandelions in 1 m^2.

(b) If the lawn is 100 m x 50 m, estimate the number of daisies in the entire lawn.

9. Green algae of the genus *Caulerpa* are common in tropical regions and are sensitive to low temperatures. This is a particularly robust and attractive algae that is used in tropical aquariums. Aquarium keepers in Europe, though, were unable to maintain the conditions necessary for its growth. In the early 1980s, however, one tropical collection of these algae proved to be exceptional. They reproduced rapidly from cuttings and were able to tolerate cool water temperatures. Within a few years this alga, named *Caulerpa taxifolia*, became the most common salt water aquarium producer world-wide. It is probably a mutation from another *Caulerpa sp.*, since it only produces male gametes and so only reproduces asexually from fragmentation.

EBI

In 1984 a small colony of these algae was discovered in the seas beside the Oceanographic Museum of Monaco. Since that time it has spread at an alarming rate throughout the Mediterranean region. From a single colony of 1 m^2 in 1984, 60 km^2 were affected in 1999. Invasions have also occurred in widely separated parts of the world—the southern coast of Australia and the Californian coast. DNA studies have shown that these are all clones of the Mediterranean form.

Caulerpa taxifolia grows in a wide variety of habitats, from the surface to the lower limits of light for vegetative growth in the oceans, from rocky shores battered by waves and currents to the soft bottoms of estuaries, in polluted and clean water. It forms extensive meadows that effectively out-compete other algae. Scientists believe that it has exceptional adaptations to extract nutrients even in the most nutrient-depleted areas.

What is more alarming, however, is that it produces a potent toxin. Many algal and plant species produce a cocktail of toxins, each in small concentrations, used to deter herbivores. This alga, however, produces one toxin in very high concentrations. The toxin is harmless to humans but confers inedibility by all marine herbivores. Marine meadows throughout the world are important in protecting coastlines and as habitats in which many species breed.

Methods to eradicate the alga have been largely unsuccessful. Because it grows rapidly from fragmentation, manual uprooting is impractical. The fragmentation that occurs from this method could result in further spread of the algae as the fragments drift in ocean currents or are picked up by boat propellers and anchors. A variety of physico-chemical treatments (dry ice, treatment with copper, air suction, ultrasound and hot water jets) have been used in experimental sites. Only one treatment has been effective. The area is covered with a tarpaulin and chlorine gas is pumped under it. Unfortunately everything else is also killed. This drastic measure could only be used in a very small area of initial growth. A sea slug, *Elysia sabonata*, has been found to feed exclusively on *Caulerpa* species in the Caribbean. It sucks out the sap and is able to neutralise the toxins. The French scientists reason that if this slug is released in spring, it will feed on and decimate the *Caulerpa* meadows until winter, when it will die from the cold water temperatures. Government authorities are, however, reluctant to undertake a remedy that may introduce a new problem in the future.

Using this information, write a reasoned discussion that outlines:

(a) the long-term effects of *Caulerpa taxifolia* on marine ecosystems

(b) preventative measures to stop the further spread of this alga.

10 HUMAN IMPACT ON THE ENVIRONMENT

10.1 THE HUMAN ANIMAL

Humans are consumer organisms and are therefore dependent upon the same sorts of resources as other consumers. They require suitable water, food and shelter. The first humans, recorded from fossils approximately 150 000 years old, were hunter–gatherers. Since their numbers were small and they were nomadic, they had little impact on the environment other than through fire. Fires were used both for cooking and in flushing out prey. It is probable that some fires accidentally got out of hand and thus large tracts of forest land were replaced by grasslands. Fires may also have been used deliberately to maintain open grasslands which supported herds of grazing animals.

In time, in many parts of the world, the hunting mode was succeeded by domestication of some animals (e.g. sheep, goats, cattle, llamas) and free-ranging flocks were shepherded by some individuals while others remained in small non-permanent villages. Eventually forests were cleared to increase the pastures for flocks. As is still the case in many tribal communities today, the number of animals owned by an individual became a symbol of wealth. In some areas this led to overgrazing, decreasing soil fertility and increasing erosion.

It was only a small step to the actual cultivation of land, with deliberate sowing of seed, to produce more pastures and make collecting edible plant products easier. Cultivating land was associated with more permanent settlements, and trees were felled for timber to construct solid buildings. The development of towns and cities, and a society with division of labour and industrialisation, have further added to destruction of the natural environment.

Colonisation of new lands over the past few hundred years reflects human cultural evolution. Australia, for example, was first colonised by hunter–gatherers approximately 100 000 years ago. As seen in Chapter 6, the use of fire by these first settlers contributed to a change in vegetation to predominantly fire-tolerant woodlands and grasslands.

The first European settlers (1788) brought domesticated animals (sheep, goats, cattle, pigs, poultry and horses) and plant cuttings (mostly from Cape Town, their last port of call) and seeds. The aim of these settlers was to tame and civilise this new country—to turn it into a replica of their place of origin. These people had come from areas which had been under cultivation for centuries and they were unaware how fundamentally different the conditions were in this new country. The land could not sustain the agricultural pursuits which were so familiar to the new settlers, without a tremendous cost both personally and to the environment.

Nevertheless, they proceeded to convert grasslands and woodlands into suitable pastures for their stock, to clear forests and to build towns with little thought of the future. Raw sewage was diverted directly into streams. Other wastes were indiscriminately dumped. This was not a great problem in the early days of settlement but, as numbers increased and towns grew haphazardly to accommodate them, the problems grew in magnitude. Although forest clearing was most extensive in the south-eastern part of Australia (up to 69 per cent), 37 per cent of the forests and woodlands in Queensland have been modified by settlement, industry and agriculture. As a result of these developments over the past 200 years, seventeen mammals, three birds and one lizard have become extinct and another 300 vertebrates have been placed on the endangered list. Australia has only recently started to come to grips with the legacy of our predecessors.

Modification of the physical environment, as well as medical and technological development, have been significant factors in the escalating growth rate of the human population. Humans have been able to manipulate their environment by growing crops and rearing animals, wearing clothes, building houses, lighting fires, producing electricity and so on. However, their activities have released polluting chemicals which have had effects on water, soil and climate. The need to feed, clothe and house the world population adds a tremendous pressure to the environment.

The biosphere, therefore, has to support three types of ecosystems—natural, agricultural and urban. For an ecosystem to be sustained there must be specific inputs, and as matter and energy flow through the ecosystem they are converted to other forms and released as outputs. Although short-term

Table 10.1 A comparison between the natural, agricultural and urban ecosystems

Ecosystem	Input	Output	Level of recycling
Natural	light** organic matter* water* mineral salts*	heat* organic matter* water*	much
Agricultural	light** organic matter* water** mineral salts* fertilisers* pesticides*	heat* organic matter** water** soil particles** nutrients**	some
Urban	light* organic matter** water** mineral salts* fuel*** industrial raw materials** oxygen*	heat*** water*** industrial and household wastes** carbon dioxide**	little

(The asterisks represent the approximate proportions of matter: * = least; ** = intermediate; *** = most.)

imbalances may result from climatic changes, a self-sustaining system is one in which the inputs and outputs are balanced over the long term.

SUMMARY

Increase in the human population, and agricultural and technological development, have resulted in three main types of ecosystems: natural, agricultural and urban. Each has different requirements and outputs. Supply of inputs to agricultural and urban ecosystems requires high levels of energy. The outputs of both can lead to land, water and air pollution. Only natural systems approach a balance of inputs and outputs.

? Review questions

10.1 List the changes in effects on the environment as humans developed from hunter– gatherers to industrialised societies with the majority of the world's population living in large urban areas.

10.2 Compare and contrast the inputs, outputs and level of recycling in a natural and an agricultural ecosystem. Which is the most balanced? Explain your answer.

10.3 In what ways does an urban ecosystem differ from an agricultural ecosystem?

10.2 Agricultural ecosystems

There is no disputing the need to feed and clothe the world's population. But it is necessary to do this without poisoning the people producing the crops or those who eat them, or altering the environment in some permanent way so that the production of these resources becomes even more hazardous in the future. The survival of the other species that share this planet is also of great significance.

10.2.1 Soil

The first development in any agricultural ecosystem is the removal of natural vegetation, and this can lead to soil problems. In grazing systems there is selective grazing of natural pastures, which can lead to their elimination and takeover by 'weeds'. Tracks made by stock compact the soil, thereby decreasing absorption of water by the soil and future germination of grasses in those areas. This makes the land susceptible to erosion. Intensive crop production involves removing the natural vegetation and replacing it with a single crop, or **monoculture** (e.g. wheat). Between periods of harvesting and seeding, the stubble from the previous crop may be burnt or ploughed in and the land left to lie fallow. With no root systems to bind it, the land is subject to severe wind and/or water erosion.

Removing vegetation may have the following effects:

- Less organic matter is returned to the soil, thus causing nutrient depletion.
- Leaves and limbs of plants intercept falling rain and release it slowly to the ground. Leaf litter absorbs moisture. Rainwater is therefore able to penetrate deeper into the soil. In cleared areas the raindrops cause soil compaction and the soil becomes less permeable to water. Only the upper surface absorbs the water and further rain becomes surface run-off.
- The soil is more prone to wind and water erosion. Water flowing down slopes carries soil with it, and this may be accelerated by tracks and plough furrows. Small watercourses may develop, subsequently scouring out further to form enlarged gullies. A single heavy rainstorm may remove hundreds of tonnes of topsoil from a completely bare paddock. Wind storms can produce a similar effect.
- Reduced vegetation results in decreased transpiration of water into the atmosphere. Thus more water flows downhill within the soil, leaching minerals from rocks and soil in its progress. In those places where the water table reaches the surface, evaporation of water leaves a high salt concentration which kills off the vegetation. This results in further erosion. Water running from these flat areas into creeks increases their salinity and produces problems in freshwater ecosystems, often far removed from the original source of the leaching.

In an Australia-wide study between 1996 and 2001, it was found that soil degradation in relation to salinity, acidity, nutrients and carbon levels was becoming increasingly problematic. The area affected by soil salinity, for example, has increased by 13 million hectares in the 10 years between 1991 and 2001. Land degradation has been estimated to cost $1.15 billion per year in lost agricultural production.

Most soil erosion problems can be overcome by responsible land management practices.

Responsible land management for grazing ecosystems

Prevention of overgrazing

Stocking should be such that ground cover is maintained. This reduces soil compaction, erosion and the influx of weeds.

Cultivation of soil-binding pastures

Some pasture plants have an extensive shallow root system. This binds the soil and reduces erosion.

Maintenance of tree areas

Trees provide shade for stock. Suitable resting places reduce the amount of movement of the animals. Since trees have deep root systems, they can draw water up from the water table, causing its level to drop. Evaporative loss of water from the leaves increases the levels of condensation in the air and promotes rain formation. The lowering of the water table decreases leaching and soil salinity. In addition, trees provide sites for insect-eating birds. Between 1000 and 2000 insect-eating birds can

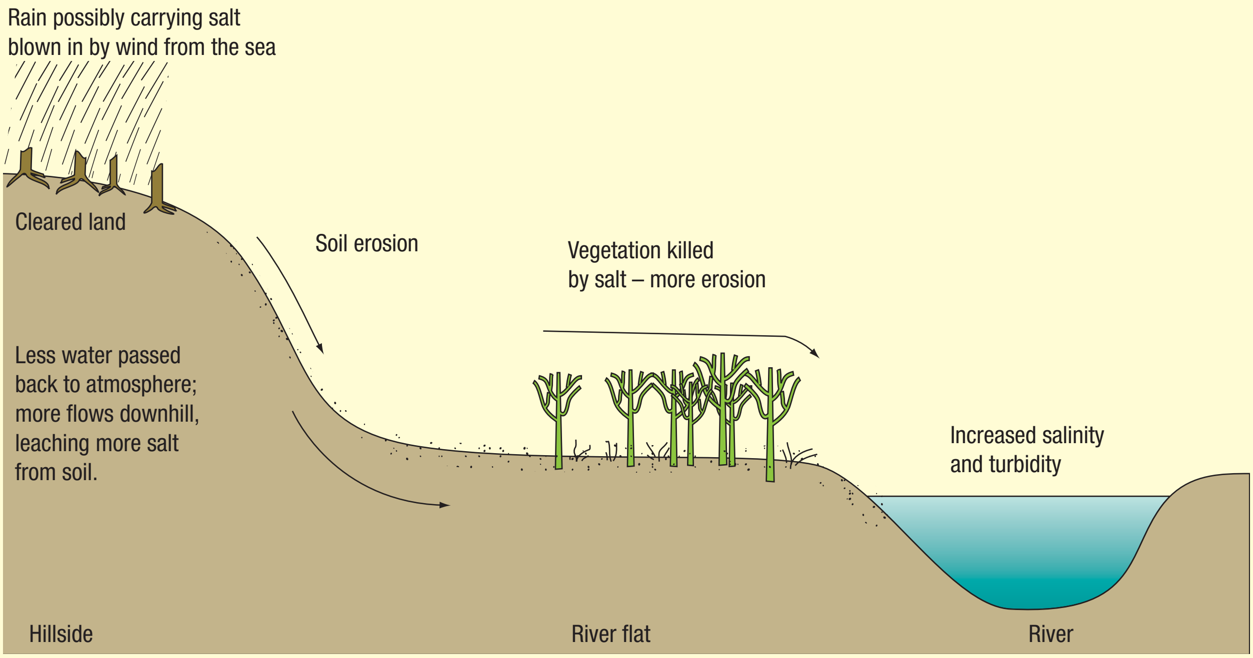


Figure 10.1 Possible effects of erosion on a slope as a result of clearing

inhabit 100 ha of native woodland. Clearing these areas means loss of these birds, and a subsequent increase in the number of leaf-eating insects. This results in increased stress on remaining trees, some of which may perish due to dieback and thus cause further erosion.

Unrestricted movement of stock in large areas

Keeping stock unrestricted reduces the development of tracks of compacted soil as they move from grazing to watering areas.

Crop ecosystems

Contour ploughing

Contour ploughing is at right angles to the slope. Water running down the slope is thereby trapped by the plough furrows, giving it time to be absorbed by the soil. More water will become available for plant growth. At the same time, erosion due to excessive surface run-off is reduced.

Crop rotation

Different crop plants extract different mineral nutrients from the soil. By growing different crops in successive growing seasons, farmers can reduce the depletion of specific minerals. Other crops are grown to release nutrients into the soil. Nitrogen-fixing, leguminous crops are sometimes grown between other crops and then ploughed into the soil as a 'green manure' to increase soil fertility.

Leaving stubble in soil between plantings

If the stubble is left after a crop has been harvested, the undisturbed roots act as a soil binder, reducing erosion. Ploughing in the stubble just before the next planting increases soil humus and thus water retention.

Planting rows of trees between paddocks

Trees planted between paddocks may themselves be crop-producing (e.g. macadamia and pecan nuts) or timber-producing (e.g. sandalwood). They act as windbreaks and reduce erosion. The trees also lower the water table and thus reduce leaching and soil salinity.

10.2.2 Water

Water resources for irrigation and for stock have been increased by dams on rivers and streams. Damming of rivers has also controlled flooding to a large extent, and increased the amount of usable farmland downstream. Often this is associated with dredging of the river to remove debris. Although this has been beneficial to humans in the short term, the long-term environmental effects are severe.

Erosion

Dredging increases movement of water in the river, leading to increased erosion of the banks.

Decreased biodiversity

Swamps and billabongs are warm, shallow fresh-water areas which are normally flushed out and refilled as a result of flooding. They are very productive ecosystems and are the breeding grounds for many large freshwater fish. Flood mitigation has effectively destroyed many of these areas, reducing the biodiversity of both the billabongs and their adjoining river systems.

Dams

Dams are deep, dark, cold and unproductive areas. Siltation builds up and can clog the feeding and respiratory structures of animals such as mussels and fish.

Dams destroy the normal cycles of temperature, turbidity, flow rate and flooding, and thus changes in the natural flora and fauna of the river system occur. The river red gums along the Murray River, for example, are dying because they are no longer annually innundated with floodwaters. In addition, the fertile silt normally carried in floodwater and deposited across the flood plains is no longer available, and so the productivity of these areas decreases.

Irrigation

Irrigation of crops has raised the natural water table and thus increased the leaching of mineral salts from the rocks and soil. As the surface waters evaporate, they leave behind a high salt concentration in the surface soil, which eventually destroys the crops that the water was designed to aid. The citrus-growing areas of the Murray River exemplify this problem: large areas of country have become unproductive and have simultaneously increased the salinity of the river itself.

The introduction of bores for watering stock in more arid regions has also increased the density of many native animals: for example, the euro (*Macropus robustus*) in the Pilbara area.

10.2.3 Nutrients

Most Australian soils are too poor in nitrogen and phosphorus for the introduced pasture species to grow well or for crops to give high yields. Trace elements, necessary for plant and/or animal growth, may also be absent in many areas. Cobalt deficiency in south-eastern parts of South Australia, for example, results in ‘coastal disease’. As a result of this disease, sheep and cattle can starve on lush pastures. The use of fertilisers to overcome these soil nutrient deficiencies is therefore standard practice, often without any real knowledge of the particular deficiency for that locality. This may result in too much of a particular chemical, which may be toxic (e.g. copper).

After heavy applications, fertilisers can be washed by rain into dams, lakes and streams, increasing the amount of nutrient ions in the water. **Eutrophication** is a natural process during which mineral nutrients (particularly nitrates and phosphates) build up in a body of water. As long as the increase is not excessive, these nutrients are taken up by plants at an increased rate and passed through the food web so that there is a balance between inputs and outputs.

When the build-up is very high there is no limitation on the increased growth of producers. Carbon dioxide is more soluble in water than oxygen. Much of the oxygen produced by photosynthesis escapes to the atmosphere, and thus at night there may be inadequate oxygen to support plant and animal respiration. Many organisms die and this results in an increased population of decomposer bacteria, which further creates a **biological oxygen demand** (BOD). Only the very upper levels of the water will therefore remain oxygenated. The natural balance of the freshwater ecosystem is thereby destroyed and may even result in the ‘death’ of that body of water.

10.2.4 Habitat fragmentation

As a result of topographic features, some areas of land are more suitable for agriculture than others. Patches of clearing occur in some places, leaving fragments of natural vegetation in the more inaccessible or less fertile areas. These areas are often too small to support viable populations of species which were once abundant in that locality. In this way the distribution and abundance of many species (e.g. the koala) has been greatly altered by agricultural clearing. The shape and size of the remaining fragments is an important factor in determining which species can survive and/or remain in the area. The outer edges receive more sunlight and are more prone to wind disturbance; and the ability of some species to utilise both the pastoral land and the fragments can be important. Some species are therefore abundant at the edges of these ‘islands’, whereas others will be found only in their interior.

It is not possible to generalise about the size of fragment that is necessary for the survival of native species. It is only by carefully analysing the needs of individual species and communities that suitable areas can be provided to sustain ecosystems, while at the same time fulfilling economic demands for agricultural development. In order to conserve biodiversity, it is important that appropriate ‘corridors’ be left, joining tracts of natural vegetation between farmlands to allow movement of native fauna.

Case study 10.1: How big is big enough?

In the 1960s, ecologists MacArthur and Wilson proposed their theory of island biogeography. They predicted that islands in the ocean, or isolated forest fragments, would contain fewer species than a comparable area of mainland or continuous forest. Natural disasters, they believed, would have a greater effect on isolated communities, sometimes resulting in the complete disappearance of some species. Wilson and a graduate student

Figure 10.2 An ‘island’ of natural vegetation surrounded by agricultural land

tested this theory. They removed a broad strip of vegetation through each of several mangrove islands. The vegetation of each island was effectively cut in half, separated by a cleared space. The researchers found that the number of different types of insects found in these smaller areas was reduced when compared with the original larger area. Habitat fragmentation results in reduced species diversity.

During the late 1970s, in an effort to increase agricultural production, the Brazilian government subsidised farmers to fell tracts of rainforest for pasture and cereal crops. Conservationists were concerned about this clearing and needed some indication of the minimum size of forest that would preserve a functioning ecosystem. Several Brazilian ranchers were persuaded to leave fragments of forest among their cleared areas, in squares of exactly 1, 10 or 100 hectares in area. These fragments were studied intensively over the following 15 years.

As expected, some species could not survive in the smaller fragments. Large, mixed-species flocks of insectivorous birds left the 1-hectare and 10-hectare plots within 2 years and many single-species flocks dispersed over the first 6 years. Even the 100-hectare plots were too small to sustain army ants (and thus the birds which feed on them) and capuchin monkeys. Other species, such as hummingbirds, were not affected and small insect-eating mammals actually increased in the 1- and 10-hectare plots.

The researchers found that the dominant factor in determining species survival was not the size of the fragment but rather how close individual species were to the edge of the forest, and the nature of the surrounding land. Trees at the edge were found to be five times as likely to be uprooted by wind storms as trees in undisturbed forest. Light penetrates the forest floor more readily at the edges, disrupting the humidity patterns necessary for rainforest survival and drying out the soil. Some trees (e.g. the Brazil nut) can tolerate these conditions better than others, such as the jacaranda, and tree composition changes the commmunity structure at the edges of fragments.

When there was a decline in the economy in the mid-1980s, the Brazilian government withdrew clearing subsidies. At around the same time many farmers started to find that soil nutrients were depleted. The fields which had provided high-yielding crops and pastures for a few years were turning into dust bowls. Many farms were abandoned, and secondary growth forests or shrub-grassland began to develop on the clearings.

The researchers found that the more forest-like the regrowth, the greater was the retention of species within the rainforest fragments and the more comprehensive was the recolonisation by those species which had previously dispersed. The fragments surrounded by cleared land that regenerated a shrub-grassland cover, however, did not fare so well. Birds living in the understorey of the forest would not cross even a short stretch of pasture. These fragments were dominated by small mammals and frogs which were able to utilise both the forest and pasture resources.

A 2002 review of the findings of 340 separate studies of the effects of clearing on Amazonian forests has shown similar results. The immense size of these forests has resulted in a large number of plant and animals species that have such specialised adaptations that they are unable to survive in even the smallest clearings. With increased future development by the Brazilian government of hydroelectric schemes, gas pipelines and highways through the Amazon, ecologists are concerned about the decline in biodiversity.

Similar studies of land clearing of woodland in the wheatbelt of south-west Western Australia have shown parallel findings with respect to climate changes within the remaining fragments. The overall effect has been the extinction of twenty-four plant species and many animal species in the area. Other animals, such as the tammar wallaby and the banded hare wallaby, are declining in abundance and range. Nutrient cycles have also been disrupted as a result of disruption of all soil fauna groups except ants, and this impacts on agricultural practices and costs. Because fauna populations are confined to small vegetation remnants, they are forced to inbreed. This ultimately leads to loss of genetic variation in populations and often to maladaptive characteristics that can further increase the population's demise.

These studies illustrate the difficulty in determining the size of suitable refuge areas and corridors in agricultural lands. While some species may be advantaged, others are disadvantaged by habitat fragmentation. These changes are related to microclimate changes and the specific requirements of each plant and animal species in the community. Either way, biodiversity is reduced.

10.2.5 Introduced species

European colonists brought with them to Australia a variety of plants and animals, either deliberately (for food, recreation or aesthetic reasons) or accidentally (e.g. the cane beetle). These species are termed exotics. They may have a major impact on the terrain, making it unsuitable for other organisms. Notable examples are burrowing rabbits or feral pigs, both of which bring about land degradation. Exotic species such as the cane toad and the Indian myna may directly impinge upon endemic (native) species through predation and/or competition for resources. Introduced animal species which have become pests in Australia include the fallow deer, Asian water buffalo, rabbit, hare, fox, camel and European carp. Plants include lantana, water hyacinth, prickly pear, salvinia, tamarisk (athel tree), blackberry and the giant sensitive plant (*Mimosa pigra*).

Case study 10.2: Associations between exotic plants and animals

The Asian water buffalo was introduced to the Northern Territory in the mid-1800s. European breeds of dairy cattle did not thrive in this tropical monsoonal area where parasitic ticks are abundant. The water buffalo adapted to these conditions successfully, and provided milk, meat and hides for the early settlers. Some escaped domestication and readily became established in the wild—that is, they became feral.

Water buffalo live on the floodplains. In dry seasons the waterholes and billabongs, reduced to muddy puddles by the wallowing buffalo, become death traps to hunger-weakened native animals. The paths the buffalo create become erosion channels, often breaking through natural levees between saline tidal creeks and freshwater billabongs. Salt water seeping through the swamp plains kills the native paperbark trees. Overgrazing prevents regeneration of plant species and results in sheet erosion of the plains—mass soil movement across a broad area.

Giant sensitive plants (native to Central and South America) became established in the wild in the 1950s. They are well suited to this area since they are drought-resistant and are also able to withstand waterlogging due to the presence of aerial roots. These plants grow prolifically and seed annually. They are able to colonise areas degraded by the buffalo and further change the floodplains by crowding out the native species, blocking the light from groundcover plants and seedling trees. The combined effect of the Asian water buffalo and the giant sensitive plant is to reduce plant species diversity and thus deplete resources for native marsupials and birds.

10.2.6 Pests

In the widest sense, **pests** are organisms which cause harm to humans or their resources, either directly or by competing with organisms which humans wish to produce. Whether they are recognised as pests depends on their numbers and the tolerance of the desired product organism. Pests may be animals or plants (usually called weeds).

A wide range of weeds compete for water, light and mineral nutrients with crops and pasture plants. Some release powerful chemicals from their roots which can inhibit the growth of other plants. Others carry crop diseases.

Many agricultural systems involve a monoculture—a single crop or stock kept at high density. These conditions favour population growth of consumers (pests) of these 'crops', which can reduce productivity of the crop and/or cause disease.

Control of both weeds and other pests is important. Large-scale use of pesticides has, therefore, become commonplace. World production of pesticides in 1986 was about 2 300 000 tonnes a year—a figure which has doubled since 1964 and is increasing at a rate of about 12.5 per cent per year.

Unfortunately, pesticides cause widespread pollution of the environment, seeping into rivers, killing off fish, and contaminating ground water, drinking water and food. In 1972 the World Health Organization concluded that there were about 500 000 cases of pesticide poisoning per year, causing 9000 deaths; by 1987 this estimate had grown to more than a million cases of poisoning and about 20 000 deaths.

Of more concern, however, is the finding that many pesticides, such as the herbicides DDT and atrazine, mimic the female hormone oestrogen causing feminisation in a number of species of amphibians, birds and mammals. This results in low reproductive rates and possible extinction of species.

Several indices are used when measuring the effects of pesticides on the environment:

Biodegradability

Can the pesticide be broken down to a harmless form by organisms during their metabolic activities?

Biological magnification

Is the pesticide passed from organism to organism along the food chain? If biological magnification occurs, each trophic level accumulates more and more of the chemical.

Half-life

The half-life of a chemical is the time it takes for half of any given quantity of the substance to break down to something else. In the case of harmful chemicals, the half-life would refer to the breakdown to a harmless form.

Suppose substance X has a half-life of 1 week, and 10 g of the substance is sprayed on an area. After 1 week, 5 g remains; after 2 weeks, 2.5 g remains; after 3 weeks, 1.25 g, and so on.

Persistence

Persistence is the length of time that measurable residues of the pesticide are found in the environment. Persistence is related to half-life.

Herbicides

Weeds can be controlled mechanically (though this is only practical in small areas), by fire, by biological control and by chemical sprays. The most common herbicides are those which interfere with plant growth, causing the plant to overgrow and die. They are very effective in the control of broadleaved weeds, while not affecting most monocotyledonous plants such as cereals. 2,4–D, 2,4,5–T and MCPA are such herbicides. Although they are toxic to animals, they have a short half-life. In other words, they do not persist for long in the soil.

Since 1965 the use of 2,4,5–T on food crops has been banned in the USA. The major concern has been the effect of a material called dioxin which is formed as a contaminant in all the formulations of 2,4,5–T. Dioxin is produced at high temperatures (which may occur during manufacture, storage or from bush fires in areas that have been treated). It is a very strong teratogen (i.e. it causes birth deformities) and is much more persistent in the soil than 2,4,5–T or 2,4–D. Its persistence is 7 years as opposed to 6 months. Workers in factories producing these chemicals have contracted a range of diseases such as neuromuscular disorders and liver damage.

Although 2,4–D and 2,4,5–T are used mainly to control broadleaved weeds in crops, their effects are more widespread. The chemicals commonly get into waterways, either through soil run-off or from aerial spraying application. The following environmental effects have been documented:

- Mangroves are particularly sensitive to herbicides. Mangrove areas in Vietnam sprayed with a mixture of herbicides including 2,4–D remained uncolonised by plants for at least 6 years.
- Sudan grass, a slightly toxic pasture grass grown in Queensland, increases its content of toxic hydrocyanic acid after being sprayed with 2,4–D.
- 2,4–D decreases the rate of photosynthesis in marine phytoplankton and thus can affect world oxygen supplies.
- Fish can suffer directly from toxicity, or experience decreased resistance to disease and infection, when exposed to these chemicals.
- The growth of oysters is reduced.
- Marine planktonic crustaceans suffer a variety of effects.

Insecticides

There are four major groups of insecticides: inorganic-based and plant-derived insecticides, chlorinated hydrocarbons and organophosphates. Some examples of these, and their effects, are given in Table 10.2.

DDT (dichlorodiphenyltrichloroethane)

DDT is a chlorinated hydrocarbon. The major problem with these chemicals is their long half-life. They remain stable for many years and concentrate in the fat tissues of animals, building up in concentration as they pass along the food chain. This increase in a substance as it passes through the food chain is termed biological magnification (Figure 10.3).

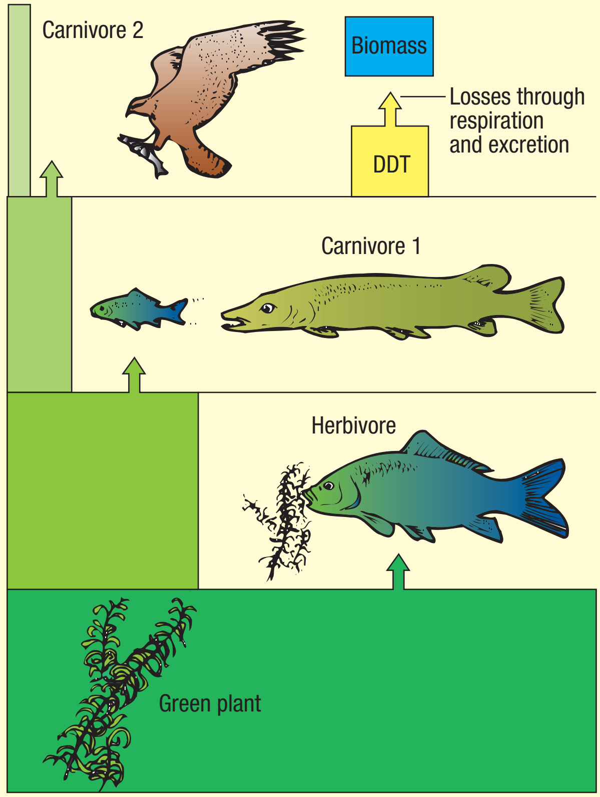


Figure 10.3 Increasing concentrations of DDT in a food chain

DDT blocks the enzyme which normally controls the stimulation of nerve pathways. In insects this causes violent and continuous muscular spasms which end in death. While primarily used in the control of crop insects, this chemical has been shown to have severe side-effects, for the following reasons:

- DDT has a long half-life—approximately 15 years. Thus, although it was banned in the USA in the early 1970s and in Australia in 1987, its effects will persist for many more years.
- It is easily carried by wind and water.
- It is readily soluble in fat. Once stored in fatty tissue it is protected from breakdown, and undergoes biological magnification as it passes along the food chain. In Clear Lake, California, in an attempt to clear the lake of midges, enough DDT to give a concentration of only 0.02 ppm (parts of DDT per million parts of water) was dumped into the lake. One year later the following DDT levels were found:

Table 10.2 Some insecticides, their uses and effects

Group	Examples	Uses/effects
Inorganic based	Compounds of heavy metals, e.g. lead arsenate, copper, mercury	• General insecticides. • Slowly biodegradable; highly toxic. • Kill soil microorganisms, thus nutrient recycling limited; results in soil sterility.
Derived from plants	Nicotine Rotenene Pyrethrin	• Readily biodegradable, with rapid loss of toxicity. • Need to be applied regularly. Indiscriminate killers of all insects, e.g. bees and predatory species. • Pyrethrin occurs naturally in marigolds; companion planting with vegetable crops is an effective deterrent to insects.
Chlorinated hydrocarbons		• General insecticides with long half-life; remain stable for many years; subject to biological magnification.
	DDT	• (See text).
	Dieldrin and aldrin	• Potent nerve and liver poisons. Used against termites in homes. Banned in Australia for agricultural use in 1987. Decreased numbers of flame robins, welcome swallows, pallid cuckoos and yellow-faced honeyeaters in Victoria have been attributed to dieldrin-contaminated food sources. • High levels of dieldrin have been reported in human milk.
	Chlordane and heptachlor	• Used against termites, ants, cockroaches and spiders, and in cattle dips. Agricultural use was banned in Australia in 1987. (Heptachlor can still be used for treating sugarcane in Qld.) Allowed for external treatment of house pests. • Both can be absorbed through the skin. Affect the nervous system, may cause genetic damage, and have been linked with leukemia in unborn children.
Organophosphates		• Affect neuromuscular system of wide range of vertebrates and invertebrates; effects very rapid.
	Baits	• Used to kill dingoes and foxes, but indiscriminate killer of native carnivores.
	Marathion	• Used in flea and tick washes. Rapidly biodegradable but highly toxic. (500 mL can kill 400 humans.) Absorbed through skin.
	Malathion	• Used in flea washes. Very biodegradable. Less toxic than marathion.

Organisms	DDT concentration
plankton	10 ppm
plankton-eating fish	903 ppm
carnivorous fish	2690 ppm
fish-eating birds	greater—most died

- Many insects (e.g. mosquitoes) develop complete immunity to DDT within a few generations.
- Many beneficial insects are also destroyed by DDT.
- It causes a decrease in photosynthesis in marine phytoplankton (which produce 70 per cent of the world's oxygen supply).
- The last part of the yolk in fish eggs, which is the first food of the newly hatched fry, is the storage area of any DDT residues. This causes neuromuscular spasms and death of the young fish.
- It upsets the calcium balance in birds, as a result of which thin-shelled eggs are laid. These break when the bird tries to incubate them.
- It kills honeybees; thus crops dependent upon pollination by bees do not develop fruit (e.g. citrus and apple orchards) or die (alfalfa/ lucerne).
- It can produce the following effects in mammals:
  — It upsets the enzyme system, causing liver disease.
  — DDT passes through the placenta to the developing embryo.
  — DDT is present in milk. (The World Health Organization in 1987 warned that human breast milk is seriously contaminated.)

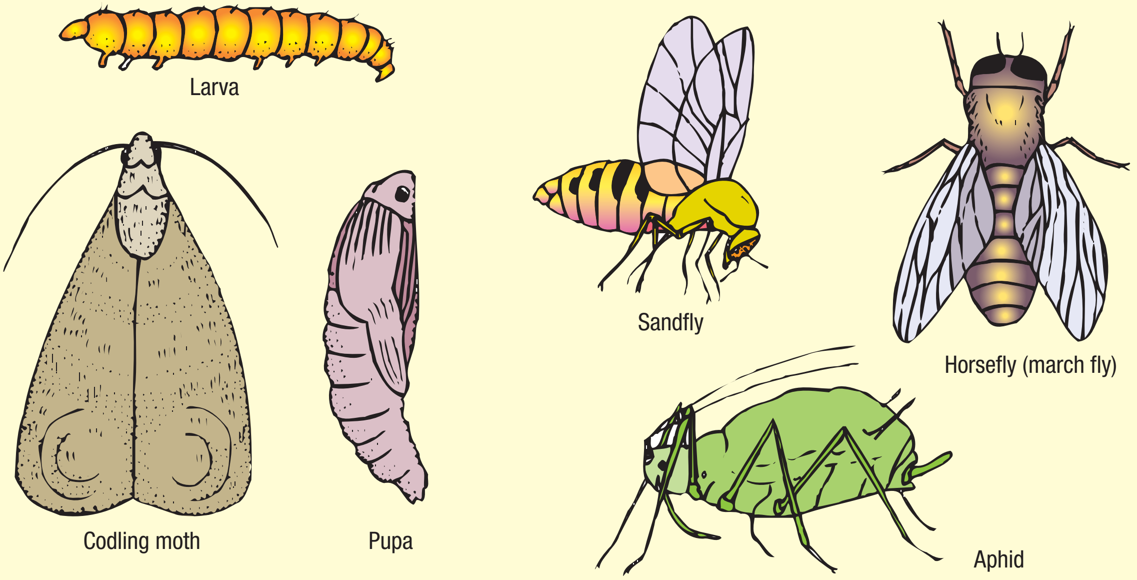


Figure 10.4 Some insect pests (not to scale)

Rationale for use of pesticides

The pesticide industry claims that without pesticides world food production would fall by 50 per cent, causing starvation. In addition many diseases carried by insects, such as malaria, yellow fever and filariasis, would run rampant and cause further deaths. A study undertaken at Cornell University in 1978, however, concluded that without pesticides financial losses would be increased by only about 9 per cent, while food crop losses in terms of food energy would increase by about 4 per cent.

Pesticides are readily available and can be stockpiled for use as the need arises. They are often the only means available to deal with an unexpected outbreak of a pest or a new pest that has suddenly appeared. In spite of the inherent disadvantages, broad-spectrum pesticides do not require any specific indentification of the pest because they are effective against many species. Because of the greater range of uses and therefore larger-scale production, they are cheaper than narrow-spectrum, more specific products. Pesticides with a longer half-life generally require fewer applications than non-persistent ones, and a choice is available depending on the circumstances.

10.2.7 Alternatives to pesticides

Pesticides are only one option available for the control of unwanted species.

Biological control

In many cases, introduced pests are organisms that are quite unobtrusive in their place of origin. They

(a) Ladybird (lady beetle), which controls plant bugs

(b) *Cactoblastis* caterpillar, which controls prickly pear

Figure 10.5 Some biological control agents

Table 10.3 The main options for pest management

Control method	Example
Chemical	Insecticides, miticides, herbicides etc.
Biological	Natural enemies
Cultural	Crop rotation, mulches, covers, resistant varieties
Preventive laws	Legislation, social expectations concerning hygiene
Mechanical/physical	Cutting, hoeing, fly-swatters, fly-papers
Genetic	Genetic engineering
Integrated	Combination of methods

are usually introduced accidentally, and become pests only when they establish in a different environment. Biological control is the use of their natural enemies (predators, parasites and pathogens) to bring about a reduction in the pest. Depending on the pest, this may result in either increased productivity of crops or decreased environmental degradation or disease.

Worldwide interest and acceptance of biological control was first aroused in 1888 by the spectacular consequences of introducing an Australian ladybird, *Rodolia cardinalis*, into the United States to control another Australian insect, the cottony-cushion scale *Icerya purchasi*, which was ruining the Californian citrus groves. In those regions of the world in which biological control has been most successful (California, Hawaii and Australia) the common feature is that most of their agriculturally valuable plants are introduced species. Pests have often travelled with the plants or have arrived later. Biological control has involved the transfer of selected natural enemies from the home country of the pest.

Selection of the control organism(s) is of great importance. The control must be carefully screened to ensure that its attack is confined to the target pest, that it will not damage other plants and animals, and that its numbers will dwindle as it reduces the pest.

Case study 10.3: Biological control out of control

A classic example of unsuitable selection of a control organism is the introduction of the cane toad into Australia. The cane toad, *Bufo marinus*, was successfully used in Puerto Rico to control the cane beetle, which attacks the growing shoots of sugarcane. Encouraged by this success, Australian delegates who had examined the control measures in Puerto Rico introduced cane toads into North Queensland in 1932. Although scientists warned against this without controlled experiments to study their effects in Australia, many thousands of toads were released here between 1932 and 1937. Since that time, the cane toad has spread from North Queensland to as far south as Coffs Harbour, New South Wales, and has spread inland from the high-rainfall coastal areas of Queensland across woodland cattle country into Kakadu National Park in the Northern Territory.

The cane toad proved to be a complete failure in controlling the cane beetle in Australia, and pesticides are now used for this purpose. It is a successful competitor with other amphibians, to the extent that some native species may become rare or extinct. It has been claimed that, in addition to their insect diet, cane toads also eat the young of various mammals and reptiles. Apiarists are particularly affected by this formidable animal: the toads wait at the entrance of hives to snap up the pollen-laden bees as they return, resulting in massive losses of worker bees in a matter of weeks.

Table 10.4 Advantages and disadvantages of biological control

Advantages	Disadvantages
Essentially permanent management of target pest.	Once released, agents cannot be recalled.
No harmful environmental side-effects, because each agent is restricted to one or a small number of target species.	Multiple-pest species groups cannot be controlled.
Agents are self-perpetuating, self-distributing and dependent.	Set-up costs are relatively high.
Risks are known before release into the environment.	There are risks, although much less than in other types of pest management; society must decide if they are worth taking. Native natural enemies may impede introduced agents.
High benefit:cost ratios for successful programs.	Political commitment must be made to allocate funds.
Once agents are established, no further inputs are needed.	

Predators are few, since the toad has an efficient defence in two large poison glands on the shoulders. A few birds—the pheasant coucal and the raven—are known to attack toads, and water rats and keelback snakes have been observed eating them. The only real limit on their numbers at present seems to be the amount of shelter available during the winter dry seasons.

The use of biological control is a case of applied ecology. The aim is to intoduce a natural predator, parasite or pathogen of the pest species alone. Due to the large population of the pest species, the control population increases dramatically. As the food source is depleted, the population size of the control decreases. The ideal is to create a balance of small numbers of both control and pest. Total destruction of the pest in any one area will cause eradication of the control organism and this is undesirable since outbreaks of the pest could recur.

When research (often a costly and long-term process) has been thorough and ideal control organisms have been introduced, this method has been highly successful.

Some biological control programs in Australia

Prickly pear

Prickly pear was originally brought into Australia as an ornamental plant, the fruit of which contained a red dye used to stain soldiers' coats. By the mid-1920s this cactus had invaded some 20 million hectares of pastoral and agricultural land. It was successfully controlled by the caterpillar of an Argentinian moth, *Cactoblastis cactorum*.

Green vegetable bug

The sap-sucking green vegetable bug, *Nezara viridula*, attacks a wide range of crops. Its control organism is an Italian strain of the parasitic wasp *Asolcus basalis*.

Skeleton weed

Skeleton weed, *Chondrilla juncea*, is a serious weed with a prolific root system capable of producing new plants if broken during cultivation. It is a competitor of cultivated crops, particularly of wheat. Control by a rust fungus, *Puccinia chindillina,* is proving effective for some strains of this plant.

Bushfly, buffalo fly and pasture grasses

Bovine dung is not attacked by indigenous beetles, as is that of native animals. Cattle dung pads soon dry as a hard cake where they have fallen on pasture and thus smother the grasses. Due to the acidity of the dung, grass growing near the edges of the pad tends to be rank and is avoided by the cattle. Thus pasture loss in the cattle industry is very high. It has been estimated that, every 30 minutes, 6 million cattle dung pads are deposited on the surface of Australia. Fresh pads are the major breeding grounds of two fly species—the blood-sucking buffalo fly in the tropics and the widespread bushfly. Eleven species of beetles from Africa have been introduced in a attempt to address this ecological imbalance. Beetles of one type work in the soil directly below the dung, carrying dung into tunnels in the soil in which they lay their eggs. Others roll balls of dung some distance from the pad before burying them.

Rabbits

Rabbits are responsible for considerable rural damage, with estimated costs of up to $600 million a year. They have been controlled successfully in the past by a viral disease, myxomatosis, which is carried by mosquitoes and fleas. Due to the development of resistant strains of rabbits to this virus, however, this control is no longer effective and valuable grazing

Figure 10.6 Rural land damaged by rabbits

land is once again under serious threat. The powerful organic poison sodium fluoroacetate (1080) is commonly used to eradicate rabbits, but this can also affect native fauna. In addition to causing agricultural damage, rabbits are one of the chief causes for the decline in natural wildlife in the southern parts of Australia through competition for resources, and through destruction of habitats.

In 1996 CSIRO systematically released rabbits injected with calicivirus (RDC) into warrens across Australia. The action has been surrounded with controversy, since many believe that the effects of calicivirus have not been adequately researched and there is some evidence that it may infect other species. Scientists from CSIRO, however, believe that there will be no side effects and that this virus will effectively control rabbit populations in this country. They predicted in 1996 that it would kill 80 per cent of the rabbits within 2 years.

Five months later, the findings were that calicivirus was very effective in dry country where rabbits live in burrows. In wetter, more fertile country along the coast, where rabbits live predominantly in logs and bushes and under sheds, the virus appears to be having little effect. One hypothesis is that the rabbits are not breeding in the dry country due to lack of food. In the ranges along the coast, it is thought that young rabbits, up to 8 weeks of age, are able to develop antibodies to the virus and so become immune. The overall effect of the virus on rabbits in these areas, therefore, is negligible.

Water weeds

There has been some success in controlling water weeds such as *Salvinia* and water hyacinth with insects.

Lantana

A beetle of the weevil group is used to control lantana, *Lantana camara*. The Queensland Department of Natural Resources and Mines released the beetle *Aconophera compressa* in 1995. The insect, in feeding on sap, causes stem dieback. This in turn reduces flowering and seeding and thus the spread of this plant, which is arguably our worst weed. Although the beetle was rigorously tested against native plants, this same testing was not undertaken for all exotic plants that are often grown as garden ornamentals. Thus in 2003, attacks on the introduced fiddlewood, *Citharexylum*, and ornamental *Duranta* were reported in both gardens and nurseries. While having an adverse effect on these exotics, by limiting the spread of the lantana the beetle could be considered to have a more significant, positive environmental impact.

(a)

(b)

Figure 10.7 Insects used in the control of lantana: (a) the lantana bug (*Uroplata girardi*), a leaf defoliant; (b) the lantana beetle (*Aconophera compressa*), a sap sucker

Resistant strains

Resistant strains of both plants and animals are being developed, some by genetic engineering, others by selective breeding programs. *Phylloxera* is a disease of grapevines caused by an insect that attacks the roots. It has been controlled by grafting vines with good fruit characteristics onto root stocks that are naturally resistant to the disease.

More recent work employing genetic modification has resulted in a large number of disease-resistant plants.

Other methods

Other non-chemical methods have also been successful in control of pests. They include the release of sterilised male pest insects which subsequently mate with fertile females. Since fertilisation does not occur, no offspring are produced.

Many species release hormones which are an external stimulant to other members of their species **(pheromones)**. Sex hormones of female insects are pheremones. These have been isolated and can be artificially produced. These hormones are then placed in appropriate areas, in a tin containing a trapping agent, thus attracting the males and destroying them. Reproduction is thereby reduced.

Some insects can be controlled physically. For example, some pupate in the soil and ploughing can either squash them or bring them to the surface to be eaten by predators. Diseased limbs of trees, which provide refuge for pests, can be pruned and burnt. Pests in suburban gardens can be picked off by hand rather than sprayed. The use of fly screening, mosquito nets, clothing which inhibits mosquito attack and repellents such as citronella oil can also minimise the effects of pests on people.

Sometimes the plant or animal pest may be difficult to control directly, and other methods of management may be needed. The cattle tick is a good example. This pest is controlled partly by means of dipping or spraying the cattle with pesticides. Research has shown that very few ticks survive on pastures kept free of stock for three months. Spelling of pastures, however, can be impracticable on large cattle properties in northern Australia, where environmental carrying capacity may be as low as one head of stock per five hectares. Zebu and zebu-cross cattle have a natural resistance to ticks, and heavily tick-infested areas are now being stocked with these strains. Legislative control, such as the imposition of quarantine areas, has been effective in decreasing the spread of ticks from tropical and subtropical areas to the temperate southern regions. Fruit fly control is also governed by these regulations.

Integrated pest control

An integrated approach incorporates chemical control (utilising both pesticides and pheromones), biological control, host resistance and cultural/physical control in order to reduce damage by pests to a tolerable level. It aims to create a balance between human needs and environmental protection. The success of such pest management depends on a knowledge of the life cycle of pest species (and thus the most vulnerable stage for its control), monitoring pest numbers (indicating when and where a problem is likely to occur), combining two or more control measures, and cooperation between all stakeholders (agriculturalists, health authorities, environmentalists, chemical companies and scientists).

SUMMARY

In agricultural ecosystems land degradation can occur as a result of wind and water erosion, nutrient depletion and salination. Damming of waterways changes the normal cycles necessary to sustain freshwater and floodplain ecosystems. Irrigation can lead to salination of both soil and water.

Habitat fragmentation may result in extinction of native species. The size, shape, edge effects and surrounding land use of remnant fragments of natural vegetation, and the extent of corridors between them, determine the viability of the original ecosystem. Different ecosystems have different requirements.

Introduced species, if they become naturalised, may directly or indirectly bring about destruction of natural habitats and endemic species.

Pests are organisms which cause harm to humans. This may happen directly, through destruction of resources, or through competition for resources. Pesticides are chemical substances used in the control of pests. They include herbicides (for weeds), fungicides and insecticides. These substances may have drastic side effects, resulting from:

- long half-life
- low biodegradability
- chemical conversion to other forms
- non-specificity
- biological magnification.

Alternatives to the use of pesticides include:

- biological control (predators, parasites and pathogens of the pest)
- selective breeding or genetic engineering of resistant strains
- release of sterilised males of the pest species
- pheromone baits
- physical methods.

Integrated pest management incorporates a variety of methods at susceptible phases of the pest's life cycle to reduce damage to a tolerable level.

? Review questions

10.4 Describe the possible consequences, in relation to the soil, associated with removal of vegetation.

10.5 List ways in which soil erosion can be reduced in agricultural ecosystems.

10.6 Which region in the hillside shown in cross-section in Figure 10.8, is most susceptible to erosion? Explain your answer.

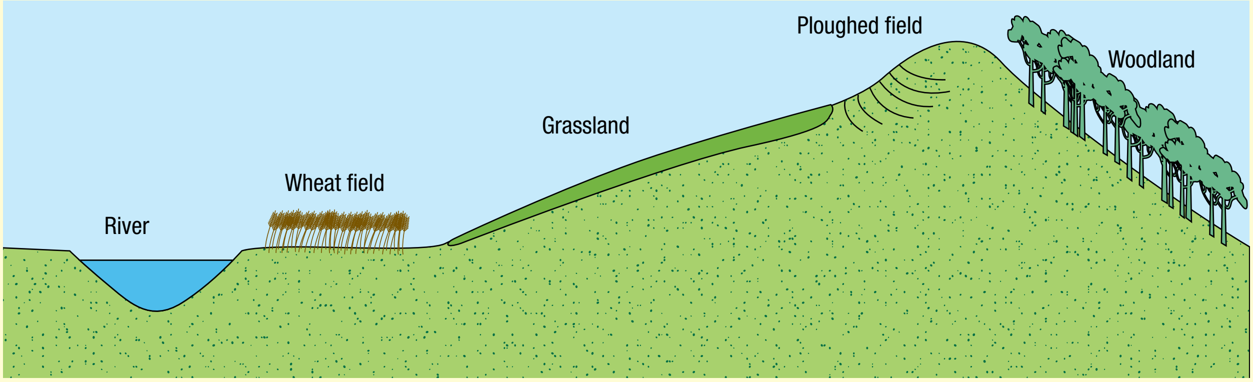


Figure 10.8

10.7 What abiotic factors contribute to the low productivity of large dams?

10.8 Why should billabongs and other wetlands be conserved?

10.9 Explain how irrigation of crops can lead to increased salinity of soils and adjoining waterways.

10.10 Define eutrophication.

10.11 How can the application of fertilisers to farmland result in the death of organisms in nearby freshwater ecosystems?

10.12 Explain how habitat fragmentation can influence species diversity.

10.13 List one plant and one animal species which, in Australia, is:

(a) endemic

(b) exotic

(c) feral.

10.14 Define the following terms:

(a) biological magnification

(b) biodegradable

(c) half-life

(d) herbicide

(e) insecticide

(f) pest.

10.15 The use of pesticides has been decried by health authorities and environmentalists. Discuss evidence which would support their stance.

10.16 In biological control of pests it is desirable that the control organism and the pest remain in small numbers in the environment. Explain why this is so.

10.17 What precautions must be taken before undertaking a biological control program?

10.18 What are the advantages of biological control over the use of pesticides?

10.19 Cite four examples of efforts at biological control in Australia:

(a) two successful programs

(b) two unsuccessful programs.

10.20 Besides biological control, what other non-pesticide means are being explored and used for the control of pests?

10.21 What is integrated pest management? What advantage does this have over a single control method?

10.3 Urban ecosystems

The industrial and technological revolution resulted in a greater concentration of the human population in urban areas. Within the developed countries, urbanisation has resulted in special problems of pollution, especially in areas where a high standard of living exists. The quantities of fuel, water and food consumed by urbanites are astronomical. There are tonnes of waste resulting from the discard of items because of changes in style or because the cost of repair exceeds the cost of replacement, added to the natural wastes of sewage and industrial by-products. Modern affluent societies are mobile. All the cars, trucks and buses on our roads pour vast amounts of waste products into the atmosphere daily. Urban pollution may be broadly classified as water, air and land pollution.

10.3.1 Water pollution

Organic wastes

Organic wastes are derived from natural materials. These include untreated or partially treated sewage, wastes from food-processing plants such as abattoirs, and waste waters from intensive animal farming. The wastes may contain pathogenic bacteria and may cause eutrophication of waterways.

Inorganic wastes

Inorganic wastes include heavy metals (e.g. mercury, molybdenum, cadmium, arsenic) and other harmful chemicals. These wastes may come from industrial plants such as steelworks, aluminium refineries (where large quantities of ammonia may be released), lead, zinc and copper smelters, from mining operations or from heavy metals (boron, selenium, molybdenum) found in some fertilisers. Although the Clean Waters Act limits the discharge of these compounds, accidents do occur, as when toxic quantities of ammonia were released from the aluminium refinery at Gladstone in 1989.

The effects of these pollutants are numerous. They can cause human deaths if concentrations are extreme, but lower concentrations are capable of causing heart, lung, kidney and nervous system disorders. Heavy metals are believed to cause birth defects. Boron is toxic to some plants. The presence of molybdenum on pastures can cause metabolic disorders in cattle. Heavy metals may kill soil organisms. Aquatic organisms may be killed or their activities decreased by the presence of these chemicals.

Siltation (sedimentation)

Siltation is the addition of soil particles to a body of water and can have several direct effects, such as clogging of the respiratory organs of aquatic animals, and decreased photosynthesis. Indirect effects are caused by the adhesion of harmful chemicals to the particle surfaces. Erosion of surrounding land is the main cause of siltation. In urban areas this may result from clearance of land for housing development, road construction and so on.

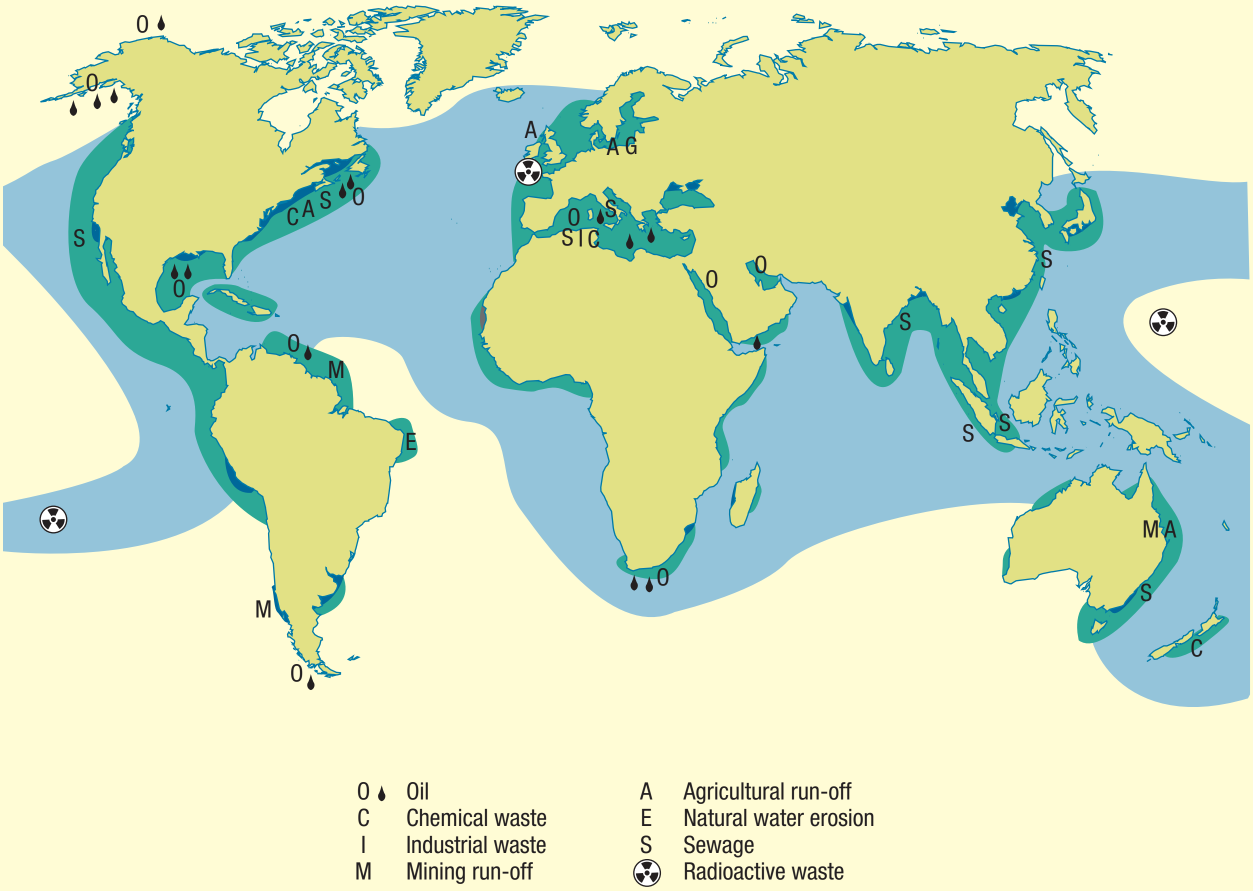


Figure 10.9 An overview of the pollution of oceanic waters

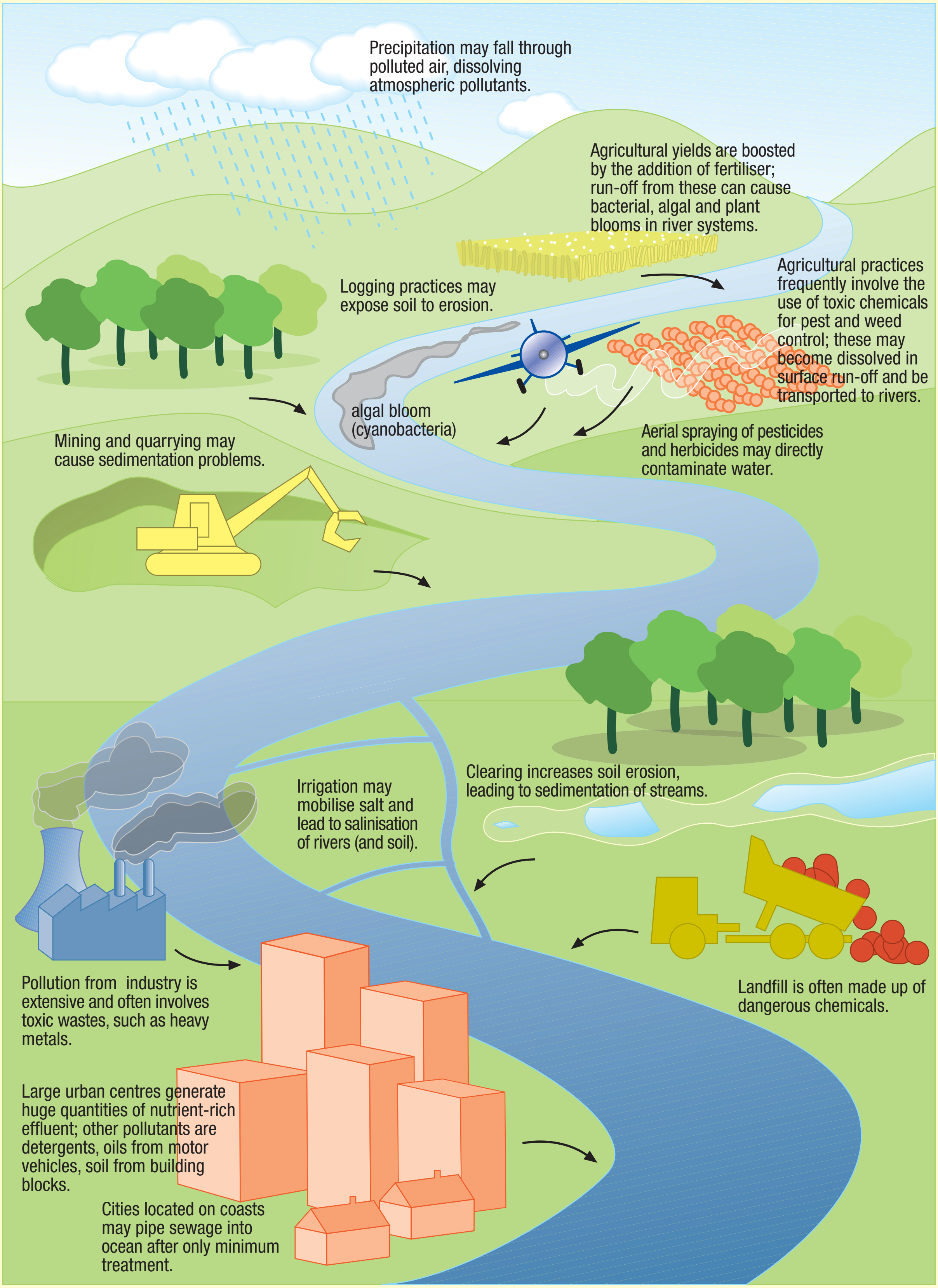


Figure 10.10 Sources and types of water pollution

Detergents

Detergents may simply cause unattractive foaming in waterways, if they have a low phosphate content and are biodegradable. However, some are high in phosphate and thus help to bring about eutrophication; others contain heavy metals such as boron.

Toxic substances

Toxic substances include fungicides, insecticides, herbicides and polychlorinated biphenyls (PCBs). The main sources of these substances may be domestic pesticide treatments or the industrial effluents from factories that produce plastics, electrical insulators or hydraulic fluids. Although these substances may not have a direct influence on aquatic organisms, they may accumulate in the food chain. Some are thought to be **carcinogenic** (causing some forms of cancer) and others are believed to cause human birth defects in high concentrations.

Fertilisers

Although the main source of fertiliser contamination of waterways is agricultural run-off, it may also originate from urban gardens and from factories manufacturing fertilisers. This form of pollution can cause eutrophication or create unpleasant tastes and odours in drinking water. Too much nitrate in drinking water may cause blood diseases in infants and can be toxic to stock that graze on pastures irrigated with polluted waters.

Thermal pollution

Thermal pollution occurs when heated waters are discharged into natural waterways (e.g. from power stations). The raised water temperature leads to increased metabolic processes in organisms (particularly plants) and oxygen depletion. These combined effects result in the death of organisms not adapted to these conditions.

Oil and petroleum

Both oil and petroleum may enter waterways from the exhausts of motorised watercraft, from accidental spillage and from oil processing plants. Floating oil slicks reduce, by a factor of up to 1000, the rate of oxygen transfer from air to water. Some chemosynthetic bacteria increase their population size dramatically in oil and thus further deplete oxygen in the water. Components of oil, especially benzene and toluene, dissolve in water and these are poisonous to aquatic life. Waterbirds and shellfish are affected by the stickiness of the oil–water emulsions that are formed. The feathers of birds and the gills of aquatic organisms become clogged. Toxic components of the oil can also be absorbed through the skin, further amplifying the problem.

Salts

Waterways become increasingly saline with increased run-off, leaching, irrigation and evaporation.

10.3.2 Air pollution

There are various types of air pollution, coming from a number of sources. A **primary pollutant** is one present in its original form, and has a direct effect on the atmosphere. Smoke, dust, and oxides of sulfur or nitrogen are examples. A **secondary pollutant** is formed as a result of the interaction between wastes and the atmosphere.

Photochemical smog and temperature inversions

Photochemical smog is a secondary pollutant produced by chemical reactions between nitrogen oxides and hydrocarbons in the presence of sunlight. The formation of photochemical smog depends not only on the concentrations of the primary pollutants in the atmosphere, but also on the weather conditions. It forms when the air is calm, at suitable levels of ultraviolet light, and when there is a temperature inversion.

Temperature inversions are a reversal of the normal situation, in that the air temperature rises with increasing altitude. Temperature inversions can have a number of causes but in cities with an air pollution problem, the effects are serious. Under normal weather conditions the pollution produced by a city is dispersed as it rises and is blown away. When a temperature inversion occurs, the pollution particles remain trapped in the air closest to the ground.

Urban microclimates

Another way that human activity has changed the atmosphere can be seen in the climate of urban areas. People have created microclimates in urban areas which vary according to the 'built environment': for example, between park areas, and near glass and concrete buildings.

The concrete city surfaces absorb more heat during the day than does the surrounding countryside. A large amount of heat is generated by industrial, commercial and urban sources. Thus city and urban areas can be likened to a warm 'island' projecting out of the cool 'sea' (the air) of the

Table 10.5 Some air pollutants

Pollutant	Possible harmful effects	Major non-natural source
Particulates: smoke, dust, grit	Corrosion and deterioration of building materials; eye, nose and throat irritation	Combustion of fossil fuels; motor vehicles; incinerators; industries; road construction etc.
Sulfur dioxide	Formation of acid rain; corrosion; chest irritations; bronchitis	Combustion of fossil fuels; smelting of mineral ores
Carbon monoxide	Binds with haemoglobin in the blood and reduces oxygen absorption—may be fatal; impaired nerve functions; heart disease	Combustion of fuels
Nitrogen oxides	Formation of acid rain, which is formed when nitrogen oxides combine with water in the atmosphere; retards plant growth; corrosive; eye and throat irritations	Motor car engines
Ozone	Irritates and disturbs functions of eyes, nose and lungs; kills leaves of plants; damages rubber and textiles	Reaction between oxygen and nitrogen in the air
Hydrocarbon vapours	Retards plant growth; abnormal growth of buds and leaves; carcinogenic	Motor car engines; solvents in paints and dry-cleaning
Lead compounds	Toxic; reduction of brain function	Motor car exhaust; smelters
Radioactive materials	Increased risk of mutation; cancer; genetic disturbances	Nuclear weapons; radioactive waste dumps
Peroxacetyl nitrate (PAN)	Attacks plant leaves; irritates eyes; disturbs lung functions	Chemical changes in the atmosphere due to the sun's action on other pollutants

surrounding landscape. The peak of the urban heat island is towards the city centre, with the gradient sloping off to the outskirts of suburbia. The effects are numerous. Plants in cities have been shown to bud and bloom earlier, and some birds are attracted to this warmer area. The climate may be stressful for people if the city is already located in a warm area. Greater airconditioning of buildings may be needed in summer, but heating of buildings in winter will be reduced.

Table 10.6 Changes in urban climate

Phenomenon	Consequences
Heat production (the heat island)	Rainfall increase Temperature increase
Retention of reflected radiation by high walls and dark-coloured roofs	Temperature increase Wind decrease
Surface roughness increase	Eddying increase Fog increase
Dust increase	Rainfall increase, due to increased particulate matter on which water may condense

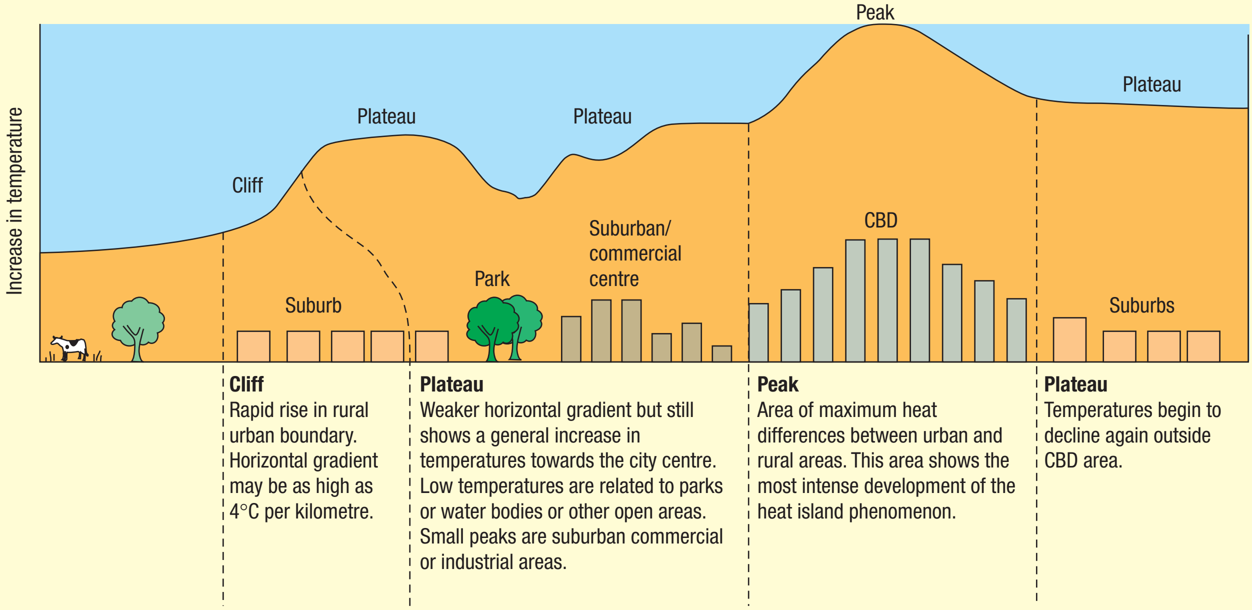


Figure 10.11 Microclimate changes in the urban heat island

10.3.3 Land pollution

Land pollution occurs through land clearing, from the extraction of raw materials for industry and from the disposal of wastes, as well as from agriculture. The problem is greatest in built-up areas with a high standard of living, where the disposal of waste material has reached monumental proportions. The transportation of this waste—cans, cartons, bottles, broken gadgets, worn-out furniture and appliances—and where to put it has become a major problem for all cities. Continued trends toward non-returnable, non-reusable containers present special problems. Glass, aluminium and plastics are durable and are not even completely consumed by incinerators. Incineration of plastics has been a serious cause of air pollution.

The great bulk of solid waste is placed on unused land at the edges of cities. Apart from aesthetic undesirability, two side-effects can result: air pollution from burning refuse and water pollution from seepage as organic matter reacts with water to form acid leachate. Increased use of private cars has resulted in major disposal problems, and in many cases reclamation is not economic.

According to a report in late 2002, Australians throw out enough rubbish to provide a 10 cm cover over the entire state of Victoria every year. Approximately 80 per cent of all rubbish finishes up in landfill, compared to only 11 per cent in Holland and 13 per cent in Switzerland. Even with recycling, glass and plastic still forms a high proportion of all household rubbish in Australia. Most of the material in rubbish does not readily break down into harmless substances—orange peel can take 2 years to break down, disposable nappies between 200 and 500 years, plastic-coated paper anything up to 1000 years, while glass and plastic can remain in the landfill indefinitely.

New rules governing air and water pollution have made industrial land pollution even worse. Many by-products of industry are now converted to solid waste which is dumped in the soil. The safety of such practices is under question, since much of this waste is either toxic or potentially toxic. With some wastes, the toxic status is unknown.

SUMMARY

As a result of urbanisation, freshwater and marine ecosystems can become polluted. Pollution may originate from organic wastes (e.g. sewage, oil and petroleum) or inorganic ones (e.g. factory effluent of heavy metals and other toxic matter, fertilisers, detergents, pesticides, salts); or from sedimentation, discharge of hot water or leaching.

Air pollution, too, has a variety of sources. A primary pollutant is one which produces a direct effect; a secondary pollutant results from chemical changes to wastes that take place in the atmosphere. Urbanisation creates 'heat islands' which bring about climatic changes and temperature inversions.

Land pollution in urban areas originates primarily from the disposal of wastes by industry, commerce and households.

Review questions

10.22 Draw up a table describing four water pollutants, their possible harmful effects and their major non-natural source.

10.23 Distinguish between a primary and a secondary air pollutant.

10.24 What is photochemical smog?

10.25 List the sources of the following air pollutants and their effects on the environment:

(a) nitrogen oxides

(b) particulates

(c) carbon monoxide

(d) hydrocarbon vapours

(e) sulfur dioxide.

10.26 Urbanisation has created changes in climate that affect whole settlements and also microclimates within specific parts of them. Explain how this might occur and what environmental effects it might have.

10.27 How can land pollution lead to water and air pollution?

10.28 What measures can be made to decrease land pollution?

10.4 Climate changes

10.4.1 The greenhouse effect

A planet's temperature depends mainly on three factors:

- the amount of sunlight it receives
- the amount of sunlight it reflects
- the extent to which its atmosphere retains heat.

Incoming solar radiation reaches the earth's surface as short wavelengths, which have a high energy level and are readily transmitted through the earth's atmosphere. When this radiation strikes a solid object it is absorbed and later re-radiated as long-wavelength energy (heat). The longer wavelengths have less energy and cannot travel through the atmosphere as readily as the short waves, so they are absorbed by gases. Water vapour and carbon dioxide are two gases which trap this heat radiation. The ultimate effect is to raise the temperature in the lower atmosphere. This is known as the **greenhouse effect** (Figure 10.12). Without this effect, the heat loss from the earth during the night would be extremely high, possibly making the planet uninhabitable.

Increased combustion of fuels since the industrial revolution has increased the concentration of carbon dioxide in the atmosphere dramatically—by 30 per cent since 1850. It is estimated that the current levels of carbon dioxide in the atmosphere

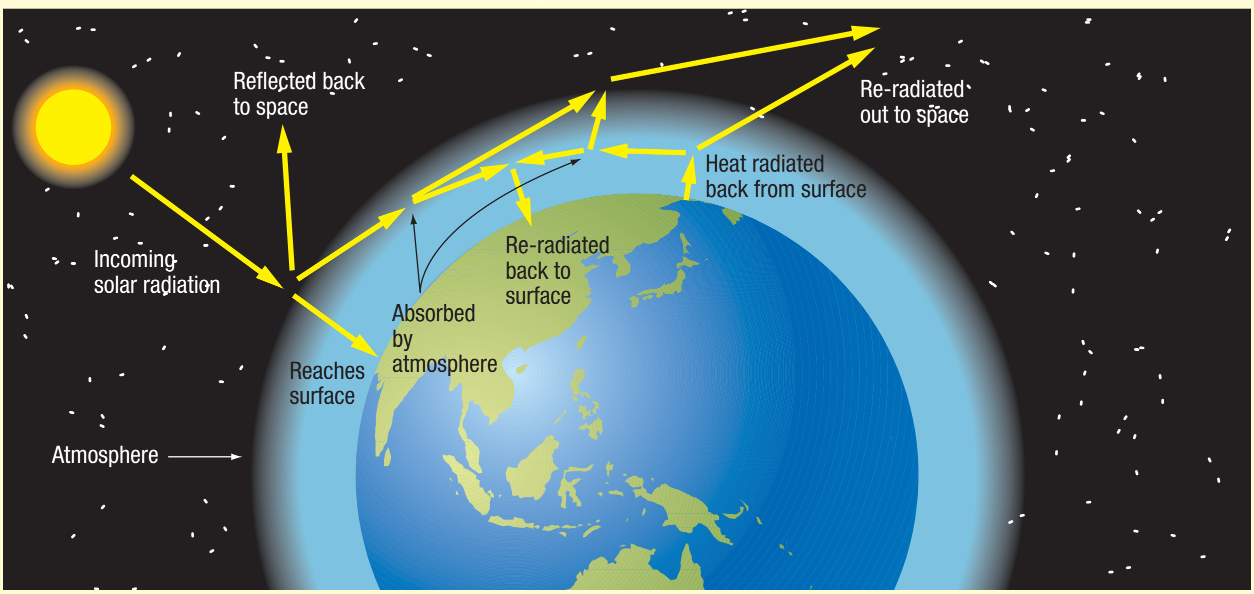


Figure 10.12 The greenhouse effect

will double by the year 2060. The increase in carbon dioxide has resulted in greater heat retention in the lower atmosphere. This has brought about increased evaporation from the oceans, thus amplifying the greenhouse effect. Other 'greenhouse gases' are believed to include ozone, methane, nitrous oxide and chlorofluorocarbons.

Massive increases in the number of cattle since their early domestication are cited as a reason for the increase in methane. These herbivores require bacteria in their stomach to digest the cellulose cell walls of their plant foods. The fermentation process that takes place releases large amounts of methane. It has been estimated that a typical animal emits 48 kilograms of methane gas per year. Further methane is released during decomposition of manure. Similarly, the large increase in human population has resulted in large outputs of sewage and thus of methane gas.

The resulting thickening of the earth's 'blanket' is believed to have several effects. One prediction of the changes that will take place in Australia by 2030 includes:

- a temperature rise of 2–3°C
- rainfall increase of up to 50 per cent in summer and decrease of 20 per cent in winter
- large regional changes in soil moisture run-off and water supplies
- tropical cyclones more frequent and further south
- more frequent weather extremes such as floods and droughts
- salinity problems inland
- higher snowline
- sea-level rise by 80 cm due to water expansion (higher temperature).

On a global scale it is predicted that polar ice caps could melt and further add to sea level rises. This, however, is believed to be a long-term rather than short-term effect. Alterations of rainfall patterns are predicted to result from changes to pressure belts due to increased temperature. Food crop production would be greatly affected by these changes.

10.4.2 Nuclear winter

Other industrial activities, however, could create another problem by increasing the amount of particulate matter in the air. This could block radiation reaching the earth's atmosphere and immediately re-radiate it into space. This could cause a lower global temperature. Air pollution from large-scale nuclear warfare could, by the massive increase in particulate matter in the air, block incoming solar radiation so that a very cold '**nuclear winter**' lasting many years could result.

10.4.3 Hole in the ozone layer

Another problem arises from the use of chlorofluorocarbons (CFCs) as propellants in spray cans and in refrigeration. Fluorocarbons are believed to damage the earth's ozone layer. This layer is between 16 and 60 kilometres above the earth's surface and serves as a shield that reduces the amount of high-energy ultraviolet radiation from the sun that reaches the earth. If these rays were to reach the earth's surface in full intensity, animal

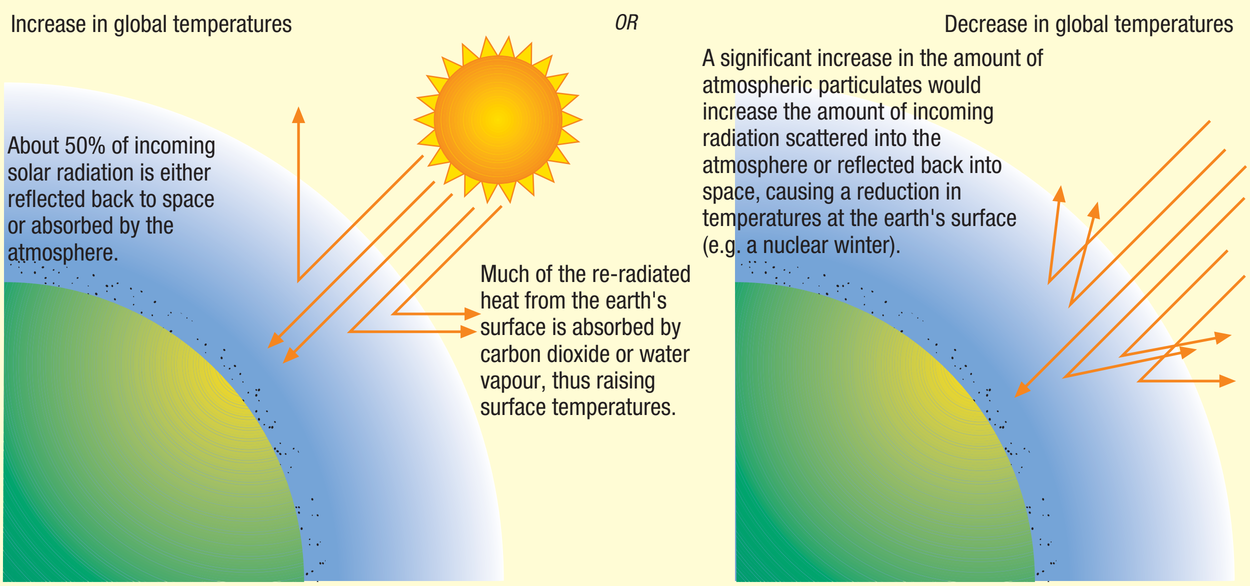


Figure 10.13 Possible outcomes of air pollution

tissue would be badly burned and all exposed bacteria (including those necessary for human survival) would be destroyed.

Since the 1960s, ozone levels over parts of Antarctica have dropped by almost 40 per cent during some months and a 'hole' is clearly visible in satellite observations of ozone concentrations over the polar cap. Monitoring of this 'hole', using remote sensing techniques, has shown that it appears each spring and disappears over summer, but that each year the 'hole' is wider and deeper. Some scientists believe that this may be the result of natural variations in the temperature or wind fields of the upper atmosphere. Other scientists claim that changes in solar activity are responsible. Rising levels of pollution provide the most plausible explanation, however, and action is being taken throughout the world to control the release of CFCs.

SUMMARY

Most solar energy reaches the earth's surface as high-energy, short-wavelength radiation. Energy is released from the surface as low-energy, long wavelength radiation (heat) which cannot easily penetrate the atmosphere. An increased greenhouse effect—due to greater retention of atmospheric heat—has been attributed to increases in carbon dioxide and water vapour concentrations in the atmosphere. It is believed that this will lead to global climatic changes. Increased particulate matter, on the other hand, could cause lower surface temperatures since solar energy may be reflected back into space before reaching the earth's surface.

The ozone layer shields the earth's surface from very high-energy radiation. Depletion of this layer has been attributed to increases of CFCs (from refrigerants and propellants in spray cans) in the atmosphere.

? Review questions

10.29 There is some controversy over whether the world is about to face another ice age, or whether there will be an increase in global temperature. What factors would be responsible in each case?

10.30 Define 'nuclear winter'.

10.31 In what ways would depletion of the ozone layer affect life on earth?

10.5 Conservation

There is an increasing need to understand the dynamics of ecosystems and the human impact on the environment, in order to restore some natural balance. We are in real danger of destroying life on earth since disruption to one component of an ecosystem can have flow-on effects to adjoining ecosystems and over time can have global effects. The goal of conservation is to maintain species diversity while achieving use of natural resources in a sustainable manner. Although some resources are non-renewable (oil, coal and minerals), others are renewable (timber).

10.5.1 National parks

There are certainly ethical reasons for conservation, with an emphasis on humans as caretakers of the planet. But there are far more practical rationales too. With increasing urbanisation, more and more pressure is put on wilderness areas as people seek a recreational area in which to relax. Ecotourism is more and more in demand, not just from overseas visitors but from local populations. The management of wilderness areas becomes a greater and greater challenge. In Queensland, for example, the first national park was established at Mt Tamborine in 1908 and many more areas have since been proclaimed. They now number over 200.

The size and shape of each national park needs to be carefully analysed to ensure that it is achieving its main goal of conserving particular species, since each community has its own requirements for survival. (See Section 10.2.4.) National parks are multi-functional: they provide recreation zones and natural research laboratories and they are areas for conservation of species. Often, they also preserve the traditional lands of Indigenous people. To what extent can our national parks continue to fulfil all these functions?

Flora and Fauna Protection Acts (1930 and 1976 in Queensland) aim to protect rare and endangered species of plants and animals. Enforcement of this legislation is difficult to achieve, however, given the vast areas involved, many of which are sparsely populated and often inaccessible. There are also limited resources to provide adequate patrols such as aerial surveillance. Illegal trafficking of native flora and fauna is still occurring, and generates high financial gains with limited risks. Random customs checks occasionally reveal wildlife smuggling but this very likely represents only a small percentage of such operations.

Figure 10.14 Queensland National Parks

Planned land management can be achieved on a smaller scale. Steps have been taken to maintain wildlife around city areas: for example 'green belts' such as the Brisbane Forest Park around suburban areas, controlled development, and the Vegetation Protection Order placed on privately owned acreage around Brisbane.

10.5.2 Preserving biodiversity

Biodiversity is an important factor in the survival of ecosystems. Few animals rely on only one food source, thus the greater the plant diversity of an area, the greater will be the animal diversity and spread of resource utilisation. Biodiversity means genetic diversity—both within a species and among communities. Genetic diversity increases the chances that a species will survive environmental change since at least some members of the species may have characteristics which allow them to flourish under the new conditions.

In attempts to improve the quality and quantity of agricultural crops, they have been selectively bred to such an extent that genetic diversity has been sacrificed, leaving them prone to pests and plague. In the middle of last century nearly a million people in Ireland starved to death as a result of the failure of their staple diet, the potato. This blight was caused by the mould *Phytophthora infestans*. From that time potato varieties were selectively bred to develop a few commercial strains which were resistant to this disease. However, new varieties of the mould, far more virulent than the original, have originated. These can overcome the genes bred into potatoes to resist blight, and have infested crops in Europe, Asia and Latin America in the 1980s, in Mexico in 1992 and North America in 1994. Known fungicides do not harm it and the mould rapidly mutates to combat resistant genes or fungicides. A similar story holds for wheat, maize, sugar, bananas and clover.

A recent assessment by the UN Food and Agriculture Organisation has revealed that the world depends upon too few crops. In all of these crops many thousands of genetic varieties have been lost as a result of selective breeding, and they fear that many millions more will die out. In the USA alone, 20 000 varieties of agricultural plants have been lost since 1903. Although attempts have been made in recent years to set up international networks of seed banks of threatened species, these have not always been successful. The seed is stored in refrigerators which, in some countries, are unreliable. Additionally, the frozen seed has limited viability, so periodic regeneration must be undertaken. This is a labour-intensive and expensive process.

Of the 30 000 known edible plants in the world, only 7000 have been grown or collected for food. Should our current crops be further decimated by pests, the maintenance of the genetic diversity in the remaining edible plants could be vital.

10.5.3 Quotas

As with the land, Australian freshwater and marine ecosystems are low-nutrient areas. In spite of a fishing zone with an area greater than that of its land, there is low productivity and many areas are over-fished.

Although the Great Barrier Reef is one of the world's great regions of biodiversity, its continued existence, like that of the rainforest, depends upon rapid nutrient recycling. Coral reefs grow only in nutrient-poor warm water which is very clear. The coral organisms live in symbiotic association with photosynthetic algae. They form the base for the great diversity of fish and other organisms that live among them. Removal of fish from the reef results in the loss of nutrients from the system and the ultimate demise of the reef. The relatively small commercial and recreational fisheries in this area, taking only 12 million kg of fish annually, are having a profound impact on the reef's ecology.

Numbers of dugongs along the Queensland coast have recently declined in some areas: a recent analysis found that the current dugong population between Cairns and the Gold Coast is about 3 per cent that of 1962. Possible causes are an increase in shark nets, killing of females by Aboriginal hunters (traditionally these are taken in preference to males because they are fatter) and clearance of seagrass beds (the source of food for the dugong) by trawlers and coastal developers. In order to sustain these marine ecosystems, there is a vital need for increased research on the ecology of commercial species, and for stringent control of quotas, fishing net mesh sizes, closed seasons and exclusion zones.

10.5.4 The living pharmacy

Many supposedly 'insignificant' species have been found to be of major importance to humans. A small sea squirt, *Ecteinascidia turbinata*, which grows on the roots of mangroves in the Florida Keys has recently been found to contain substances that can kill human cancer cells. Other anti-cancer drugs have been discovered in a California bryozoan, *Bugula neritina*, and a New Zealand sponge, *Lissodendoryx*. The rainforest areas of the world have long been the source of many pharmaceutical drugs. Once the chemicals from these plants and animals are identified, attempts are made to synthesise them, to genetically engineer bacteria to produce them, or to 'farm' the original organisms. Overexploitation in their natural state could lead to their extinction. The potential for undiscovered bioresources is enormous.

10.5.5 Practical measures

Many farmers, aware of increasing soil degradation, have formed Landcare groups. Some have reverted to farming techniques that do not use artificial fertilisers and pesticides ('organic' farming). Permaculture is gaining popularity. This is a farming method used to produce multiple crops of both plants and animals; its principle is to work *with* a particular habitat rather than attempting to change it. Organisations such as 'Men of the Trees' provide education programs and trees for reafforestation of degraded land. Forestry practices have improved with increased environmental knowledge. Sustainable yields can be calculated from knowledge of growth patterns: thus if a forest takes 100 years to mature, then 1 per cent can be cut each year. Research in Tasmania indicates that for some forest types, selective logging is less effective than complete cutting of an area and then replanting.

Feral animals, responsible for either killing native animals or degrading the environment to such an extent that it is no longer suitable for them, are being systematically removed by a variety of means. Feral cats and foxes are poisoned and shot. Water buffalo and pigs are shot from helicopters. Brumbies are rounded up and sent to knackeries for petfood production. Lethal viruses have been unleashed in an attempt to control rabbits.

The depletion of some feral animals has, however, had a secondary effect in some areas. Thus Aboriginal hunters who until the 1980s relied on the buffalo and pigs are now depending upon native fauna such as freshwater and saltwater crocodiles, green turtles and dugongs, as their food sources.

Quarantine regulations, both within Australia and between Australia and other countries, have been established to reduce the spread of pest and feral species.

Legislation controls the use of pesticides (herbicides and insecticides), irrigation, effluent from mining and industry, erosion and farming close to the banks of waterways. Despite precautions, however, accidents do happen.

Much of the environmental damage we are now experiencing has resulted from a lack of knowledge of the consequences of past human activities. Although the present generation of young people has inherited a world where pollution and destruction of many ecosystems abound, they are also armed with greater knowledge of the means by which to combat the degradation and restore the environment. Over the past 30 years, conservation groups have made the public aware of the difficulties our planet is experiencing, and this has resulted in changes of attitude at both the governmental and the individual level.

Every individual can contribute to improving the quality of the environment. Simple acts can make a large difference. A few of the many examples are listed below:

- Turn off any electrical appliances and lights when not in use. This reduces the amount of coal needed for electricity generation, and therefore carbon dioxide and heat emission to the atmosphere, thermal pollution of water, and land degradation due to coal-mining activities.
- Restrict water use. The climatic patterns in Australia make water a limited resource. Every time a tap is turned on, electricity is used at the reservoir in the purification and pumping processes. Construction of reservoirs to supply the ever-increasing demands of urban development means further destruction of an ecosystem. Having short showers, and ensuring that taps do not drip, can save enormous amounts of water. The development of native and drought-tolerant gardens adapted to the climate, and mulching garden beds with compost formed from food scraps and garden clippings, further reduce water demand.
- Walk, ride a bicycle or catch a bus rather than using a car whenever possible. This will reduce air pollution.
- Reuse plastic shopping bags or—better still—take a shopping basket or bag (calico, string, etc.) so that plastic bags will not be needed. Plastic is mainly non-biodegradable, and many plastic materials cannot be recycled.
- Buy articles which are not heavily packaged in unnecessary plastic and paper. They may look more attractive, but the packaging does not affect the quality of the article and is using resources which will be thrown away and could pollute the environment.
- Develop an awareness of needs and wants. People have basic needs for survival. Most material possessions, however, are 'wants' which can well be done without.
- Place all litter in refuse bins.
- Recycle. It takes little time to separate food scraps, paper, glass and plastic into different containers. Organic matter can be composted. If other articles are separated for collecting, they can be recycled.

Programs such as 'Clean up Australia' and 'Water Watch' highlight what can be achieved by individuals in restoring the natural environment.

SUMMARY

Conservation aims at sustainable use of natural resources with minimum effect on biodiversity. Although legislation is important to achieve the goals of conservation, it is best achieved through the awareness and actions of all individuals.

Review questions

10.32 What are the functions of national parks in Australia? Predict the effects of over-use for recreational purposes.

10.33 What factors limit the effectiveness of Fauna and Flora Protection Acts in Queensland?

10.34 List three reasons why biodiversity should be conserved.

10.35 What has given scientists cause for concern that the world's food crops could rapidly fail as a result of pandemic pest invasion?

10.36 List some examples of groups of private individuals and organisations who are striving to improve environmental quality in Australia.

10.37 List your activities during any single day into groups. For each type of activity, describe the effects on the environment and ways in which you could minimise your environmental impact.

EXTENDING YOUR IDEAS

1. Umbrella trees (*Schefflera actinophylla*) are endemic to North Queensland rainforests. They are popular as garden trees, able to grow in well-drained, frost-free areas provided there is an adequate water supply during the early growing

periods. Masses of red, nectar-rich flowers attract a variety of honeyeaters. The small succulent fruits are also a food source for many birds. They have, however, attained pest status in parts of Queensland. Rainforest refuges—for example on Stradbroke Island and other forest areas—are rapidly being overtaken by this species. The spreading roots compete vigorously for nutrient supplies and they generate rapidly. Suggest ways to control this endemic pest species.

2. UB It has been suggested that halving the number of cattle in Britain between 1996 and 2000 and planting 5 per cent of the grazing land with trees would reduce greenhouse emissions by at least 2.5 per cent over that time. Discuss the basis for these assumptions.

3. EBI A Commission for the Conservation of Natural Beauty and Wildlife drafted recommendations for the management of a country's ecology. One of their proposals was the division of territories into three zones, as shown in Figure 10.15:
   - *cultural zones*—animals may be killed or expelled by humans
   - *wildlife management zones*—both wild and domestic animals are managed
   - *natural zones*—reserves and parks with stringent protection and without human settlement.

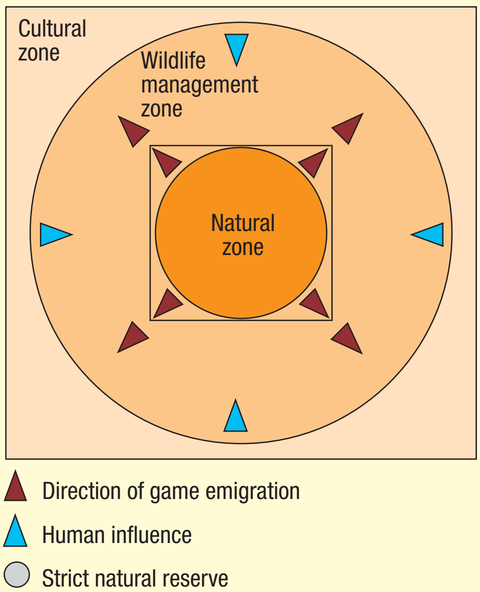


Figure 10.15

As a member of the commission, write a report 'selling' this plan, while anticipating problems in implementation and long-term success, to a group of biologists who are known to oppose it on ecological grounds.

4. EBI One of the largest problems facing modern societies is the disposal of rubbish (both industrial and domestic). Imagine you are responsible for controlling this problem in a large country town. What measures would you insist upon in the disposal of rubbish? How would the problems you face differ from those in a large city?

5. UB Eradication of infectious diseases has been the thrust of government policy in Africa. Meanwhile it has been estimated that more than 90 per cent of children in some African cities suffer from lead poisoning. If the concentration of lead in the blood reaches 100 micrograms per litre, it can lead to a marked reduction in IQ, loss of short-term memory, impaired hearing, problems with coordination and learning disabilities.

   Suggest the major source of lead poisoning in African cities and propose measures to eliminate it.

6. EBI (a) For your local area, create a table showing likely sources of pollution and the types of pollutants originating from these sources.
   (b) Use critical evaluation on your findings to propose methods to limit the most damaging source of pollution.

7. IB (a) Graph the frequency and severity of air pollution in your local area, using information from news reports or the weather bureau.
   (b) Evaluate your findings in relation to weather conditions and/or specific activities (e.g. crop spraying, industry etc.)

8. IB Fluoride from smelters can affect some native vegetation in four ways, as indicated in Figure 10.16. Each has a serious consequence to the plant.

   Redraw the flow chart and complete it with suggested likely outcomes.

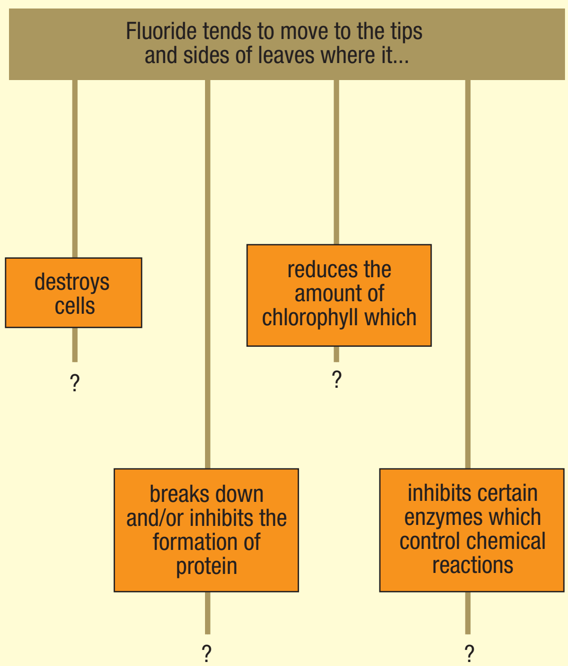


Figure 10.16

9. Figure 10.17 shows the population numbers of three species UB of organisms in a river. In 1996 hot water was emptied into the river, and in 1998 there was pollution from a chemical factory. The three organisms were a kind of algae, a fish and a herbivore that ate algae. Identify the organism that each graph (A, B and C) represents, giving reasons for your choice.

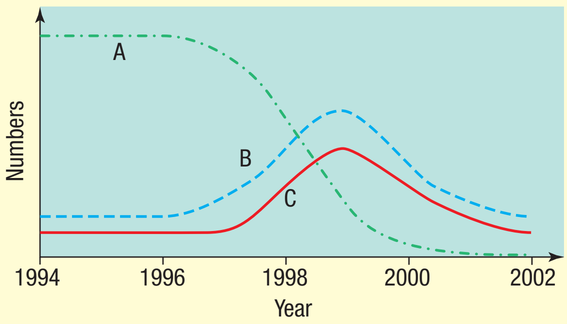


Figure 10.17

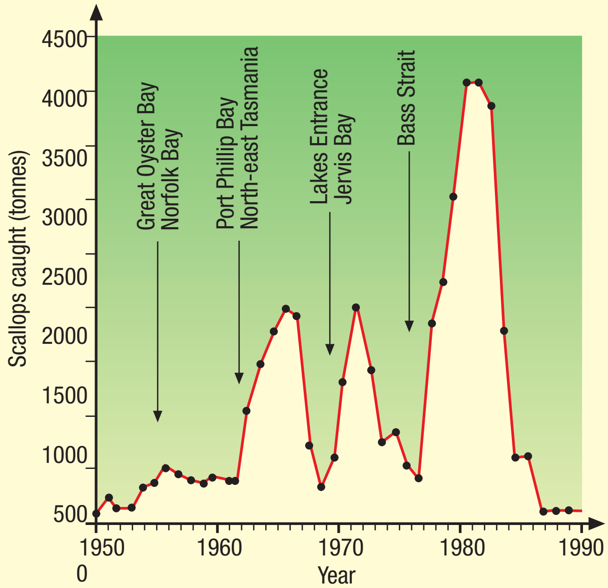


Figure 10.18

10. You have just read a report where a biologist measured the EBI amount of water absorbed by the ground during rainfall which continued steadily for several days. Three equal-sized plots, with different characteristics, were examined. The results of the investigation are shown in the table below.

Plot	Absorption rate (mm/h)
Undisturbed forest floor	60
Forest floor cleared of litter by recent fire	49
Unimproved pasture	24

You have 50 ha of gently sloping open forest, which you wish to subdivide into 5 ha blocks. You are concerned that the development of these blocks could lead to environmental degradation unless a condition of sale is legally bound by some non-negotiable criteria.

Using your knowledge of sources of environmental degradation and the information given, develop the criteria you would use as conditions of sale of the subdivision.

11. Figure 10.18 shows the combined annual Australian scallop EBI catches. The arrows indicate the opening of new fishing grounds. Scallops are molluscs which live and breed on the bottom of sheltered saltwater bays. They are caught from boats which drag weighted metal nets along the seafloor.

(a) Draw a conclusion from the data, stating the assumptions upon which the data were based.

(b) As a principal member of the Australian Fisheries Management Committee, propose a recommendation from these data which could result in future sustainable catches.

12. In 1986 the nuclear power station at Chernobyl, in Russia, UB suffered a meltdown. The release of the resulting radioactive cloud had far-reaching effects. It has been estimated that 380 x 1012 becquerels of strontium and plutonium were deposited on the floodplains around the reactor.

Heavily contaminated sections of the reactor, a large number of fatally irradiated pine trees and radioactive wastes were buried in shallow pits around Chernobyl. Peaty sediments in the Opromkh bog in southern Belarus 2500 km away absorbed the radioactive materials and continue to release caesium-137 into the surrounding water. Lake Kojanovskoe, 250 km from Chernobyl, was found to be the most heavily contaminated from the cloud, because heavy showers of rain fell on the lake in the days after the accident. Fish from this lake still contain up to 67 times the safety limit of caesium-137.

The plains surrounding Chernobyl have been flooded six times in the past 10 years and this has resulted in continued contamination of the waterways. Reservoirs downstream from the damaged reactor provide drinking water for 9 million Ukranians, as well as irrigation and fish for another 23 million. The contaminants are washed down the Pripyat River into the Dnieper which flows 800 km via Kiev to the Black Sea.

It has been estimated that fish from Lake Kojanovskoe will still contain above acceptable levels of contaminants in

30 years' time, and the Pripyat River will continue to have contaminants added for at least another 10 years.

(a) Explain why the contaminants have such long-term effects.

(b) Why is there a concern that the reactor and wastes were buried in only shallow pits?

(c) Discuss factors which have contributed to the continued contamination of the Pripyat River.

13. One of the biggest problems facing the Wildlife Conservation Society of Tanzania is the naturalisation of a black wattle (*Acacia meansii*). As a means of boosting a poor economy, farmers were encouraged to develop plantations of these low trees on the many plateaux (about 2000 m altitude). The trees are an important source of tannins (chemicals in the bark used in tanning leather), construction timber and charcoal. Experience in South Africa, however, showed that this species rapidly escaped the plantations. Because they are more competitive in obtaining water than indigenous tree species, they readily took over large areas and have been declared a noxious weed, the cost of eradication being very high in that country. Wildlife officers have noticed a similar trend in southern parts of Tanzania. Faced with an ailing economy, and because the plantations are financially lucrative, the government is reluctant to ban the cultivation of the black wattle.

EBI

Write a scientific report to the government to convince it that short-term gains could lead to long-term crippling of the economy if it does not reverse its current policy. As part of your argument list the broad environmental effects of replacement of native vegetation on the plateaux by an invading monoculture.

14. The largest protected area in the world is the Serengeti National Park in Tanzania. Since it one of the last remaining areas in which annual migrations of large wild animals exists, it was declared a World Heritage Site by UNESCO.

EBI

Nearly 2 million wildebeest, zebra and Thomson gazelles disperse into the southern grasslands of the park and the Ngotongoro conservation area during the rainy season between December and April. This is a dry area at other times of the year and so at the end of the wet season the herds congregate and begin their annual migration into northern parts of Tanzania and, as the dry season progresses, into the Masai–Mara Reserve in Kenya. This area is fed by the Mara River and its tributaries and even in times of drought provides sufficient water and grazing for the survival of these animals. Estimates from known data on animal losses during severe drought suggest that if the Mara River were to stop flowing for even a few weeks, 20 to 80 per cent of the migrating animals could die. It could take 20 years for the populations to recover with a 50 per cent die-off rate and ecologists believe that they would never recover if 80 per cent of the animals were to die.

Over the last 30 years, the flow of the Mara River has been decreasing as a result of increased irrigation for mechanised wheat farming and forest clearing. In 2003 the Kenyan government announced a planned hydropower project for the Mara River that would involve water diversion and three dam cascades in order to produce about 180 MW of electricity.

Write a newspaper report to outline the effects on the total Serengeti/Masai–Mara ecosystem (predators, other herbivores, vegetation, structure of the plains and savannahs) if the planned Kenyan hydropower project is implemented.

Figure 10.19 Migrating wildebeests

15 Each of the following two statements is correct:

UB

Water, an essential component for life, is a renewable resource in that it is recycled.

Australia has the highest rate of desertification in the world.

Critically analyse, giving specific examples, how these two statements can be reconciled.

16. The noisy minor (*Manorina melanocephala*) is a honeyeater that feeds on lerps, the sugary protective shields and nymphs of tiny, sap-sucking bugs called psyllids that inhabit eucalypts, as well as a variety of other small insects and nectar.

EBI

The noisy minor is a highly territorial, communal species. They will tolerate few other species of bird in their area, attacking other small insectivorous species and honeyeaters and aggressively harassing herons, ducks, dogs, cats, foxes, cattle, horses, wallabies and bats. They are woodland birds, preferring a vegetation structure of tall trees in an open canopy above a grassy under-storey free of thick shrubbery. This allows them to harvest insects and nectar at all levels of vegetation including the ground. Where thick forests are fragmented by clearing or roads, they live along the edges. In these areas there is no protection for the smaller forest birds. Records indicate that there has been a rapid increase in the noisy minor along the east coast of Australia, with invasions in areas where this species was previously unrecorded, and a commensurate decrease in other forest species.

Tim Low, a consultant ecologist, rates the noisy minor as a more serious pest of native birds than the cat in Brisbane. He warns against planting bird-attracting shrubs in local gardens unless they replace lawns. He suggests that land holders should only remove the introduced weed, lantana, if it is immediately replaced by native shrubs such as wattle and native peas. Paths, firebreaks and picnic areas should be kept to a minimum in bushland reserves. He suggests that vegetation corridors and green-belts are ineffective in preserving diverse bird species in Brisbane.

Are these recommendations justified? Give reasons for your answer.

17. EBI Patterson's curse (so named after the woman from whose garden in Albury, New South Wales, it is said to have spread) is an attractive purple-flowered meadow plant that colours whole hillsides in South Australia, parts of the Riverina and the entire length of the Great Southern Railway in Western Australia. It was introduced into Australia from Europe early in the twentieth century. The plant is also called Salvation Jane in South Australia. The plant is so prolific that it has overtaken vast amounts of glasslands, rendering them unsuitable for grazing purposes. The honey produced from the flowers, however, is of a high quality and much sought after. As a result, a large number of bee keepers (apiarists) have established an extremely profitable business in these areas. In the 1960s CSIRO scientists were able to a determine a suitable biological control insect to control Patterson's curse. Such pressure was put on the government of the time by the apiarists, however, that the agent was never released. Recently, environmental agencies again pushed for the control of the plant. If the case is won, the area will again be suitable by grazing by sheep but if lost, Patterson's curse may spread further and maintain a profitable honey production.

You have been employed to present a report to the government advocating, despite a strong lobby from the apiarists, the biological control of Patterson's curse. Outline arguments you would pursue in this report.

18. UB Mammals do not have an enzyme that digests cellulose. Herbivores have evolved strategies to ensure maximum absorption of nutrients from the plant material that they eat. In all cases, this involves breakdown of the cellulose by bacteria that live mutualistically in some part of the herbivore's gut. Sheep and cattle house these bacteria in the forepart of the stomach. After the bacteria have digested the cellulose the animal regurgitates the food, chews it again (cud-chewing) and then swallows it into another part of the stomach where it undergoes normal digestion. The bacteria produce the gas methane (CH_4) which is released into the atmosphere during cud-chewing. A sheep typically burps out 25 litres of methane a day, while a cow can expel 280 litres in the same period.

Kangaroos also produce hydrogen when they digest grass, but the bacteria convert this to a substance called acetate rather than methane. The acetate can be used by the kangaroos as a further source of energy. A Queensland scientist is currently attempting to isolate the bacteria in kangaroos that are responsible for this conversion. The ultimate aim is to culture the bacteria and introduce them into the stomachs of sheep and cows.

Propose, with reasons, why successful implantation of these kangaroo stomach bacteria into sheep and cattle would be a significant environmental breakthrough.

UNIT 4

Animal behaviour

Animal behaviour refers to the observable responses an animal makes to stimuli in its internal and external environment. Behaviour is adaptive in that it aids survival and reproduction. The complexity of responses that any particular species can achieve depends on the complexity of its sensory and coordinating systems and of its musculoskeletal system. Like these systems, behaviour is governed by genes and undergoes evolution. The gestures and postures which can be observed as animal behaviour form a continuum of responses—simple reflexes, orientation, innate social behaviour and learned behaviour. These actions influence the survival of the individual and/or the survival of the species within a particular ecosystem.

Key concepts

- Multicellular organisms are functioning sets of interrelated systems.
- Organisms live an interdependent existence in environments to which they are adapted.

Key ideas

- All systems are interrelated and interdependent.
- Systems of the body work together to maintain a constant internal environment.
- The external features and internal functioning of organisms together enable an organism to obtain its needs.
- An organism has adaptations specific to its environment.

11 Animal behaviour

11.1 The basis of behaviour

A characteristic of living organisms is irritability, which is the ability to detect changes in the environment and to respond to them. All living organisms can detect changes in their environment and respond to them. Animal behaviour is defined as the visible signs of an animal's reactions to its environment. These reactions are usually in the form of movements, of either the whole body or part of it. The environment may be internal (e.g. the concentration of chemicals in the cells) or external (e.g. the temperature).

The internal functions of the body and reactions of the whole body are very closely related. Both, however, are dependent upon the organism's ability to detect a change in the environment and to respond to it in an appropriate manner. This involves some form of communication between different parts of the organism, whether it is a single-celled protozoan, a colonial sponge or a complex, multicellular animal such as a human.

In order for a stimulus to be meaningful, it must be detected. Detection is achieved by **receptors**, which include the cytoplasm of individual cells, the cell membrane and specialised cells which operate either individually or grouped together into a structure such as the eye. The information detected by the receptors is passed to the appropriate part of the cell or organism (**effector**) in order to bring about a response. The level of response depends on the structure of the organism. This can be summarised as:

stimulus → receptor → transmitter → effector → response

There are two coordinating mechanisms in animals that control their responses to stimuli: hormones, and the nervous system.

11.1.1 Hormones

A **hormone** is a chemical that regulates body functions in the more complex animals. (Hormones also occur in plants.) Hormones are transmitter substances which bring about specific responses. Since it takes time to produce, release and move hormones from one place in the body to another, hormonal responses tend to be relatively slow. It also takes time to switch off the release of the hormone and for existing hormones circulating in the body to be broken down. The responses, therefore, are usually long lasting.

11.1.2 The nervous system

The nervous system is the second coordinating system found in most animals. It links detection of a stimulus with the response. The nervous system is composed of cells called **neurones**, which are specialised to carry information. Although there are different types of neurones, each adapted to a particular function, they all share certain features. The nucleus is contained in a part of the cytoplasm, called the cell body, from which a number of thin fibres extend. These fibres either receive 'messages' or pass them on.

In the most primitive type of nervous system (found in the Cnidaria), the nerve cells are simply linked together to form a net over the entire body. As more complex organisms have evolved, their nerve fibres have become grouped together into nerves, and the cell bodies grouped into ganglia. Nerves transmit impulses more quickly than individual nerve cells, and the ganglia efficiently gather information from various receptors, deciding on the best response and sending the information to the appropriate structure.

Ganglia at the head end of the animal ultimately evolved into the brain, the major organ for co-ordination and control. The central nervous system (CNS) consists of the brain and the major nerve chord leading from it. In invertebrates this nerve cord is ventral, whereas in chordates it is dorsal. It is termed the spinal cord in vertebrate animals. As a result of this structure, nervous responses tend to be rapid over a short time period.

11.1.3 Combined responses

In combination, nervous and hormonal responses allow an organism to respond to the environment rapidly, while sustaining the activity over a period of time if necessary. The structure and function of the hormonal and nervous systems are described in more detail in Chapter 18.

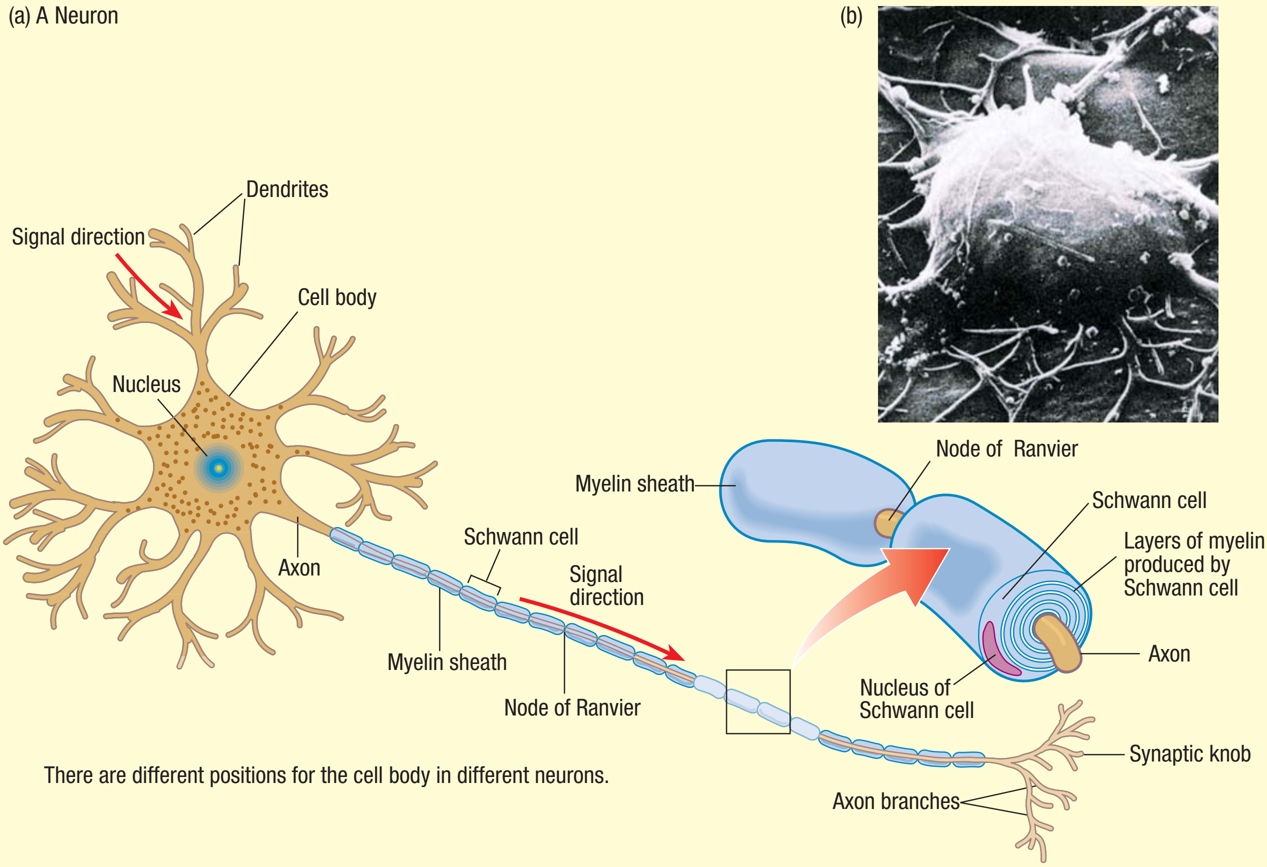


Figure 11.1 The structure of a neuron

The range of behaviours displayed by an animal depends on the organism's:

- ability to detect stimuli
- ability to analyse stimuli
- ability to respond to stimuli
- genetic constitution.

Obviously, an animal with well-developed and complex hormonal, nervous and musculoskeletal systems is able to respond to a wider range of environmental stimuli, and with more precision, than a less structurally developed organism. It would be physically impossible, for example, for a barnacle to build a nest.

As different animal species have evolved, they have developed behaviour patterns that are advantageous in their own particular environment. These patterns include **innate** behaviour ('programmed' by the genes an animal inherits) and learned behaviour (modified as the result of experience).

Five questions can be asked about any pattern of behaviour.

- What causes it?
- What is its function?
- How does it develop?
- How did it evolve?
- How much of it is inherited?

11.1.4 Ethology: the study of behaviour

The study of behaviour (**ethology**) is difficult, for various reasons. Firstly, the details of responses to any particular stimuli must be painstakingly recorded. Recording must be objective, in that any interpretation by the recorder must be avoided, particularly any form of **anthropomorphism** (attributing human thoughts and feelings to the animal). The range of circumstances under which a particular behaviour occurs must be complete, so the observations must be done in the field under natural conditions. Follow-up experiments in the laboratory can be helpful, but are artificial.

Interpreting an animal's behaviour is also very difficult. Whenever an animal is watched, only a very small part of the whole complex which is responsible for the behaviour can be observed. The sense organs detecting the stimulus may select only small aspects of the stimulus to pass on to the central nervous system. This information may be further filtered in the brain, depending on the organism's genetic make-up, physiological state and previous experiences. The exact mechanism of transmitting the information to the organs that bring about the response is largely unknown. Thus there is rarely a direct causal relationship between stimulus and response. If you give your dog a slap, for example, there are many things that could occur. It could ignore it, push against you for more attention, turn and bite, run away and whine, and so on. Much will depend on the dog's internal state and past experiences.

SUMMARY

Animal behaviour is defined as observable body movement triggered by some stimulus, either internal or external in origin. Thus all behaviours originate in a stimulus which is transmitted in the body to achieve a relevant response which aids individual, and thus species, survival. The capacity for a particular behaviour has a genetic basis and so is subject to evolution.

The types of behaviour exhibited by an organism are related to its:

- ability to detect stimuli
- ability to analyse stimuli
- ability to respond to stimuli
- genetic composition.

These abilities are directly linked to the complexity of the coordinating and musculoskeletal systems. Animal behaviour is coordinated by chemicals called hormones and, in most animals, the nervous system. The responses form a continuum of simple reflexes, orientations, innate social interactions and learned patterns.

The study of behaviour requires objective, non-anthropomorphic recording of relationships between stimulus and response under natural conditions.

Review questions

11.1 Define animal behaviour.

11.2 Distinguish between animal behaviour and ethology.

11.3 List factors that determine the kinds of behaviour patterns of an animal.

11.2 Behaviour as an adaptation to the environment

The most important function of an individual organism is to stay alive until it has reproduced. Any structure, or way in which the structure operates, that aids the survival of an organism in its environment is adaptive. Thus an animal's behaviour is an adaptation to its environment. Like structural components of its body, behaviour is subject to evolution. It serves two main functions:

- the survival of the individual by adjustment to changes in the environment, either within a day or seasonally
- the survival of the species through reproduction.

Survival of the individual can be classified in physiological terms:

- feeding, drinking and breathing
- chemoreception (taste and smell)
- visual reception
- sound reception
- hormonal influence
- sleep.

While many of these responses are basic to all organisms, the manner in which they are achieved may be quite specific. Both the barnacle and chiton, for example, live in the intertidal zone of a rocky shore. The barnacle, cemented to the rocks, filters small food particles from the water that surrounds it. The chiton, on the other hand, moves over the rocks, scraping algae off the surfaces with its rasp-like radula. Although both live in the same general habitat, they have different structures and niches, and their behaviour associated with feeding is different.

11.2.1 Individual behaviours

Feeding, drinking and breathing

Feeding, drinking and breathing are important in maintaining a constant internal environment regardless of changes in the external environment.

Drinking is a cyclic activity, but breathing occurs constantly. Although feeding shows great variability, it tends, like drinking, to be a cyclic activity. It includes exploring the environment in which the food resource is to be found, followed by selection, preparation and ingestion. These behaviours are usually interspersed with other types of activities, such as sleeping and resting.

The physiological demands for feeding and drinking behaviours determine the amount of time spent on them. A snake, which does not expend a great deal of energy in maintaining a constant body temperature, may have to feed only weekly, whereas a wallaby grazes for many hours per day.

Taste and smell

The senses of taste and smell are important features of feeding behaviour and predator–prey relationships. For example, it has been found that human body odour attracts the louse, while carbon dioxide and temperature direct the female mosquito to warm-blooded animals.

Vision

For vertebrates, vision is the most important sense in determining behaviour. Many orientation behaviours depend on simple light detection. The freshwater planarian avoids light. It rests under rocks during the day and feeds at night. The simple eyespots on the dorsal surface of the head can detect the presence of light and stimulate the animal's movement into a darkened area. Animals which can see images can respond to stimuli that are a considerable distance away.

Sound

Sound reception informs organisms of unseen dangers, helps them locate food, and familiarises them with other aspects of the environment.

Hormones

Hormones are involved in coordination activities within the body, and in initiating behavioural responses. For example, levels of the hormone insulin in the blood increase with food intake. A high level of insulin in the blood will suppress the sensation of hunger, so an animal which has just fed will not normally feed again if presented with food.

Hormones released by individuals of a species can influence the behaviour of other individuals. These 'external' hormones are called pheromones. One such pheromone is released by female fruit flies and can attract males from several kilometres away. Many pheromones have been identified, particularly in insect groups.

Sleep

Although not a lot is understood about sleep, it is known to be a natural, rhythmic period of relative inactivity during which there is a decrease in responsiveness. From an adaptive point of view, sleep appears to regenerate activities which the organism performs when awake. Although most organisms can function normally with less sleep than is part of their normal behaviour pattern, research has shown that there is a certain minimum amount of sleep necessary for survival.

11.2.2 Interactions between individuals

Although individual behaviour patterns are important for the survival of the single organism, they are in reality directed towards reproduction and thus the greater goal of species survival.

Most animals do not live alone. Therefore the interactions between members of the species are important, and must 'make sense' to all members. Species-specific behaviour patterns are an integral part of social dynamics.

SUMMARY

Animal behaviour is adaptive. It ensures that each species responds to environmental stimuli in a manner which leads to the survival of both the individual and the species. Thus behaviour is related to the physiological needs of the animal—feeding, drinking, breathing, sleeping, reproducing, and so on.

? Review questions

11.4 Explain why behaviour is considered to be subject to evolution.

11.5 In what ways can the internal state (e.g. hunger, thirst) direct the type of response an animal makes to any particular stimulus?

11.6 Why are species-specific behaviour patterns important?

11.7 Male dogs will travel many kilometres to a female dog on heat. What is the stimulus for this behaviour?

11.3 Innate behaviour patterns

Innate behaviour is all unlearned behaviour. Because responses to specific stimuli are the same for all members of a species (for example, dilation of the eye pupil in response to darkness), innate behaviour is also termed **stereotyped behaviour**. Some innate behaviour can be modified by experience, and patterns of behaviour will often show an intermingling of the stereotyped behaviour and learning.

Many innate behaviour patterns are not exhibited by an individual until it is mature. Although born with the potential to fly, the young bird cannot physically achieve this behaviour until feathers have formed and flight muscles have developed.

11.3.1 Simple reflexes

Simple reflexes usually affect only a small part of the animal. The pupils of the eye, for example, rapidly contract as the individual moves from a dark to a light area. In those animals with a poorly developed nervous system, however, the reflex may affect a larger proportion of the body. Thus, when the tentacles of a sea anemone are lightly brushed, the whole body responds. The tentacles are retracted into the gastrovascular cavity, which contracts both downwards and inwards. In animals with more developed nervous and structural systems the responses are more complex, and reflexes, although they occur, are less obvious.

11.3.2 Complex reflexes

A complex reflex consists of the coordinated actions of many simpler reflexes and as a consequence involves a greater part of the CNS, including the brain. Complex reflexes are based on three movements: orientation, kinesis and taxis.

Orientation refers to any behaviour by which an animal positions itself in a certain way in relation to its surroundings.

Kineses (singular *kinesis*) are changes in rate of activity in response to a stimulus. Experiments have shown that organisms displaying this form of behaviour cluster in areas of optimum environmental conditions merely because they move more slowly, or because they change directions of movement less frequently there and thus must spend more time in that area. Lice, for example, become more active in dry areas and less so in humid ones (Figure 11.2).

Taxis is directed movement, either towards a stimulus (positive taxis) or away from it (negative taxis). Thus moths fly straight towards a light by keeping a balance between the two eyes. They are said to be positively phototactic. If one eye is damaged, the moth cannot fly straight. The backswimmer, *Notonecta*, locates its prey from vibrations in the water. The long 'rowing legs' are well supplied with sensory hairs and the animal turns until both legs are equally stimulated. It can then swim directly towards its prey (Figure 11.3). If an organism avoids a particular stimulus, it shows a negative tactic response. In this way, an amoeba avoids acidic conditions.

Not all taxes will be directly towards or away from a stimulus. Some involve orientation at a constant angle to the stimulus source. Ants and bees use a 'sun compass' orientation in this way to find their way back to a nest or hive. Orientations using celestial clues (sun, moon, stars) are called **navigation**.

Complex navigation behaviour, particularly that involving long migrations, will involve many more clues than just celestial ones—for example, the earth's magnetic field, chemical odours and variations of forces resulting from the rotation of the earth. Thus salmon which have matured at sea over several years will return to spawn in the exact stream in which they hatched. This orientation has been shown to be in response to the particular odour

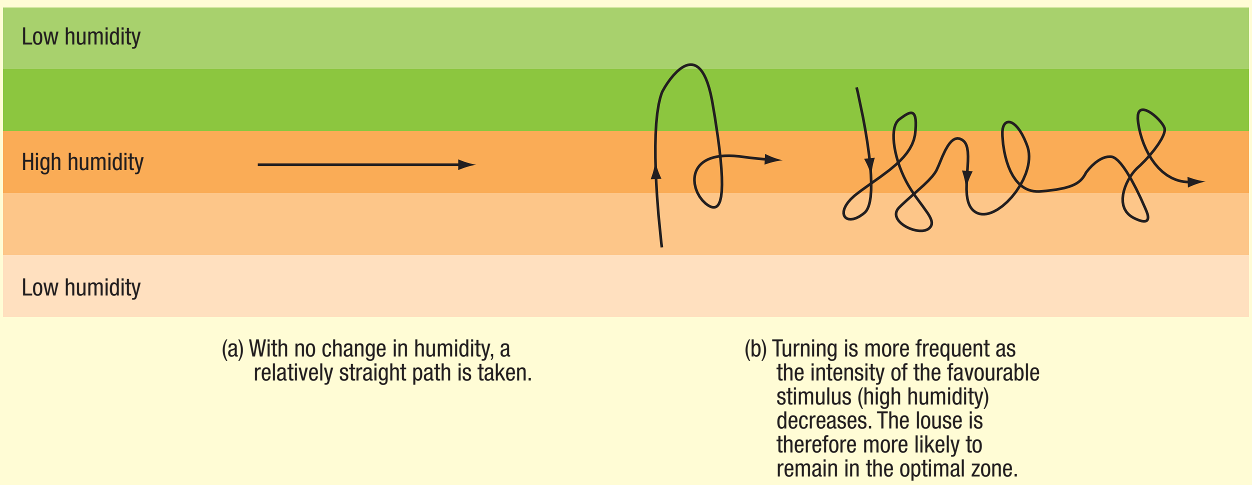


Figure 11.2 Movements of the body louse, *Pediculus humanis*, in response to changing levels of humidity

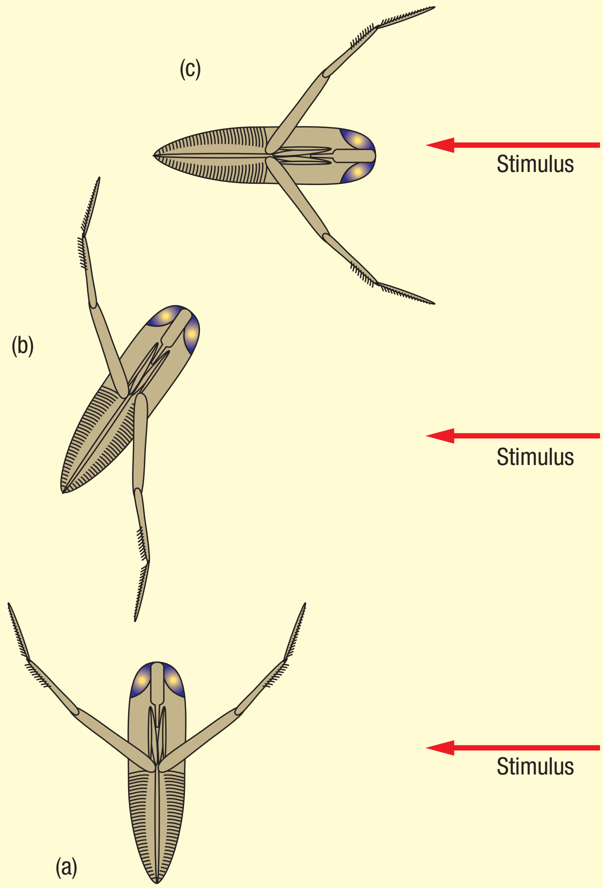


Figure 11.3 Hairs on the 'rowing' legs of the back-swimmer detect vibrations in the water. If the vibrations are not detected by both legs at the same time (a), the insect turns (b) until the legs receive the stimulation simultaneously (c).

of the stream. Learning of specific landmarks has also been shown to be significant in the navigation of many animals; for example, the honeybee.

These forms of behaviour are not as rigid as they sometimes appear. The strength of any response to a stimulus may be moderated by other factors such as hunger or thirst. Thus woodlice clustered under bark in darkness and humidity must emerge at some time to feed. When the temperature drops in the evening, the positive response to humidity weakens as the need for food increases, and they emerge from the bark to feed.

11.3.3 Complex innate behaviour patterns

Most innate behaviour patterns are a series of one or more complex reflexes. The internal state of the animal provides the motivating force or **drive** which determines to which stimuli the organism is most likely to respond. Thus if an animal's blood sugar levels are low, the hunger drive is activated. Stimuli not associated with satisfying this drive will usually be ignored. A very hungry animal is not likely to be involved in grooming behaviour until it has fed.

Since the total behaviour is a sequence of complex reflexes, this type of behaviour is usually very stereotyped for a particular species. Although the onset of the drive results from the internal state of the animal, the stimuli which elicit the actual behaviour are invariably external to it. The animal cannot skip a step in the sequence of actions, since the successful completion of one action acts as a stimulus for the next one. The sight of food, for example, is the stimulus for actions which bring about capture of the food. The next action, ingestion, can then occur. Eating then dissipates the hunger drive.

Usually only one drive is activated at a time. The longer the animal takes to release a particular drive, however, the less specific is the stimulus needed to release the behaviour pattern(s) associated with it. Sometimes the drive becomes so intense that the behaviour pattern is released without a stimulus—a **vacuum activity** occurs. Pseudopregnancy in dogs and sheep is a classic example of this. The reproductive drive of the female is so great that, even in the absence of mating, she will undergo all of the physiological and behavioural changes associated with pregnancy. Sheep have been known to 'steal' newborn young of other ewes in these circumstances.

Sometimes two drives can be equally motivated. When this occurs there can be two different kinds of outcome:

- The animal may alternate between the two behaviour patterns. Herring gulls have a tendency to incubate round objects in the nest and to remove red objects from the nest. If red-painted eggs are placed in a herring gull's nest, the bird will alternate between trying to incubate the eggs and rolling them out of the nest. This is called **ambivalent behaviour**.
- The animal may display a behaviour not associated with either of the two drives. This is called **displacement activity**. Finches normally wipe their beaks against the branch on which they are perched as a cleansing activity after feeding. The same behaviour is also displayed by the male during courtship as a displacement activity. The male has two conflicting drives operating: to chase away the intruding female and to court her. The tension between the two drives is released through unrelated beak-wiping behaviour.

11.3.4 Rhythmic behaviour

Although a particular behaviour pattern may be motivated by an internal state, most reactions of an animal are to external environmental stimuli. There is a type of behaviour, however, that appears to be completely under internal control. These behaviours can be grouped together as **rhythmic behaviours**. The rhythms may be short or long. The marine worm *Arenicola*, for example, has a 40-minute rhythm. It lives in the mud in a U-shaped tube, both ends of which open into the water above ground. During the 40-minute period it alternates between moving backwards to defaecate at one end of the tube and forwards to breathe at the other end.

A great many animals have a 24-hour (diurnal) rhythm. Some are active only during the day (e.g. hawks); others (e.g. owls) are active at night. Longer rhythms may be related to lunar cycles or be seasonal. The palolo worm rises to the surface of the sea to spawn only at a particular phase of the moon. Most birds begin to sing, nest and court in the spring only when food is plentiful for developing young. Many animals migrate to warmer areas, or hibernate, at the onset of winter.

Many experiments have been performed to determine the basis for these rhythms. There appears to be no external stimulus for these activities. Golden squirrels in America, for example, will hibernate at the correct time in the laboratory regardless of temperature conditions. Little mutton-birds (*Puffinus pacificus*) migrate to the Australian coast to breed during November and December. On Heron Island the birds will arrive within a few days at the same time every year. The adults leave the breeding grounds for the central western Pacific by April, and the young birds leave some time later. Banding of birds shows that they find the same wintering grounds as the adults and return to the islands of their 'birth' at approximately the same time every year.

Rhythms, therefore, seem to be genetically controlled and have probably evolved from an avoidance of regularly occurring adverse environmental conditions.

SUMMARY

Innate behaviour tends to be species-specific and consists of simple and complex reflexes. Simple reflexes usually involve only a small part of the animal, whereas complex reflexes consist of a series of simple reflexes coordinated by the central nervous system.

In complex innate behaviours, the internal state of the animal provides the drive for a particular set of behaviour patterns. In the absence of the appropriate external stimulus to release this drive, the internal tension for the drive may build up to such an extent that the stimulus for the response may be inappropriate or, in the case of vacuum activity, absent. When two drives are equally motivated, the animal may either display ambivalent behaviour (alternating between the two drives) or displacement activity (perform a third, unrelated response).

Most animals exhibit an internally controlled rhythm which is relatively independent of external environmental stimuli.

Review questions

11.8 Define the following terms:
- (a) ambivalent behaviour
- (b) displacement activity
- (c) vacuum activity
- (d) drive
- (e) kinesis
- (f) reflex
- (g) taxis

11.9 Compare and contrast a kinesis and a taxis, giving an example of each.

11.10 What is the significance of innate behaviour?

11.11 From your own experience, describe an example of each of the following:
- (a) vacuum activity
- (b) displacement behaviour
- (c) ambivalent behaviour.

11.12 After the threat of attack by a predator has passed, members of a baboon troop are often observed to chase each other around frantically. How would you define and explain this behaviour?

11.13 How does rhythmic behaviour differ from other stereotyped behaviour?

11.4 Social behaviour

Not all groups of organisms are social. They may come together independently of each other as a result of some external factor. For example, moths congregate around a light source as a result of the phototactic response of each individual—they do not react to or with one another.

Other aggregations, however, are the direct result of interactions. Where there is some form of interdependence, the interaction is social behaviour. These animals compete and cooperate with each other in order to obtain food, to reproduce and to maintain themselves in a suitable place to live.

11.4.1 Communication

All social responses are the result of communication, and must involve a communicator and a recipient. For the communication to be effective, it must be recognised and understood.

Innate communicative signals may serve one or more of the following functions:

- species recognition
- group recognition
- individual recognition
- sexual recognition.

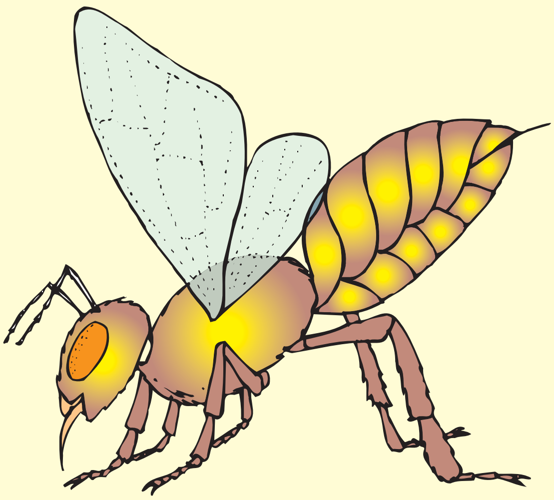
Species recognition

Animals must be able to recognise their own species. Species recognition signals are not directed to any particular individual. Recognition must be particularly efficient in those animals that are sparsely distributed. Often, species recognition signals are physical signals. Many Australian finches are a basic grey colour, but each species has at least a few distinctive colour patterns common to both sexes; for example, the red beak and legs and distinctive calls of the zebra finch, and the special display colours of the male. Since these birds often flock together in large, mixed groups, these differences are important. It has been found that species recognition of the highly coloured male is innate in the female—she only accepts, as a mate, a male displaying the correct visual signals. The male, on the other hand, learns species-specific colour patterns during the nesting stage in a special process called imprinting.

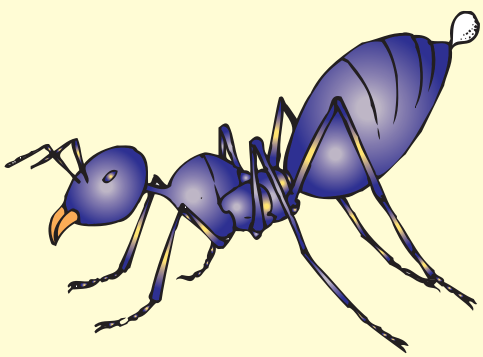
Group and individual recognition

Social animals generally recognise members of their group by sight, odour, vocalisation and/or particular behaviour. This is group recognition. This level of communication produces cohesion of the social group and antagonistic reactions to strangers. Social insects such as ants distinguish strangers by odour, and attack them. Among the more highly evolved vertebrates, group members are often identified by individual recognition. Social groups often consist of various age and sex classes and specific signals are used for identification of these.

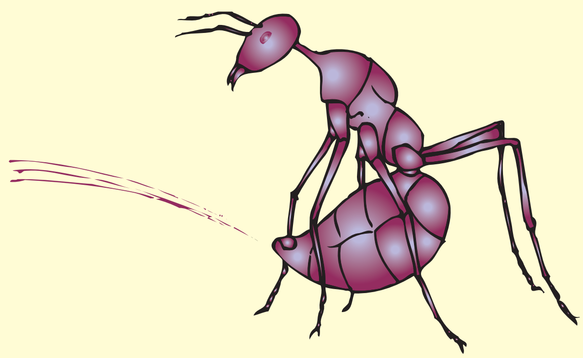
Signals that assist in maintaining the relationship between parents and their offspring are very important, because if the relationship ceases to exist the offspring could die. The gaping mouth of young birds, and their persistence in begging for food,



(a) A disturbed honeybee releases its alerting chemical while exposing the sting. This stimulates other bees to attack.



(b) The ant *Lasius niger* exposing an odorous droplet from the anal region. Other ants flee from such a chemical signal.



(c) An alarmed worker of the ant *Formica polyctena* ejecting a fluid containing poison and an ant-alerting substance.

Figure 11.4 Chemical signals used in communication evoke the feeding response in the parents. Usually, the hungriest bird begs the most and therefore is fed first. As the young birds mature they begin to look more and more like the adults. In order to prevent aggression on the part of the parent birds, the young assume a submissive attitude in their posture (which is often similar to that assumed by the female during courting behaviour).

Sexual recognition

Sexual recognition is necessary for the reproductive behaviour of most bisexual animals, but this may or may not be based on individual recognition. If the two sexes are similar in appearance, it is behaviour that distinguishes them, at least during the reproductive stage. These behaviours include scents, movements and sounds, such as the 'love song' of the male frog which draws mature females of the same species to him.

Location of food

Interesting methods of communication are found among honeybees. When they return from a new source of food, they dance in the hive to inform others of the discovery. The hive-mates learn what kind of flower to look for from the scent attached to the dancer's body, and the location of the flowers from the type of dance. The 'round dance' indicates that the new food source is close to the hive, whereas the 'waggle dance' indicates the direction and distance of the food source. In both the 'waggle' and 'round' dance, the speed of the dance is inversely proportional to the distance between the hive and the food. Some races of honeybee use a 'sickle dance' instead of the 'round dance', the axis of the semicircle drawn by the dancer indicating the direction of the goal. Some of the dancing patterns of honeybees are illustrated in Figure 11.5.

11.4.2 Cooperative behaviour

Many animals form social groups in which the activities of the individuals are integrated or regulated. Cooperation often serves more than one purpose, such as reproduction, safety and conservation.

Conservation behaviour

Conservation behaviour is usually concerned with the utilisation of food resources but may also relate

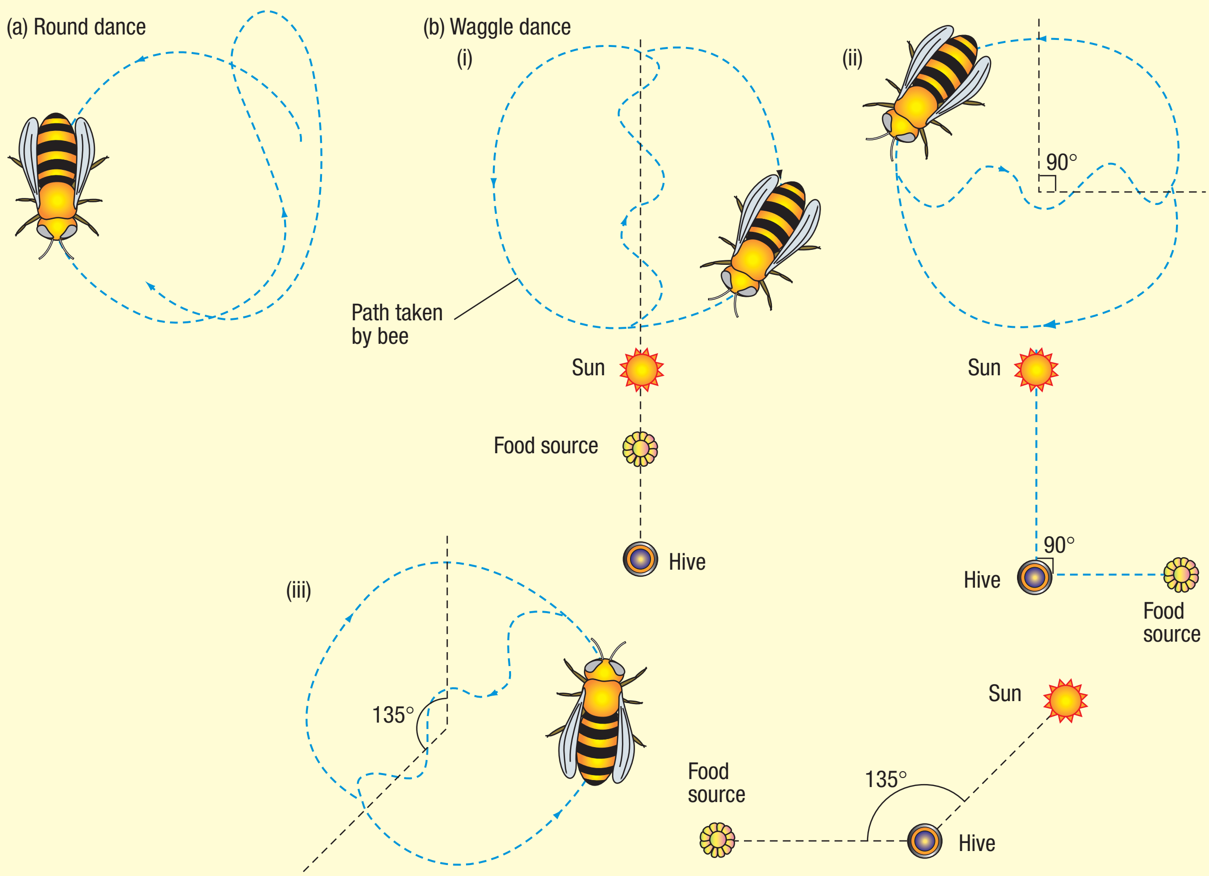


Figure 11.5 Dancing patterns of the honeybee

to other physiological activities. The desert hopping mouse (*Notomys alexis*) lives in and around the Simpson Desert in very adverse conditions. During the heat of the day the mice live in family groups, in burrows dug into the sand. These burrows are dug by a group of animals. The front one excavates the sand, which is passed backwards from animal to animal to the outside. As the burrow gets deeper, more individuals are involved in this process. Water must be conserved at all times, since the majority of their water supply is obtained from the seeds they eat. During the day, therefore, they huddle together in a small, cool chamber at the end of the tunnel. Some water is inevitably lost by their breathing, but the humidity this creates keeps evaporative water loss to a minimum. They come out to feed in the cooler evening.

In some cases, individuals cannot survive alone. An individual grain beetle, for example, cannot crack open a grain of wheat by itself. Several beetles are needed for this task and thus the provision of a food supply for all. Hyenas which are isolated from a pack cannot hunt but must assume the role of scavenger, since the method of bringing down prey is dependent upon group activity.

Safety behaviour

Most safety behaviour is a response that provides escape from predators; for example, schooling of small fish. In a foraging baboon troop, some members are posted as lookouts, and when the troop moves from place to place, there is a set pattern of individuals. The dominant males, the females and the young form the centre of a diamond-shaped troop, with the younger males surrounding them.

Many social animals have some sort of signal to warn members of the group of approaching danger. Thus, warning calls made by a member of a group of noisy miners will elicit the mobbing response, where all adult birds of the group noisily attack the intruder. Many alarm calls are recognised by other species; for example, when a kangaroo thumps the ground as a warning signal, other animals will also respond.

Reproduction

For many species, reproduction consists of the release of gametes into the environment and their subsequent union, without any interaction between the adults producing them. Successful fertilisation does, however, depend upon the release of the two types of gametes at the same time and in the same place. Invariably external factors, such as temperature or lunar cycle, are the stimulus to bring the members of the species together.

In higher organisms, chemical, visual or vocal signals prepare individuals for breeding and making physical contact. Courtship is a social behaviour that breaks down the physical avoidance of one animal by another. Often the aggressiveness of the male must be suppressed and this is usually achieved by the female 'answering' his aggressive behaviour movements with submissive ones.

In the breeding pattern of the three-spined stickleback (*Gasterosteus aculeatus*), the male fish makes a small depression at the nest site by boring his snout into the sand. He packs the shallow pit with green algae and cements them together with a sticky substance secreted from his kidneys. He then wriggles through this mass of algae to form a tunnel. Females, meanwhile, remain in schools until they become heavy with mature eggs.

The male stickleback, having built a nest in his territory, and having now developed a brilliant colour, makes a series of jerky motions as he searches for a stimulus. The appearance of another male in his territory stimulates aggressive behaviour, whereas the appearance of a mature female with a swollen abdomen stimulates courtship behaviour—zigzag leaps towards and away from the female. If the female is not sexually mature, she will not respond to the zigzag dance, but if she is ready to spawn her response is to assume an upright posture. The subsequent behaviour patterns that lead to spawning are a series of responses, each of which is triggered by the partner's action (see Figure 11.6 on page 278).

The nest and fertilised eggs are tended by the male. It is at this time that other males find the nest owner less threatening than when he is courting and will often attempt to sneak in and ejaculate over the eggs. There is sperm competition to fertilise the eggs. It has been found that if there are other males nearby when courtship proceeds, the courting male will actually ejaculate more when the female spawns.

11.4.3 Competition

Social animals have a better chance than solitary animals of finding a good food source, because of the numbers involved in searching. Excessive competition for food, however, could offset the advantages of social living. Therefore, social systems which minimise this competition tend to be selected in the course of evolution. Group sizes tend to be kept small so that the demand for food will never be too great. When the group becomes too large, it will split into smaller groups.

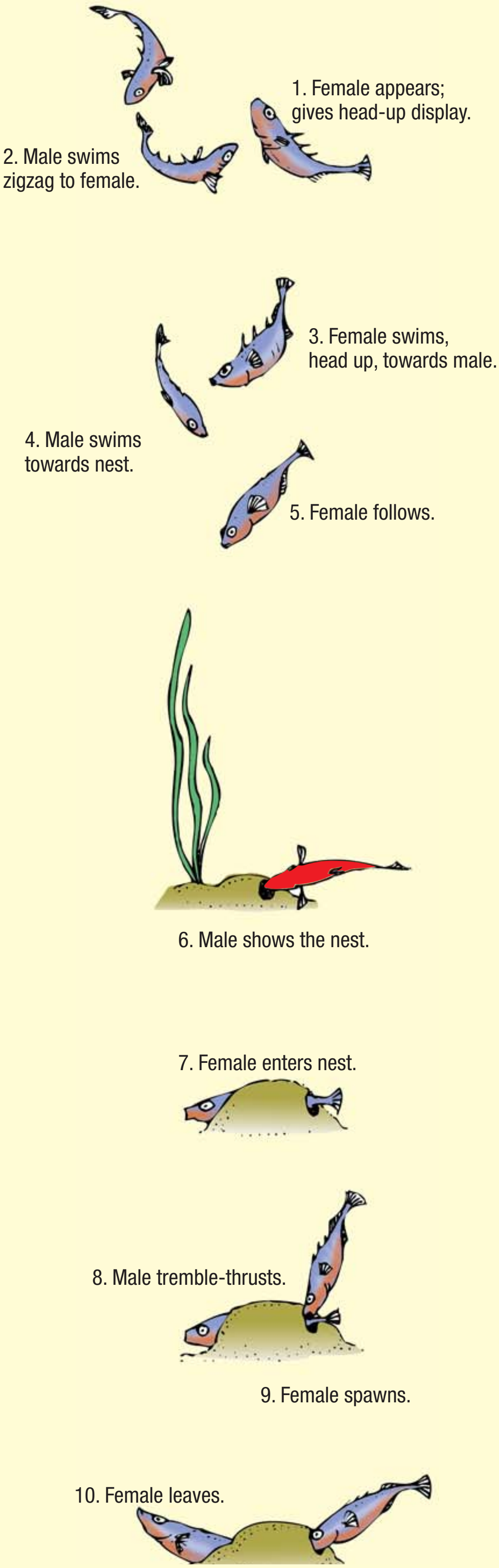


Figure 11.6 Courtship behaviour of the three-spined stickleback

Castes

In extreme cases division of labour is established, so that individuals perform specific tasks for the benefit of the group. Individual ants and termites develop structural and functional differences that correspond to the specific tasks they perform.These different individuals within a species are called **castes** (Figure 11.7). The reproductive caste is concerned only with establishing the colony and producing other castes.The worker caste is generally sterile and concerned with collecting food, feeding others, and maintaining the nest. The soldier caste often has large jaws; these individuals guard the nest and protect other castes.

Different sexes and age groups of higher animals, if they assume different functions, may be referred to as castes or classes, but they do not form such a rigid system as that displayed by the insects.

Agonistic behaviour

There may be competition between species or between individuals of the same species. This competition can be for a variety of factors, such as food, breeding space or nesting materials. Competition may lead to direct aggression. The aggression may result in severe harm, even death, of a protagonist in some species.This is particularly so in herd animals where one male defends the right to mate with the females. In the day-to-day life of the members of an animal society, however, aggressive physical contact or bodily harm do not usually occur. The behavioural postures adopted by antagonists are usually adequate communication for non-physical resolution to occur. This type of behaviour is referred to as **agonistic**, and describes both threatening and submissive behaviour patterns.

Fighting between individuals of the same species varies from mild threat displays to severe fighting, depending on the motivation of the animals involved and the circumstances causing the fighting. Within a particular species, therefore, specific postures are adopted which signal the intent of one animal towards the other. An aggressive dog, for example, will show this by the extent that the hackles are raised, ears flattened against the head and teeth bared. A very submissive dog, on the other hand, will roll over and display the belly, signalling its vulnerability to attack.

The colour of the Australian gudgeon (*Mogurnda striata*) is related to aggressive behaviour. These fish can change colour in two ways, forming either distinctive grey blotches on the upper surface, or an overall grey colour. Dominant fish have the normal colour pattern but fish behaving submissively often develop grey blotches.

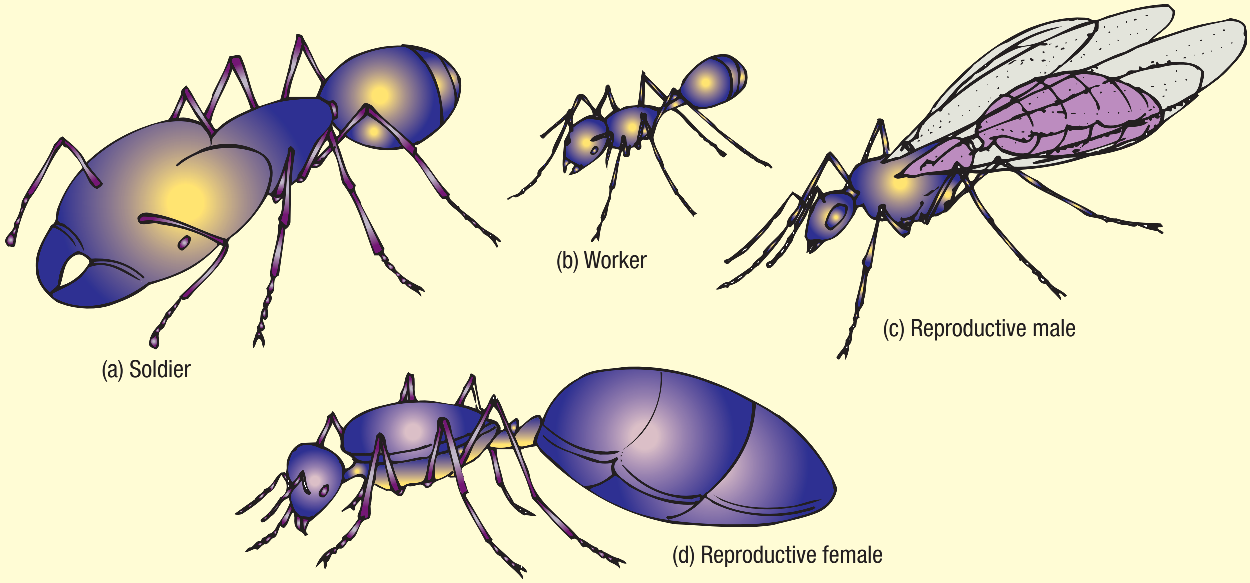


Figure 11.7 Different castes of the ant species *Pheidole instablis*

Momentary submission tends to lighten the colour, but with sustained submission the colour darkens. This behaviour is illustrated in Figure 11.8.

The silvereye (*Zosterops lateralis*) is a small bird found around the coast of Australia, except in the north and north-west. It is absent from Cape York to Carnarvon in Western Australia. Typically, this species forms flocks over winter, and may migrate from the southern regions (e.g. from Tasmania to southern Queensland). In spring the flocks disperse to breed. A variety of threat postures have been recorded for the silvereye in competitive situations. The response varies according to the intensity of the stimulus. Thus flattening of the feathers occurs in mild threat, but as aggression increases the bird responds with other behaviours such as wing fluttering and threat calls. Submissive birds take on the posture of the immature animal, with feathers fluffed out.

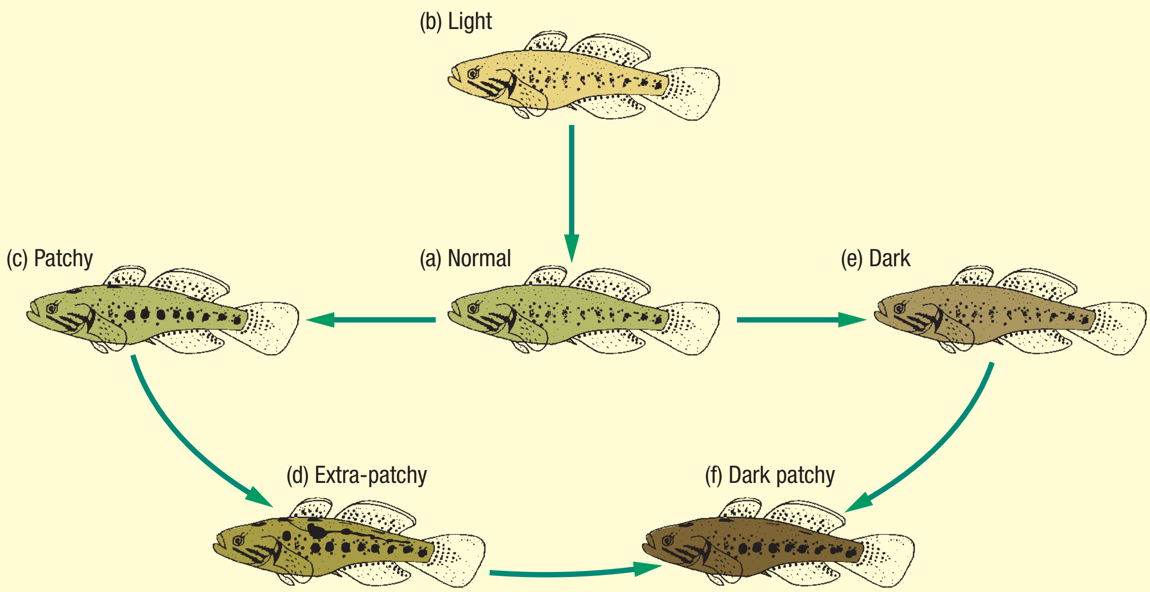


Figure 11.8 Colour patterns of the Australian gudgeon

Social hierarchies

If aggressive encounters between individuals in a group result in an order of dominance, the social order is called a **hierarchy** or a peck order (after the pecking behaviour of birds displaying this organisation). Among domestic hens the initial contest determines the dominant–submissive relationship between the two birds, and once dominance is established it is not usually challenged in subsequent encounters. Prior residence gives an animal an advantage over one which fights in a strange environment. This behaviour, therefore, is an advantage to animals such as flocks of birds or herds of mammals, which normally live in large groups, since it reduces aggression. Normally, individual recognition occurs among members of such a group, and mild threat displays are the only reinforcement required to maintain the relationships.

In a social group there is often a **leader** or group of leaders who guide the movements of the whole group. Leadership is not associated with age, gender or position in the hierarchy, but with ability to integrate group behaviour.

Territorial behaviour

The social response of defence against other individuals, particularly those of the same species and sex, leads to **territorial behaviour** if the defence is restricted within a certain area. This often leads to a spatial arrangement of individuals, pairs or family groups. The size of the territory varies: it may be just the nest and nest site, or may include the entire area in which food is foraged.

The territory-holder often 'advertises' its ownership, thereby avoiding unnecessary contact with other individuals. Many territorial mammals use secretions from scent glands (pheromones) to mark strategic sites within the territory. Male brushtail possums and koalas have this gland on the chest, and typically rub the chest at the base of trees within their territories. Dogs urinate at specific points within their territory. Humans put fences around their properties. Perching birds often sing from a conspicuous place. The use of ritual threat displays is usually adequate deterrent to prevent others entering a territory, and so fighting is a rare occurrence.

Territorial systems probably have a range of functions:

- Spatial distribution decreases competition for resources such as food and nest sites, and decreases the spread of epidemic diseases.
- Since not all males will be able to find and protect a suitable nest site, only those best adapted to the environment will breed and thus pass on suitable genes to the next generation.

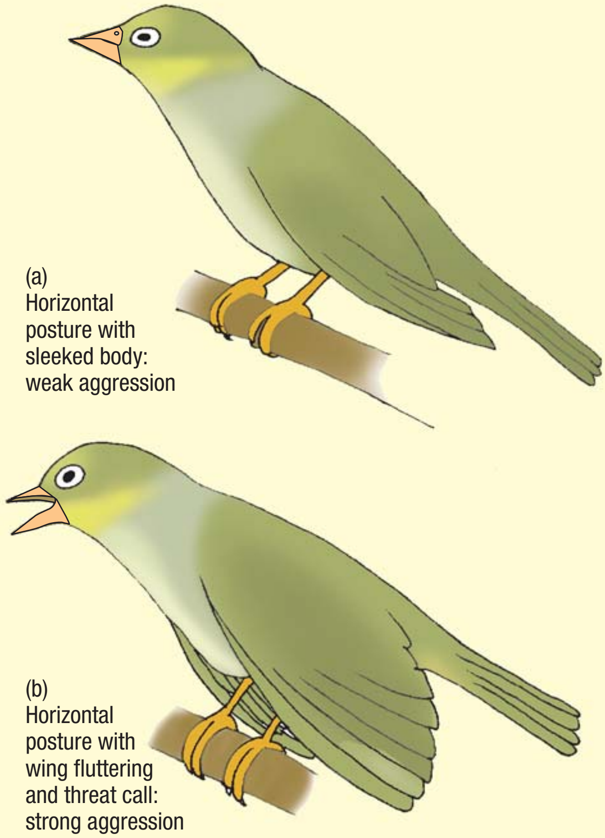


Figure 11.9 Threat postures of silvereyes

- The chances of inbreeding and predation are reduced.
- Interference with reproductive activities is reduced.
- Greater protection is given to the young.
- Waste of energy through direct aggression is prevented.
- Population density is regulated.

A distinction between **home range** and territory must be made. Home range refers to any area traversed by an animal in its normal activities. For some species the territory may include the total home range. For other species, however, the territory is a defended area within the home range. The occupants of several adjoining territories may all use a common area for feeding, drinking and so on. Thus the home ranges for each may overlap and are neutral zones.

SUMMARY

Social behaviour describes the interactions of two or more animals, usually of the same species. Living in groups may result in competition for resources or mates.

Agonistic behaviour involves a contest (usually with ritualised threat and submission postures) over a limited resource. Some animals show dominance hierarchies, with higher-ranked individuals having greater access to resources than those of lower rank.

Territorial behaviour, in which an animal defends a specific portion of its home range against intruders, uses agonistic interactions.

All social interactions require a high level of communication, through the various senses and pheromones.

Review questions

11.14 Define the following terms:
- (a) agonistic behaviour
- (b) hierarchy
- (c) territory
- (d) caste
- (e) home range
- (f) communication
- (g) leadership.

11.15 How can pheromones be significant in communication between individuals of a species?

11.16 Describe an example of cooperative behaviour.

11.17 What functions does communication serve?

11.18 Compare and contrast caste and hierarchical social organisation.

11.5 Human social behaviour

The social nature of humans has resulted in the development of societies. Society, as an environment, is composed of two forces—the actions of other people and the physical structures of civilisation and culture. These forces are a part of the total biotic environment to which the individual or group is adapted in order to survive. Like other aspects of the environment, they are subject to change.

As a type of behaviour, society consists of the interactions which occur between individuals and groups, and is adapted to the biotic and abiotic environments.

Social behaviour has been subjected to change and has evolved in much the same manner as other aspects of the living world.

11.5.1 Communication

In human communities, most communication is by the learned skills of language. Many communications are, however, non-verbal. Due to the complex nature of learning in human beings, it is difficult to 'prove' the innate nature of most human behaviours. However, studies of individuals who were born blind, and cross-cultural investigations, suggest that many behaviours are innate. Some examples include:

- *submissive gestures*—eyes cast down and a quick smile when a stranger closely approaches head on; arm across chest
- *aggressive gestures*—eye contact maintained when approaching a stranger; arms to sides
- *greeting*—eyebrow flash; smile
- *frustration*—frown; stamping feet.

Many gestures are the same across cultures, but their meanings have changed through cultural learning. For example, the thumb and forefinger forming a circle can indicate everything is all right, money, or an obscenity, depending on the cultural context.

Figure 11.10 Eyebrow flash: an innate behaviour

11.5.2 Social interactions

There are different levels of social interaction among people. An **aggregation** is a group of individuals performing the same type of behaviour but not interacting in any specific way: for example, a group of young children playing separately and independently in the same area. **Interpersonal behaviour** relates to the interaction between two individuals in which both are affected by the presence of the other as well as by the environment; a mother–child relationship is an example of interpersonal behaviour.

Whenever three or more people interact, **group behaviour** takes place. This may be a free social interaction, or a culturally determined interaction regulated by institutions, laws and traditions. In group behaviour the individual adjusts his or her activities according to the accepted norms and traditions of the society.

Culturally patterned activities are broad patterns of behaviour which are an integral part of a particular civilisation and are related to religion, government and education. The individual within the society adapts to certain patterns of behaviour that fit within cultural expectations.

Within the social environment the behaviour of the individual determines his or her role as much as the role sustains the behaviour of the individual. There are many different possible roles—parent, teacher, leader, team member and so on—and most people fill more than one role. Within different contexts, therefore, the behaviour of any individual changes to suit the particular role that is activated at the time. When someone chooses a particular role, there are social pressures imposed which may force that person to change or establish new behavioural patterns to meet group expectations. Acceptance or rejection of these social pressures may be translated, through the brain of the individual, into physiological reactions that result in feelings of well-being or anxiety.

Human territory

Three types of human territory—tribal, family and personal—have been proposed. Physical fighting for these spaces is uncommon due to the success of a variety of visual and verbal signals which have developed to prevent disputes.

Humans evolved as tribal animals living in comparatively small groups. The basic social unit was a group in which everyone knew everyone else. Any neighbouring group intruding on the social space (home base and hunting grounds) was driven away. In advanced countries, the numbers in these tribes have swelled to such enormous numbers that tribal boundaries in the original sense have broken down. Tribal territory is now associated with nations, each of which is surrounded by a fixed, often strongly defended, border and symbolised by a special flag.

These impersonal territories are, however, inadequate for the development of a sense of belonging. Smaller subgroups (clubs, friendship groups, business organisations) exist, in which all members of the group are known. They often have special slogans, 'uniforms', buildings and badges to advertise tribal identity. Membership of such groups is usually rigidly controlled, and certain criteria must be met for acceptance into the group. Each member must conform to specific behavioural expectations, often governed by rules and regulations. Membership of the group, however, provides a sense of belonging and a feeling of security which promotes self-worth. Hostile displays such as verbal criticism towards rival groups (e.g. sports fans) may occur, but rarely lead to direct fighting.

Figure 11.11 As if a uniform is not enough, these schoolgirls have chosen similar hairstyles.

The family territory is a breeding ground where members of the family are part of a breeding unit. The bedroom, or nest, is the central part of this territory. It is the place where the individual feels most secure. This space is usually isolated from the general living area where contact is made intermittently with the outside world. Surrounding the house, there is often a garden which can be viewed as a remnant of the ancient feeding grounds. A conspicuous fence or hedge separates this area from neighbouring territories. Each family territory is usually distinctively 'marked' by its design, colour and decorations.

When the family goes out as a group it extends its territory, taking markers (personal belongings) which it will distribute around in the new situation (e.g. a picnic in the park, or a visit to the beach) to advertise the presence and solidarity of the group.

Figure 11.12 Personal belongings mark out a new territory during a visit to the beach.

Each person has a personal territory—a space around the individual, encroachment on which is felt as threatening except in very intimate and desired situations. This is particularly evident in an empty cinema. A person comes in and sits on a chair at one end of a row. The next person who comes in will sit halfway along the row. The third person will take the largest gap left, and so on until someone is forced to sit next to another person. If forced to relinquish 'personal space', as in a crowded lift, individuals compensate by turning the other bodies into 'non-persons'. Each individual ignores all others. The face becomes devoid of expression and the eyes are directed towards some inanimate object such as the control buttons of the lift, the floor or the ceiling.

Social interactions are reduced in crowded situations. Thus children in high-density playgroups interact less in a positive context, showing more aggressive and destructive behaviours in their play. 'Spectator crowds' are a special situation. Discomfort at the close proximity of others is eventually overcome by focusing attention on a specific feature in front of the crowd. The individual relates to the actor on the stage or the sporting team on the field. In the rush-hour crowd, on the other hand, each member of the crowd is competing with every other individual. There is no escape to spatial relation with a distant focus. Such a situation can cause the individual extreme anxiety, the only recourse being to avoid eye contact with others and assume a 'non-person' stance.

Body space is related to two forces, both of them powerful: hostility and loving. When someone invades another person's private space, the 'invader' is, in effect, threatening to extend his or her behaviour into one of these two highly charged areas of human interaction. Although personal space is characteristic of human beings in general, its extent appears to be culturally determined. Thus people from Mediterranean regions have a much smaller personal space than do those from western Europe. This has created some problems in diplomatic and business circles.

Figure 11.13 In a crowded environment such as a train carriage, individuals avoid the discomfort of close proximity by ignoring the people around them.

SUMMARY

Studies suggest that much human behaviour has an innate basis. Many non-verbal signals are significant in communication of intent. There is much in common between the group behaviour of humans and of other vertebrate groups, but in humans there is a learned cultural component. It is hypothesised that human societies recognise three types of territory: tribal, family and personal.

Review questions

11.19 How can cross-cultural studies indicate that a particular human behaviour pattern is innate rather than learned?

11.20 Describe two human, non-verbal signals and the situations in which they would be displayed.

11.21 What is meant by 'culturally patterned activities'?

11.22 Can an individual display more than one culturally patterned behaviour? Explain.

11.23 Distinguish between tribal and family territory.

11.24 Each individual has a specific personal space within which they feel comfortable when interacting with another person. What is meant by personal space? Can the size of this space vary with the interacting person? Explain.

11.6 Learned behaviour

Learning is behaviour which involves some choice of responses to a given stimulus. Learning should be distinguished from changes of behaviour that are related only to the development of the individual. Young chickens, for example, are not able to accurately peck at grains of food on the ground. Over time the accuracy improves, and it has been shown that this improvement occurs irrespective of the amount of practice the chickens have. It is a function of maturation rather than learning. Learning, in contrast, is not directly controlled by the genetic make-up of the animal, so the response can be changed by experience.

Learned behaviour is acquired during the lifetime of an animal as a result of constant experience. It is a flexible behaviour which varies from individual to individual; it is not species-specific. The types and degree of learning of which any particular species is capable depend on its physical traits and the complexity of its central nervous system. Its physical and neural capabilities, however, are only part of the story; the outcome depends ultimately on the general physiological state of the animal, which may be controlled by such factors as diet and stimulus enrichment of the environment.

Learning can be classified into two broad categories: associative and non-associative. **Associative learning** occurs in response to a stimulus or property of the environment in which either a positive or negative reinforcement occurs. An external stimulus is not involved in **non-associative learning**.

11.6.1 Habituation

When an animal is exposed to a repeated stimulus which is irrelevant to its survival, it gradually stops responding. **Habituation**, therefore, is learning to ignore certain unimportant stimuli and is therefore non-associative. All young animals will react to a strong stimulus by retreating from it—a loud noise will cause a kitten to run away. If the noise is a regular feature in its environment, the kitten's response decreases with time until ultimately it may merely twitch its ears when the noise occurs. As long as the stimulus is not accompanied by an unpleasant consequence, the initial reaction ceases to occur. It is an important development in the behaviour of young animals to learn to understand neutral elements in their environment, such as movements due to wind.

Habituation can be easily confused with **sensory adaptation**. The difference lies in the permanence of the adaptation. People living in heavy traffic areas or next to a train line accommodate to the noise level, and after a period of time simply do not hear the noise. After a short time at a loud party or disco, individuals filter out the background noise and are able to focus on a conversation which initially was hard to hear. In these examples the effect is only temporary, in contrast to habituation, and the adaptation must be re-established each time such a situation occurs.

11.6.2 Conditioned learning

In **conditioning learning** a particular response becomes associated with a specific stimulus, as a result of reinforcement.

Conditioned reflexes

The simplest form of conditioning is seen in **conditioned reflexes**. Dogs normally begin to salivate when they see or smell food. This is an **uncon-**

ditioned reflex. If, over a period of time, a bell is rung as food is given, the dog associates the bell with food. It will then salivate when the bell is rung, even if food is not presented. A new conditioned reflex is established. In this case the conditioning is an **involuntary reflex**, since the animal did not take an active part in finding the new stimulus.

Trial-and-error learning

By repeatedly trying a task, an animal learns by its mistakes. An earthworm, for example, can learn to move to a particular arm of a T-maze. In this situation both a positive (reward) and negative (punishment) reinforcement can be used. By placing food in one arm of the maze and an electric shock in the other arm, the earthworm soon learns to turn into the arm containing the food. This is termed **trial-and-error learning**. Many examples of this type of associative learning have been observed in the field. For instance, young insectivorous birds and frogs very rapidly learn to avoid insects which are coloured yellow and black, because these colours are often associated with stings (e.g. the wasp) or irritating hairs.

Operant conditioning

Trial-and-error learning is the basis for **complex** or **operant conditioning**, such as training an animal to perform tricks or respond to certain cues. By receiving a reward for a particular behaviour pattern (e.g. a dog retrieving a ball), an animal soon learns a new behaviour pattern. The dog gets a biscuit, or a pat, for retrieving the ball, and punishment (which may simply be lack of reward) for not performing the behaviour on command. In this case the animal learns a **voluntary response** that gets a desired effect and is a result of the animal's own activity.

In all forms of conditioning, the conditioned response is most rapidly achieved if:

- the new stimulus and the original one with which it is to be associated occur at the same time and place
- distracting stimuli are minimised
- the associated stimuli are repeated together many times
- reinforcement is provided.

As with all forms of learning, motivation, reward and punishment are all criteria for success.

In most animals the motivation to learn may be to satisfy a basic need such as hunger or avoidance of pain. In humans the motivation may be more difficult to pinpoint. Thus a student may be motivated by the desire to achieve good results, and the reward is a feeling of pride. However, the motivation may be more concrete, such as a promise of a material reward for good results or punishment for poor ones.

Much human behaviour is a result of conditioning. Young children learn to respond quickly to commands such as 'No!' or 'Do not touch!' due to negative reinforcement. During development through childhood, adolescence and adulthood, certain behaviours are conditioned as acceptable or unacceptable according to the cultural and social mores of specific groups. Thus humans are conditioned to behave in a certain manner in any particular situation.

11.6.3 Imprinting

Imprinting is a simple, very rapid and irreversible form of learning which occurs during a short critical period of an animal's life. Precocial species of birds such as ducks and geese (i.e. species that can move about as soon as they hatch), follow and attach themselves to the first moving object they encounter. In natural situations this would be the mother. During a short period of time (about 36 hours in these birds), the **critical period**, the young irreversibly learn the features of their species from those of the mother. This has obvious survival value for the species. In experimental conditions, however, the young can imprint onto very inappropriate objects, such as a box pulled by a string or a human being. Although these animals can develop most normal behaviours, they will direct their reproductive activities only towards the imprinted object.

Further studies have shown that altricial species (those which are helpless and dependent at birth) may also imprint. The famous biologist Konrad Lorenz relates the delightful story of an adult male raven, which he had hand-reared, attempting to stick worms into his ears and nostrils. Part of the normal courtship behaviour of the male raven is to feed the female.

Imprinting is an example of interaction between innate behaviour and learning.

Inheritance determines:

- the critical period
- the types of objects to which the response may be directed
- the tendency to respond promptly and strongly to the first object of the correct type that is encountered
- the irreversibility of the attachment, once it is formed.

Learning establishes the tie between the animal and the particular object to which it imprints.

Table 11.1 Comparison between imprinting and learning

Imprinting	Learning
Occurs in a short, critical period.	Occurs at any time.
Is specific to one object.	Is general in relation to object.
Initial response is strongest.	Latest response is strongest.
Is irreversible.	Is reversible.
Invariably relates to an event some time in the future (e.g. mating).	Relates to an immediate event.

11.6.4 Latent learning

Latent learning occurs in many animals in situations in which there is no immediate gain for the organism. A wasp, for example, learns significant features of its general environment as it flies to and from the nest. Although this knowledge is unimportant initially, it can be significant if the wasp is forced to drag back to the nest a captive caterpillar that is too large to carry in flight. The homing ability of many grazing molluscs such as chitons and limpets has been shown to be related to latent learning of topography.

11.6.5 Insight

Insight is the ability to respond correctly the first time to a situation that differs from any previously encountered. The animal is able to apply its prior learning to the new situation by mental endeavour rather than overt trial and error. Thus the animal can mentally put together several elements that it originally learned separately. It uses reasoning and symbolic behaviour to develop a concept which is able to be applied in new situations. For example, a hungry chimpanzee placed in a large cage containing several boxes, and some bananas hung out of its reach, will stack the boxes in order to climb up and get the bananas. The chimp formed a concept or plan to achieve a result.

This form of learning involves many neural connections between a variety of past experiences and their outcomes. As a consequence it is limited to the higher animals, particularly the primates, where development of the central nervous system is greatest.

SUMMARY

Learning is defined as the modification of innate behaviour by experience. As animals evolved more complex structural and physiological features, the degree of learning within the behavioural repertoire increased.

Habituation is a simple form of learning involving loss of sensitivity to unimportant stimuli.

Associative learning (e.g. classical conditioning and trial-and-error learning) involves linking one stimulus with another.

Imprinting is a form of learning with a significant innate component which occurs only during limited critical periods of the animal's life. Unlike other forms of learning, it is generally irreversible.

Insight involves the ability to reason and develop concepts from a number of past experiences.

? Review questions

11.25 Distinguish between learning and developmental behaviour.

11.26 Define associative learning.

11.27 How does insight differ from trial-and-error learning?

11.28 Distinguish between habituation and sensory adaptation.

11.29 In what ways are conditioned reflexes and operant conditioning similar? How do they differ?

11.30 Insight is restricted to animals with a highly developed central nervous system. Explain.

EXTENDING YOUR IDEAS

1. Using the following key, identify statements (i) to (vi).

UB *Key:*

A. innate

B. learned

C. ambivalent behaviour
D. displacement activity
E. home range
F. territory
G. conditioning
H. insight
I. anthropomorphism

(i) I am madly infatuated with a really beautiful person who has promised to telephone me and I cannot wait for the call to come. I do, however, have an assignment to complete tonight and if I can get one section rewritten I should get really good marks for it. I can't really settle down to the work because I keep getting hunger pains and there is nothing worthwhile eating in the house.

(ii) My dog was really mad with me the other day. He kept growling and baring his teeth whenever I came near him.

(iii) Joe was really easy to toilet train. Every time he dirtied his nappy Mum scolded him and then put him on the potty. When he 'performed' on the potty, she gave him a big hug. He very quickly got the idea.

(iv) The yearling was finally put into the paddock with the two other horses. The black gelding was the boss of these two. He only had to glance at the mare and she would move away. He could move in to her feed bin without any overt conflict. We were worried that he would harass the youngster and were amazed to find the two of them sharing food. All the yearling had to do was move towards the gelding making funny mouthing motions, with eyes down-cast, and he could go where he wanted without any reaction from the gelding.

(v) There are several families of magpies living around the house and they tend to 'fight' between groups. However, every evening, they all come down to the veranda to collect the meat I put out for them and intermingle without any conflict.

(vi) The last question on the maths paper was really difficult. Jodie stared at the question for nearly 10 minutes without really understanding what was being asked. With only 5 minutes left in the exam, she suddenly 'saw' the solution and was able to complete it in time.

2. IB Silvereyes are small birds which form feeding flocks over winter. During this time a social hierarchy develops. Two groups of silvereyes were kept in similar cages over one winter. Both groups were fed the same amount of food each day. The control group had a constant supply of food which was provided on two trays. The experimental group was provided with a single feeding tray and was deprived of food for 1 hour every morning. All birds were weighed at the beginning and the end of the experiment, and percentage increase in mass calculated. The social rank was determined for each group. A rank of 1 indicated the dominant bird; a rank of 10 indicated the most submissive. The percentage body mass gain of each bird was plotted against its social rank, as illustrated in Figure 11.14.

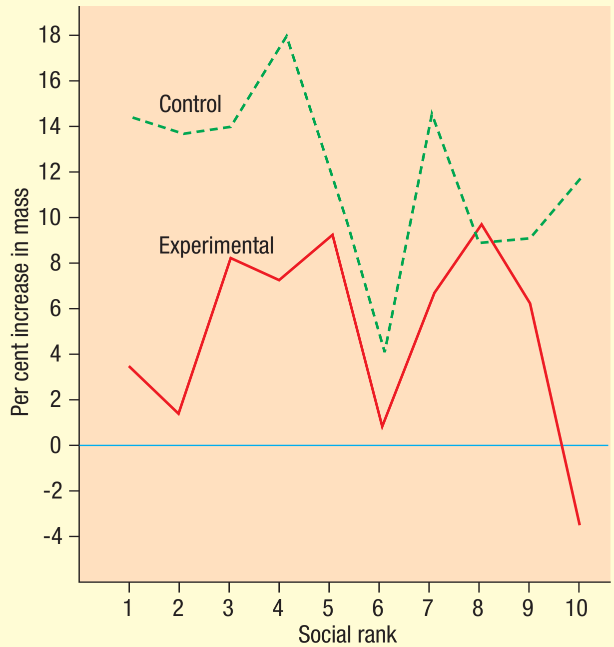


Figure 11.14

(a) Regardless of social rank, which group displayed the greatest percentage gain in body mass?

(b) Using evidence from the graph, suggest a hypothesis to explain the results.

3. UB Since territorial organisation often means that not all members of a population breed during any particular season, how can this system be seen as an adaptation for species survival?

4. UB A dog licks a person's face. The person, in pushing the dog back, rubs the dog's belly. The dog and the person both repeat the behaviours many times. The dog gets the 'belly rub' reward for face licking; the person gets the 'dry face' reward for rubbing the dog's belly. Is the dog or the person conditioned in this example? Justify your answer.

5. UB Analyse the significance of the predominant use of gestures, bluffs or loud noises in territorial defence.

6. UB Zebra finches live in grasslands of Australia and breeding usually only occurs with the onset of a particular level of rainfall. They form permanent pair bonds at about 6 months

of age. The bond is formed during a complex courtship dance which is initiated by the male. The female has the final decision in the acceptance of a mate. Males, however, prefer to initiate courtship with females who have been on a high-protein diet. (It is uncertain how the males discriminate between these females and others since it does not seem to be associated with body mass.) Once the bond is formed, it is maintained during the non-breeding periods with a variety of behaviours such as mutual preening, roosting close together and contact calls. Evaluate the probable survival value of the above behaviours for the species.

7. **UB** Several species of brightly coloured African parrots, commonly known as lovebirds, build cup-shaped nests inside tree cavities. Females typically make nests from thin strips of vegetation (or, in the laboratory, with paper) that they cut with their beaks. In one species, Fischer's lovebird, the bird cuts relatively long strips and carries them back to the nest one at a time in her beak (Figure 11.15a). The peach-faced lovebird, in contrast, cuts shorter strips and usually carries several at a time by tucking them into the feathers of the lower back. Tucking is a fairly complex behaviour since the strips must be held just right and pushed in firmly, with the feathers then smoothed over them (Figure 11.15b).

   These two species are closely related and have been experimentally interbred. The resultant hybrid females exhibit an intermediate kind of nest-building behaviour. The strips cut by these birds are of an intermediate length. They usually make some attempt to tuck them into their rear feathers, but sometimes do not let them go after pushing them a short distance (Figure 11.15c). In other cases the strips are manipulated or inserted improperly, or simply dropped. This results in failure to transport the strips to the nest. After a period of time these hybrid birds transport the strips in their beaks although, even when several years old, they always make a token tucking attempt (Figure 11.15d).

   Is nest-building behaviour in lovebirds innate or learned? Justify your answer.

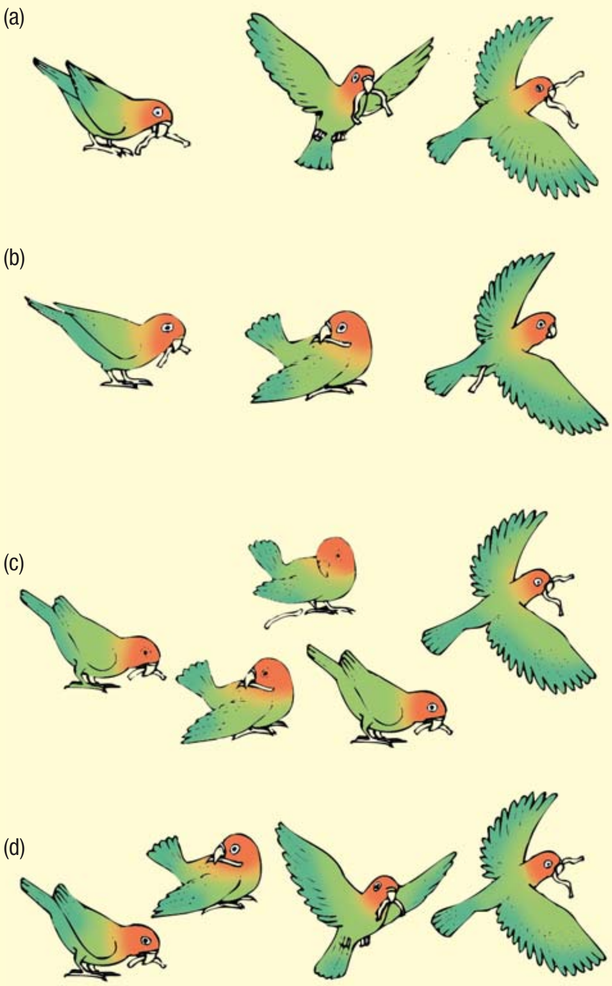


Figure 11.15

8. **UB** In the animal world, the males of many species compete for the right to mate with the females. In some cases the competition may be physical and the males have elaborate secondary sex characteristics such as horns and tusks to assist them in combat. In other species endurance rather than size or strength is the crucial factor. These males usually congregate at a particular site where they are visited by females. The longer a male can remain at the site (i.e. the better his body condition), the more matings he can achieve. The marsupial *Antechinus stuarti*, of south-eastern Australia, remains at the mating site until its death of stress-related disease. The sons of the more successful stayers are the males that meet at the mating site the following spring. Justify how this behaviour is adaptive to the species.

9. **UB** Although imprinting is classified as a form of learning, many ethologists dispute this. Present an argument either for or against this classification.

10. **UB** The following sequence, Figure 11.16 (a)–(c), of behaviours was observed at a bird feeding station. Describe the body postures of each bird. Analyse the communication between the postures of the galah and the magpie and use this to explain what is happening.

11. **UB** The male satin bowerbird, *Ptilonorhynchus violaceus*, builds a bower to attract females for mating (Figure 11.17). The bower is made from interwoven twigs which are often bent to form an arch. The bower is highly decorated with natural and artificial objects, most of which are blue in colour. The male advertises the presence of his territory through song. When a female enters the territory he performs a ritualised courtship dance to entice the female to the bower, where

(a)

(b)

(c)

Figure 11.16

mating occurs. The female leaves the bower to build her nest, lay and incubate the eggs and rear the young. A single male may mate with several females. The female chooses the male with whom she will mate. This selection is based on his ability to build, maintain and decorate the bower. Males will attempt to steal objects from nearby bowers, and scrub turkeys will try to remove the bower for their mound material. A successful bower owner, therefore, effectively uses threatening postures and calls to intimidate members of his own and other species.

Figure 11.17 Male bowerbird

The activities of the male bower bird described above illustrate several aspects of complex innate behaviour patterns.

(a) Which drive activates bower building?

(b) What stimulus activates:

(i) agonistic behaviour

(ii) courtship by the male

(iii) the female entering the bower

(iv) mating?

(c) List two types of communication described in the passage and for each explain how the communication is achieved.

12. UB Several authors have attempted to classify basic human social behaviour. Konrad Lorenz proposed that the basis of human social organisation is agonistic and hierarchical. Desmond Morris, however, has suggested that territoriality is inherent to the human condition.

Present an argument that supports **either** of these two views. In your response ensure that you have adequately defined the type of behaviour and provided detailed supporting evidence.

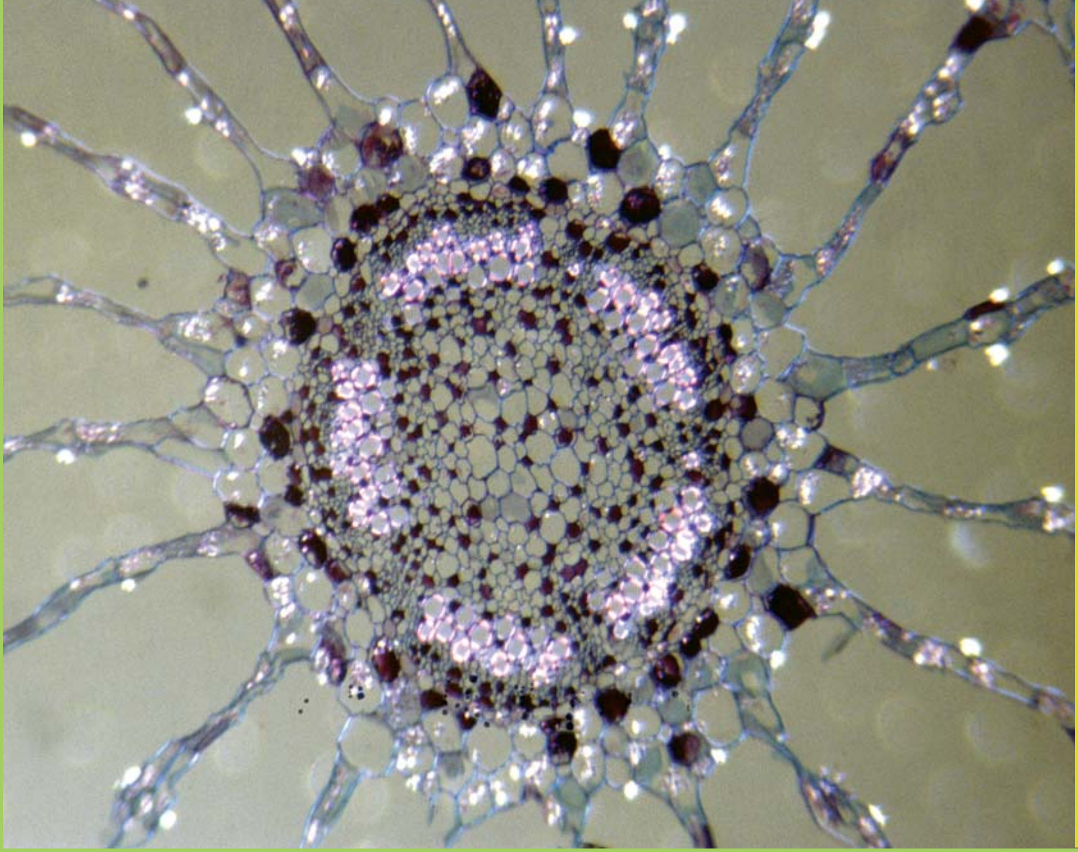
13. UB While many species of birds have disappeared as a result of urban development, others have flourished. The crow (Figure 11.18), a carrion and seed eater, is one such bird that has adpated well to city life. It scavenges on food scraps and eats the fruit and seeds of trees from urban gardens and city parks. The crow has a strong beak capable of removing the coat or shell of many seeds and for tearing apart larger chunks of food.

In highly urbanised cities in Japan, however, food is much scarcer for the crow population. The few trees in the cities bear seeds covered in a hard nut. In one city of Japan crows were observed to carry these nuts to overhead powerlines crossing roads. They waited until a vehicle approached and then dropped the nut. The combined impact of the nut falling on the road below and the vehicle running over it cracked the nut to expose the seed. The bird then flew down to gain its food. This method of food procurement is fraught with obvious dangers.

Another group of crows dropped their nuts on a pedestrian crossing, flew down to the footpath and waited for the walk lights before crossing the road to retrieve the seed.

Using information from the data to justify your answer, discuss the intelligence level of the crow and the type of learning it displayed.

Figure 11.18



UNIT 5

Cell biology

The fundamental unit of all living organisms is the cell. This microscopic structure is composed of organic chemicals which are organised into subcellular structures or organelles. Different parts of the cell, therefore, have different structures and functions. Chemical reactions, which sustain life, occur within the cell. Cellular activities require energy. This energy may be supplied as light energy or as chemical compounds capable of releasing energy when broken down. The size of the cell is limited by its ability to take in and release materials efficiently. For this reason, large organisms are composed of many small cells interacting together. In complex organisms there is division of labour, with different parts of the body carrying out different tasks. A group of similar cells which together perform a particular function is termed a tissue. Different tissues are grouped into organs, and organs into systems. All systems are coordinated so that the body as a whole maintains homeostasis. Tissue development and cell replacement involve a process of cell division called mitosis. Cells involved in reproduction may undergo a cell division called meiosis.

Key concepts

- Cells are the functioning units of living things.

Key ideas

- Cells have a chemical composition that must be maintained for the continued life of the cell.
- Organelles contribute to the structure and functioning of eukaryotic cells.
- There are different types of cells and the ways they are organised influences their functioning.
- Energy required by all living things is obtained in different ways.
- Cell division is an integral part of growth and reproduction.

12 CHEMICALS OF LIFE

12.1 THE STRUCTURE OF MATTER

12.1.1 ATOMS, MOLECULES AND COMPOUNDS

The universe is composed of **matter**, which is anything that has mass and occupies space. Atoms are the building blocks of matter; they are the smallest part of matter that can take part in a chemical change or reaction. An **element** is a substance that cannot be split into simpler substances by normal chemical means, and therefore contains only one type of atom. Different elements combine, in fixed ratios, by forming chemical bonds between them. These substances are termed **compounds**. All of the matter found on earth is made up of millions of different combinations of just over a hundred elements.

The atom is composed of a dense, central nucleus (made up of two types of subatomic particles, protons and neutrons) surrounded by a cloud of electrons. Protons and neutrons have approximately equal mass, but the electrons have such a small mass compared with the nucleus that it is negligible. Protons are positively charged particles and electrons are negatively charged. The number of protons is equal to the number of electrons in an atom, and so the atom is neutral. Neutrons are neutral (i.e. they are not charged). The atomic number of an element refers to the number of protons. The atoms of different elements have different numbers of these three particles and thus different atomic masses (number of protons + neutrons).

The atoms of a particular element may differ in their numbers of neutrons. This means that, although they have the same number of protons and electrons, and thus chemical properties, their atomic masses differ. These differing atoms are called **isotopes**. For example, hydrogen normally consists of one proton and one electron. It has a mass number of one. However, some hydrogen atoms may also have a neutron which, although not changing the chemical properties, doubles the mass number to two. This isotope of hydrogen is called deuterium. Another isotope, tritium, has two neutrons and thus a mass number of three. Some

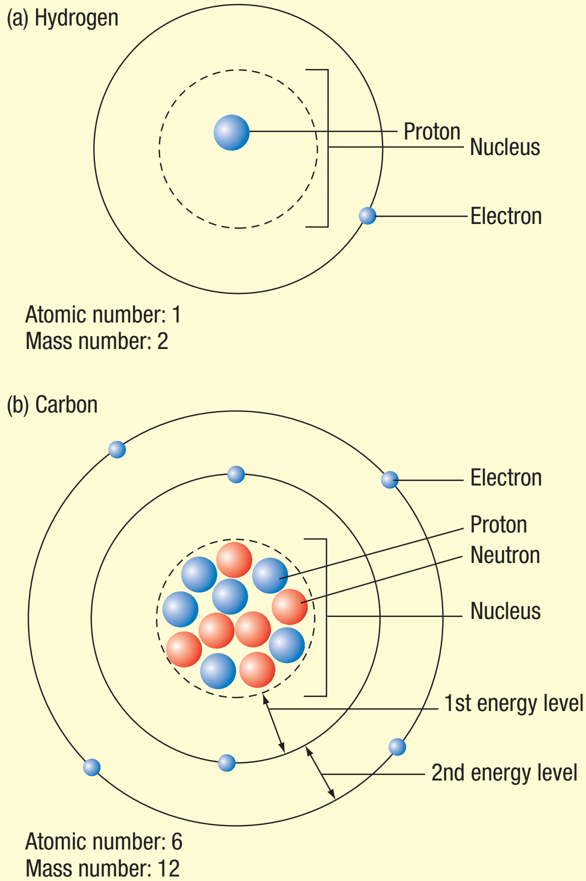


Figure 12.1 Basic structure of the atom

isotopes are very stable, whereas others—**radioactive isotopes**—are unstable and decay over time to a more stable form.

Isotopes are usually taken up and used in biological systems in the same way as the 'normal' form of the element. Carbon, which forms the framework of the chemicals of living things, has three common isotopes—^{12}C, ^{13}C and ^{14}C—with 6, 7 and 8 neutrons respectively. Because of the difference in mass of these atoms, scientists have been able to trace their chemical pathways and thus gain a greater understanding of many biological processes.

The electron cloud surrounding the nucleus of the atom has different energy levels within it. The distance between an electron and the nucleus is determined by its potential energy or stored energy.

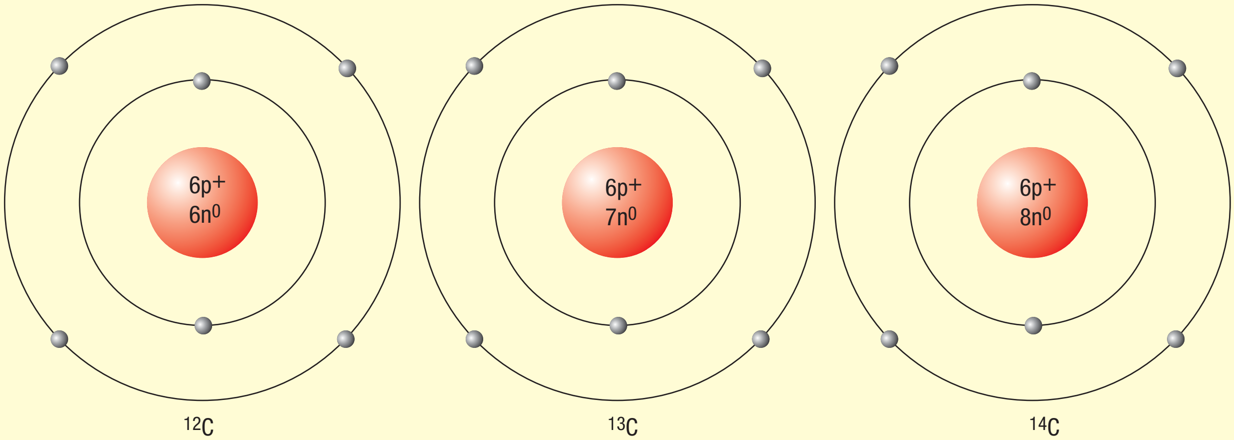


Figure 12.2 Isotopes of carbon. Each isotope has the same atomic number (6), but a different mass number, due to the number of neutrons.

It takes energy to move a negatively charged electron further away from a positively charged nucleus; so the greater the amount of energy it holds, the further the electron will be from the nucleus. Electrons close to the nucleus, on the other hand, are at a low energy level. An atom is most stable when all of its electrons are at their lowest possible energy levels. Thus the inner energy levels are filled before the cloud extends further out. The first level, nearest the nucleus, can hold up to two electrons, and the second can hold up to eight electrons. The maximum number of electrons that can be held in the outer energy level after this is limited to eight. The formula used to determine the maximum number of electrons in an energy level is $2n^2$ where n is the energy level.

When its outer energy level is filled with electrons, an atom does not usually react chemically. The atoms of the majority of elements do not have their outer energy level filled with electrons and so are chemically reactive. The atoms of these elements may:

- gain electrons and become negative, producing negative ions or **anions** (This is termed **reduction**.)
- lose electrons and become positive, producing positive ions or **cations** (This is termed **oxidation**.)
- share electrons with another atom and form a molecule (the smallest part of matter that can exist alone).

An ion is an atom which has lost or gained one or more electrons. Elements that gain electrons and produce anions are non-metals; those that lose electrons and produce cations are metals.

Positive and negative ions, being of opposite charge, are attracted to each other. The electrostatic force of attraction forms an **ionic bond** which holds the ions together in an **ionic compound**. When ionic compounds dissolve in water they dissociate into their respective ions and are thus capable of conducting electricity. If an ionic solution has a greater number of hydrogen ions (H^+) than hydroxide ions (OH^-), it is termed an **acid**. A solution with a greater number of hydroxide ions than hydrogen ions is termed a **base**. If there are an equal number of hydrogen and hydroxide ions, the solution is **neutral**.

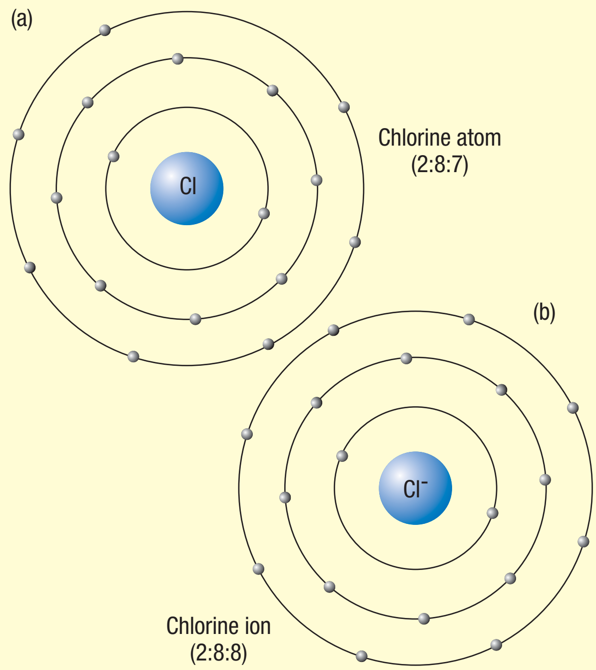


Figure 12.3 Chlorine: (a) atom; (b) ion—since the atom has gained one electron, it has one negative charge.

Table 12.1 pH values

Solution	pH	
Very dilute hydrochloric acid (HCl)	1.1	strongly acidic
Very dilute sulfuric acid (H_2SO_4)	1.2	
Gastric juice	2.0	
Lemons	2.3	
Vinegar	2.9	moderately acidic
Soft drinks	3.0	
Apples	3.1	
Oranges	3.5	
Bananas	4.6	
Bread	5.5	weakly acidic
Rainwater	6.2	
Milk	6.5	
PURE WATER	7.0	NEUTRAL
Eggs	7.8	weakly basic
Sea water	8.5	
Milk of magnesia	10.5	moderately basic
Very dilute ammonia	11.1	
Washing soda	11.6	
Very dilute caustic soda (NaOH)	13.0	strongly basic

A special measure called '**pH**' (on a scale of 1 to 14) is used to compare the hydrogen ion concentration of solutions. A neutral solution has a pH of 7. Acids have a pH of less than 7, and bases have a pH greater than 7. Some substances dissociate readily, thus there will be a greater concentration of hydrogen or hydroxide ions present in solution for these substances than for equal amounts of others which do not dissociate into their component ions as readily. The strength of the acid or base is greater in those ionic compounds that readily dissociate.

A **salt** and water are formed when an acid and a base react together. The hydrogen of the acid is replaced by a positive ion. This hydrogen chemically combines with the hydroxide of the base to form water.

$$\text{acid} + \text{base} \longrightarrow \text{salt} + \text{water}$$

$$HCl + NaOH \longrightarrow NaCl + H_2O$$

When atoms share electrons, the forces holding them together are called **covalent bonds**. If different types of atoms share electrons they form a **molecular compound**. Water is a molecular compound, for example; it is composed of the elements oxygen and hydrogen. Oxygen contains six electrons in its outer energy level, whereas hydrogen contains one electron only. Thus two hydrogen atoms and one oxygen atom share their electrons.

The number of electrons in an atom which are lost, gained or shared is referred to as the **valency**, or combining power, of that atom. Different elements therefore have different valencies.

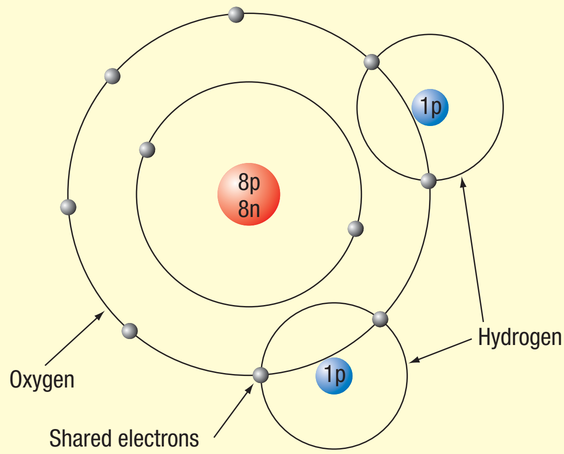


Figure 12.4 Representation of the water molecule

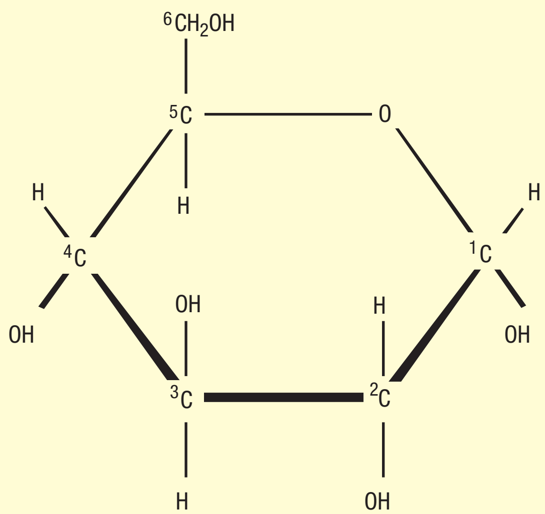
A **chemical formula** represents the number and kind of each atom in a molecule of a compound. Thus the chemical formula for water is H_2O, with the subscript 2 indicating that there are two atoms of hydrogen and one atom of oxygen in every molecule of water. Five water molecules would be indicated by a number in front of the formula: $5H_2O$.

Polyatomic ions (radicals) are groups of covalently bonded atoms that remain together in chemical reactions, so that when they form compounds they behave as a single ion. Most of the common polyatomic ions are negatively charged. Here are some examples:

hydroxide	OH^-
nitrate	NO_3^-
sulfate	SO_4^{2-}
carbonate	CO_3^{2-}

The number beside the charge indicates the number of electrons lost or gained. Thus the carbonate ion gains two electrons whereas the hydroxide ion gains only one. When more than one molecule of a polyatomic ion is involved in a compound, the formula indicates this by showing the whole ion enclosed within brackets and the number of molecules as a subscript at the end of the brackets. The chemical formula for aluminium sulfate, for example, is $Al_2(SO_4)_3$, showing that there are two atoms of aluminium combined with three sulfate ions in one molecule of aluminium sulfate. This type of formula is called a **simple** or molecular **formula**.

(a)



(b)

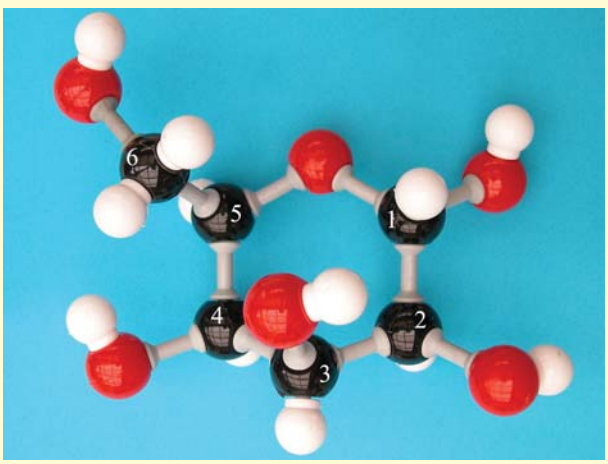


Figure 12.5 Structural formula of the glucose molecule

A **structural formula** shows the actual arrangement of the atoms in the molecule.

12.1.2 Mixtures

Different substances may be mixed together without combining chemically. If the molecules of two substances, when mixed, disperse evenly together (i.e. become **homogeneous**), they are called **solutions**. One substance (the **solute**) becomes dispersed throughout the other (the **solvent**). In biological systems the solvent is usually water—in which case the solutions formed are termed **aqueous**. The **concentration** of a solution refers to the amount of solute dissolved in the solvent. Solutions are transparent (crystal clear) and the solute will never settle out.

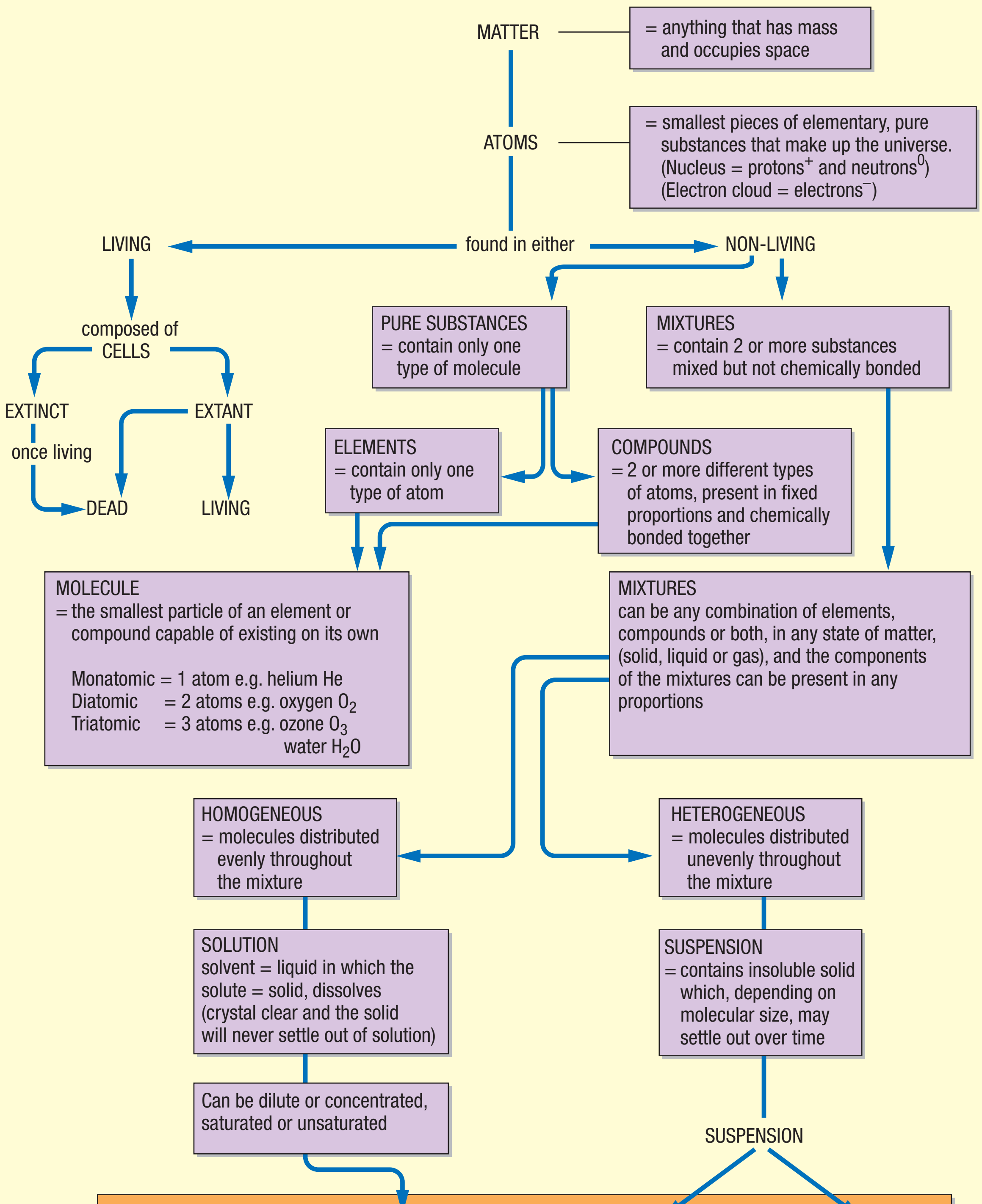
When covalent compounds form a solution, they dissolve as separate molecules. For example, a solution of sugar in water consists of water molecules and sugar molecules equally dispersed throughout the solution. Samples of any part of the solution will contain similar numbers of water and sugar molecules.

When ionic compounds form a solution, their ions dissociate and move independently in the solution. Thus a solution of salt and water will contain water molecules, sodium ions and chloride ions, equally dispersed.

Other substances, when mixed together, do not form a solution. In some, the particles settle to the bottom to form an **insoluble suspension**. In others, although the particles do not settle out, small groups of molecules remain together in clumps and disperse unevenly throughout the liquid. These are called **colloidal suspensions**. Colloidal suspensions are translucent: they will disperse a beam of light. Both colloidal and insoluble suspensions are examples of **heterogeneous mixtures**, since they form uneven distributions of molecules in the mixture.

Particle size is one of the properties which determines whether or not a mixture of a solid in a liquid will be a solution, colloidal suspension or insoluble suspension. All particles are in constant random motion, the speed of which depends on the size of the particles and on the temperature. The extent of motion determines the state (solid, liquid or gas) of the substance. Thus liquid molecules move more freely than solid molecules, and so liquid molecules buffet solid molecules mixed with them. The irregular movement shown by the solid molecules is called **Brownian motion**.

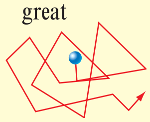
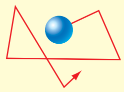
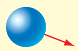
If the solid molecules are very small, Brownian motion will cause them to be kept in constant motion and ultimately spread evenly throughout the liquid (dissolve). A solution results. The larger the



	SOLUTION	COLLOID	INSOLUBLE
1. Dissolves	Yes	No	No
2. Light passes through	Yes	No	No
3. Appearance	crystal clear	cloudy to opaque	opaque
4. Settles out	No	No	Yes
5. Can be filtered	No	No	Yes
6. Particle size	<0.000 000 1 cm	>0.000 000 1 cm but < 0.000 1 cm	>0.000 1 cm

Figure 12.6 Components of matter

Table 12.2 Relationship between particle size and type of mixture

Particle size	Properties			Type of mixture
	Buffeting by liquid molecules	**Brownian motion**	**Appearance**	
small 	great 	great	crystal clear	solution
medium 	medium 	medium	translucent translucent to opaque	colloid suspension
large 	minimal 	negligible	opaque	insoluble

solid molecules, the more slowly they move, and the less effective will be the buffeting effects of the liquid in dispersing the solid. The force of gravity may be greater than the movement of the molecules, causing them to settle out on the bottom as a sediment. In this case an insoluble suspension forms. The molecules in these cases usually remain clumped together in large groups.

Intermediate between insoluble suspensions and solutions are colloidal suspensions. Colloidal molecules are larger than the molecules in true solutions but smaller than insoluble molecules. Brownian motion of the solid in this case is very slow. Colloidal matter separates out into small groups of molecules which stick to each other, unevenly dispersed between the liquid molecules.

Colloids may be found in two states—sol and gel. When the particles are dispersed throughout the liquid, they remain fairly fluid and the suspension is in the sol state. In the gel condition the particles become attached to each other in a loose network which traps liquid molecules within it. The movement of molecules in the suspension becomes restricted and the colloid becomes jelly-like. Some colloids can change reversibly between the sol and gel state. The protoplasm of most cells is colloidal in nature.

SUMMARY

Matter is anything that has mass and occupies space. Atoms are the building blocks of matter. Each atom has a nucleus composed of central protons (positively charged) and neutrons (no charge) surrounded by a cloud of electrons (negatively charged). There are the same number of protons and electrons in any particular type of atom. Atoms with differing numbers of protons (and thus electrons) are termed elements. There are approximately 100 different types of elements on earth.

Atoms are most stable if their outer energy level of electrons is full. If this is not the case, the atom either gains or loses electrons to form charged ions, or shares electrons with other atoms to form molecules. Ions with opposite charges are attracted together to form ionic compounds held together by ionic bonds. When atoms share electrons they are held together by covalent bonds, and form a covalent molecule (same type of atoms) or compound (different types of atoms). Energy is stored in chemical bonds.

Each different compound is composed of specific atoms in a fixed ratio, chemically bonded together. A chemical formula represents the number and types of atoms (or ions) in a molecule of a compound. It may be a simple formula, or may show the arrangement of the atoms in the molecule (structural formula).

When ionic molecules dissolve in water they dissociate into their constituent ions. Acids are solutions in which there are more hydrogen ions than hydroxide ions ($pH < 7$). Neutral substances (pH 7) do not have an excess of either hydrogen or hydroxide ions. Bases ($pH > 7$) have more hydroxide ions than hydrogen ions.

A mixture is composed of two or more substances not chemically bound together. It may be homogeneous (a solution) or heterogeneous (a colloidal or insoluble suspension).

Review questions

12.1 Why does a free atom have no electrical charge?

12.2 What happens to the outer energy level when an atom joins with another atom?

12.3 Compare and contrast ionic and molecular compounds.

12.4 What is meant by the expression $3H_2O$? How many atoms are present in $3H_2O$?

12.5 Compare and contrast a homogeneous and a heterogeneous mixture.

12.6 Distinguish between a solution, a colloidal suspension and an insoluble suspension.

12.7 What causes Brownian motion?

12.8 Why is a solution of hydrogen chloride in water an acid?

12.9 A chemist tests two solutions. One has a pH of 6 and the other a pH of 2. Which is more acidic? Explain.

12.10 On what characteristics is the pH scale based?

12.2 Living matter

Matter can be divided into living and non-living. Both are made up of the same elements, but in living things elements are arranged into large complex chemical compounds which contain carbon: organic compounds. These large compounds consist of units of smaller molecules bonded together to form large macromolecules. All other compounds are said to be inorganic compounds. The atoms and molecules in biological systems obey the same physical and chemical laws as those of non-living matter.

The properties of the complex organic molecules depend upon the organisation of the atoms within the molecule. In a similar way the properties of a living cell depend on the organisation of molecules within the cell, and the properties of multicellular organisms depend on the organisation of cells within the body. **Biochemistry** is the study of the chemicals of living organisms.

The four most common elements found in living things are:

Element	Symbol	Valency		
Hydrogen	H	1	Most common	= 99% of mass and number of all atoms
Carbon	C	4		
Oxygen	O	2		
Nitrogen	N	3	Least common	

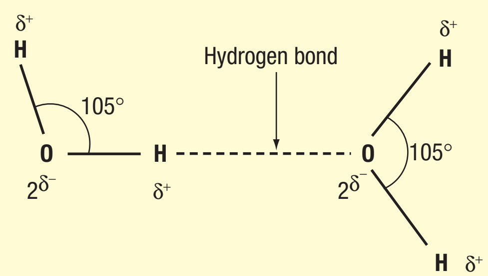
Water, oxygen, carbon dioxide and nitrates are examples of inorganic compounds and elements which are important to living things.

12.2.1 The importance of water to living things

Water is the basis of life. The majority of organisms live in water, and those that live on land still depend on water for a number of activities. Water is the major constituent of living cells: 60–95 per cent of an organism's live mass. Many of the properties of water result from the small size of the molecule, its polarity and hydrogen bonding between its molecules.

Polarity is an uneven charge distribution over a molecule. One end of the water molecule is slightly positive and the other end is slightly negative. In other words, it forms a dipole (two ends with different charges). When covalent bonds are formed in the water molecule, the larger oxygen atom pulls the electrons closer to its centre and away from the smaller hydrogen atoms. Thus the oxygen part of the molecule is negative and the hydrogen part is positive. Water molecules, therefore, have an electrostatic attraction for each other. Opposite charges of adjacent molecules come together and form weak **hydrogen bonds** between the hydrogen of one molecule and oxygen of the other. These bonds are not as strong as ionic bonds but still exert a strong force of attraction between the molecules. The force of attraction between molecules of the same type is termed **cohesion**.

A large number of substances dissolve in water. Water is a good solvent because of its polarity, which increases the dispersal of solutes by Brownian motion. Water, therefore, is a suitable medium for chemical reactions in the living cell. Materials which



Two water molecules, showing polarity of the molecules and the formation of a hydrogen bond between them

δ^+ = very small positive charge

δ^- = very small negative charge

Figure 12.7 The hydrogen bond as seen in water. Each water molecule can form four hydrogen bonds.

enter and leave cells are usually dissolved in water. Gases, food molecules, excretory products and hormones are all transported in an aqueous solution (e.g. extracellular fluid and blood plasma). A large proportion of blood and lymph is water.

Water has a very high **heat capacity** (the amount of heat required to raise the temperature of 1 kg of a substance by 1°C). Much of the heat energy is used in breaking the hydrogen bonds between the water molecules. As a result water maintains its temperature well, even with great changes in air temperature. Thus plants and animals can exist successfully in water. Since most of the living cell is composed of water, this property also ensures a fairly stable temperature for chemical reactions to take place within living cells.

Water has a high **latent heat of vaporisation**. This is a measure of the heat energy required to vaporise a liquid—to overcome the forces of attraction between the molecules so that they can escape as a gas. A relatively large amount of energy is required to break the hydrogen bonds of water sufficiently for it to vaporise. Thus water has an unusually high boiling point for such a small molecule. Evaporation of water causes cooling, because of the energy that needs to be extracted from the surroundings. This is put to good use in the sweating and panting of mammals, and transpiration of plants, in keeping the organism cool. A large amount of heat can be lost with minimal water loss from the organism.

Water has a high **latent heat of fusion**, which means that liquid water must lose a relatively large amount of heat energy to freeze. Thus cells and tissues are protected to some extent from the adverse effects freezing can have on them.

Water increases in volume and decreases in density between 4° and 0°C. Thus ice forms initially on the surface of water where it is in contact with the cold air and floats on the more dense, warmer water. This insulates the warmer water below from colder air above. Aquatic plants and animals can therefore survive in areas of very cold winters.

Water molecules have a high **surface tension**. This is a phenomenon arising from a system of molecular attraction at the surface of a liquid, causing it to act as though it is covered with a tightly stretched membrane. As a result, water occupies the least possible area due to inwardly acting cohesive forces between the molecules at the surface. Cohesion is the force of attraction between molecules of the same kind; **adhesion** is the force of attraction between molecules of different substances. The high surface tension, cohesion and adhesion of water play important roles in movement of water in plants. The high surface tension of water also allows some insects to 'walk' on water, and the high cohesion between water molecules makes water a very buoyant medium for aquatic organisms.

Water has a pH of 7, and thus is a neutral liquid medium. This factor, and the properties listed above, contribute to the fact that water takes part directly or indirectly in all the metabolic reactions that occur in living matter.

Case study 12.1: Living in freezing conditions

Very few fish can survive the cold conditions of the Antarctic seas. The average temperature of the Antarctic Ocean is –1.5°C, with little variation between summer and winter. Total darkness exists for 4 months of the year, and even in summer the water under the ice receives only 1 per cent of the sunlight that strikes the surface.

One group of perch-like bony fish, the suborder Notothenoidei, have evolved adaptations which are so successful in these conditions that they account for approximately two-thirds of the fish species and 90 per cent of the individual fish in the area. These fish are carnivorous.

Adaptations to the following environmental conditions have been necessary for their survival:

- extreme cold and dark
- multiple layers of sea ice (up to 3 m deep) which cover the water for 10 months of the year. This is supplemented by platelet ice, consisting of large, elongated aggregates of crystals dangling from the surface, which can penetrate gills and skin. In waters less than 30 m in depth, a layer of anchor ice coats the surface.
- low oxygen content
- low productivity.

Thus the fish tend to be slow-moving bottom dwellers, although a few are mid-water swimmers. They must conserve energy and produce biological antifreezes to depress the freezing point of body fluids. The freezing point (FP) of pure water is 0°C.

In most marine fish, body fluid salts (particularly sodium chloride) account for 85 per cent of FP depression. The remainder is due to small amounts of calcium, potassium, urea, glucose and amino acids. Their bodies freeze at approximately –0.8°C. Antarctic fish, however, will not freeze until the temperature reaches –2.2°C. Salt and other small molecules account for 40–50 per cent of the FP depression in these fish; the rest is achieved by eight different types of glycoproteins which are found in all the body fluids except the urine and fluid surrounding the eye.

The freezing point of most solutions depends on the number of solute particles present, rather than the nature of the particles. The more particles there are, the less likely it is that the water molecules will aggregate and form ice. Glycoproteins do not act in this way. It is thought that they attract minute ice crystals onto their surface. This action prevents further growth of the crystals. The type of particle is more important than their number, in this case.

Unlike their temperate water relatives, mid-water notothenoids in the Antarctic lack a swim bladder (a gas-filled sac that typically results in neutral buoyancy, or weightlessness in water, which spares the fish from expending energy on flotation). The skull, tail skeleton and pectoral girdle, however, are composed of cartilage, which is less dense than bone; and the vertebrae are nearly hollow. A thin collar of bone surrounds a gelatinous notochord, which is rich in fats that are less dense than the surrounding sea water. All these characteristics give the fish neutral buoyancy, enabling them to exploit the mid-waters of the Antarctic.

SUMMARY

Water forms hydrogen bonds between molecules, giving it the following properties and making it an essential substance for living organisms. Water:

- is a very good solvent
- has a very high latent heat capacity
- has a high latent heat of vaporisation
- has a high latent heat of fusion
- increases in volume and decreases in density when it freezes
- has a high surface tension
- takes part in metabolic reactions
- has a pH of 7.

Review questions

12.11 What is meant by the statement that water exhibits polarity? Explain how this comes about.

12.12 How does a hydrogen bond differ from an ionic bond?

12.13 List properties of water which are of significance to biological systems.

12.14 How does the presence of hydrogen bonds contribute to the properties of water?

12.15 What is an antifreeze?

12.16 In the Antarctic, there are relatively large numbers of birds (e.g. penguins) and mammals (e.g. seals and whales) and yet few fish. What basic difference between the fish and these two groups accounts for this?

12.17 Explain why the Antarctic notothenoids need to conserve energy.

12.18 Water freezes at 0°C; the bodies of fish consist of up to 90 per cent water; and the waters of the Antarctic have an average temperature of −1.5°C. Why is it that the fish in this area do not freeze and die?

12.2.2 Carbon and its biological importance

Carbon is a small atom, having six protons, six, seven or eight neutrons (depending on the isotope) and six electrons, able to share four electrons in covalent bonds. It has a valency, or combining power, of 4.

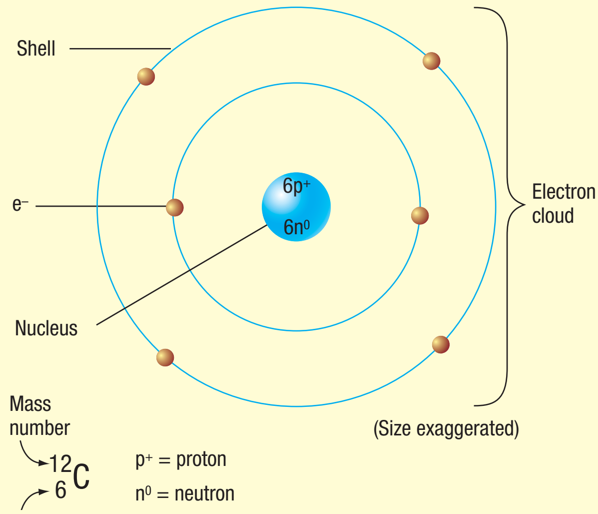


Figure 12.8 Structure of the carbon atom

The compound methane is a simple example of single carbon bonding, where each carbon bonds with four separate atoms or groups of atoms.

Carbon can form covalent bonds with other carbon atoms to form stable chains or rings. The C-C bond is often referred to as the skeleton or backbone of the organic molecule.

Carbon can also share either two or three electrons with another atom (e.g. nitrogen, oxygen or another carbon atom), and so form strong multiple bonds. The number of lines drawn between two atoms in a structural formula indicates the number of electrons they share. If a compound

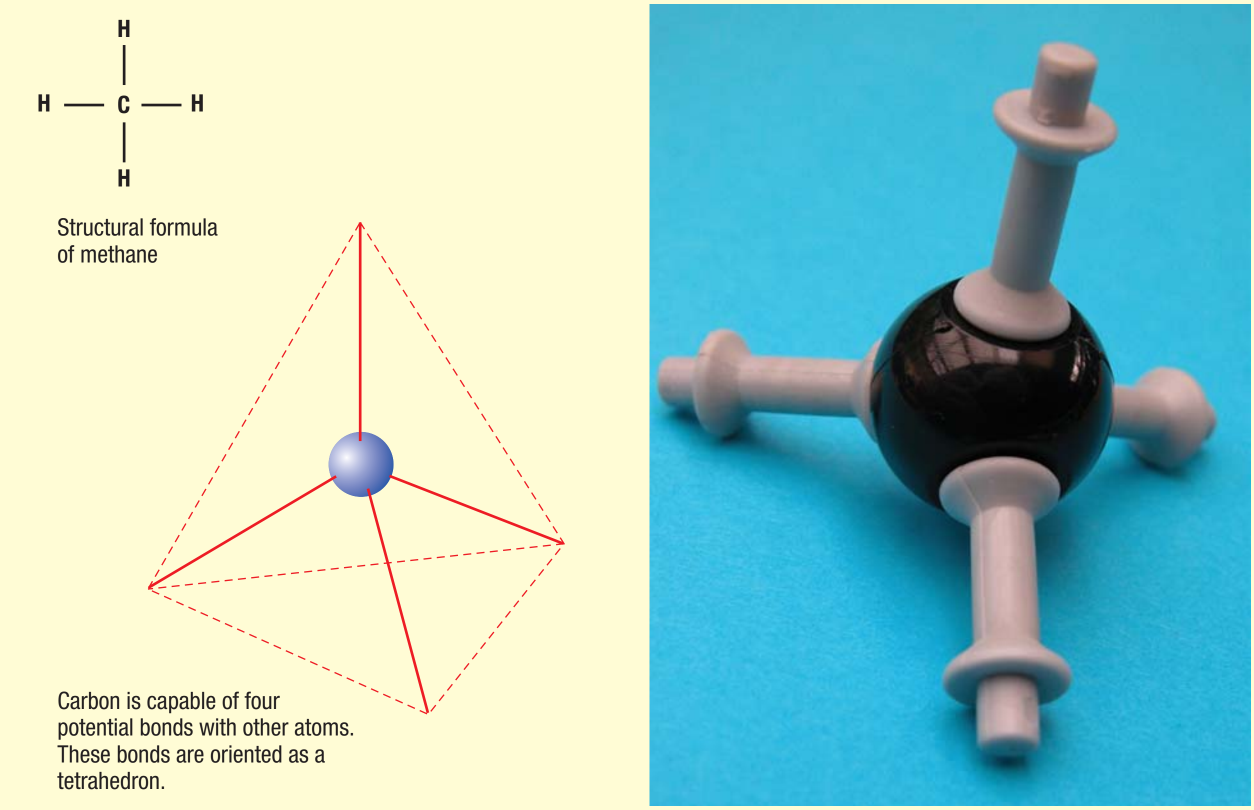


Figure 12.9 The structure of methane

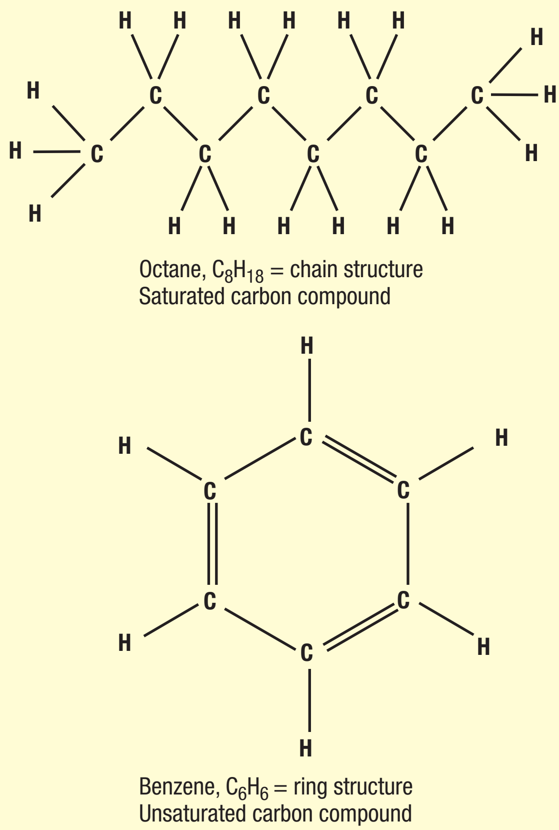


Figure 12.10 Carbon skeletons

contains any multiple carbon–carbon bonds it is said to be **unsaturated**. A **saturated** carbon compound contains only single carbon–carbon bonds.

12.2.3 ORGANIC COMPOUNDS FOUND IN ORGANISMS

Simple organic molecules present in all living material are called **monomers**. They all contain carbon and are the building blocks for the larger macromolecules or **polymers**. Two monomers bond together by the removal of water (a hydrogen is removed from one monomer and a hydroxyl from the other). The formation of this bond takes place in the presence of an **enzyme** (a chemical which changes the rate of biological reactions) which is specific for that particular reaction. This type of reaction is termed **dehydration synthesis**, since water is removed and a larger molecule is formed. Another term also used for this reaction is **condensation**. For each monomer that is added, a water molecule is removed.

Polymers can be broken down into smaller molecules and monomers by addition of a water molecule between each monomer. Again a specific enzyme brings about the reaction. This type of reaction is called **hydrolysis**.

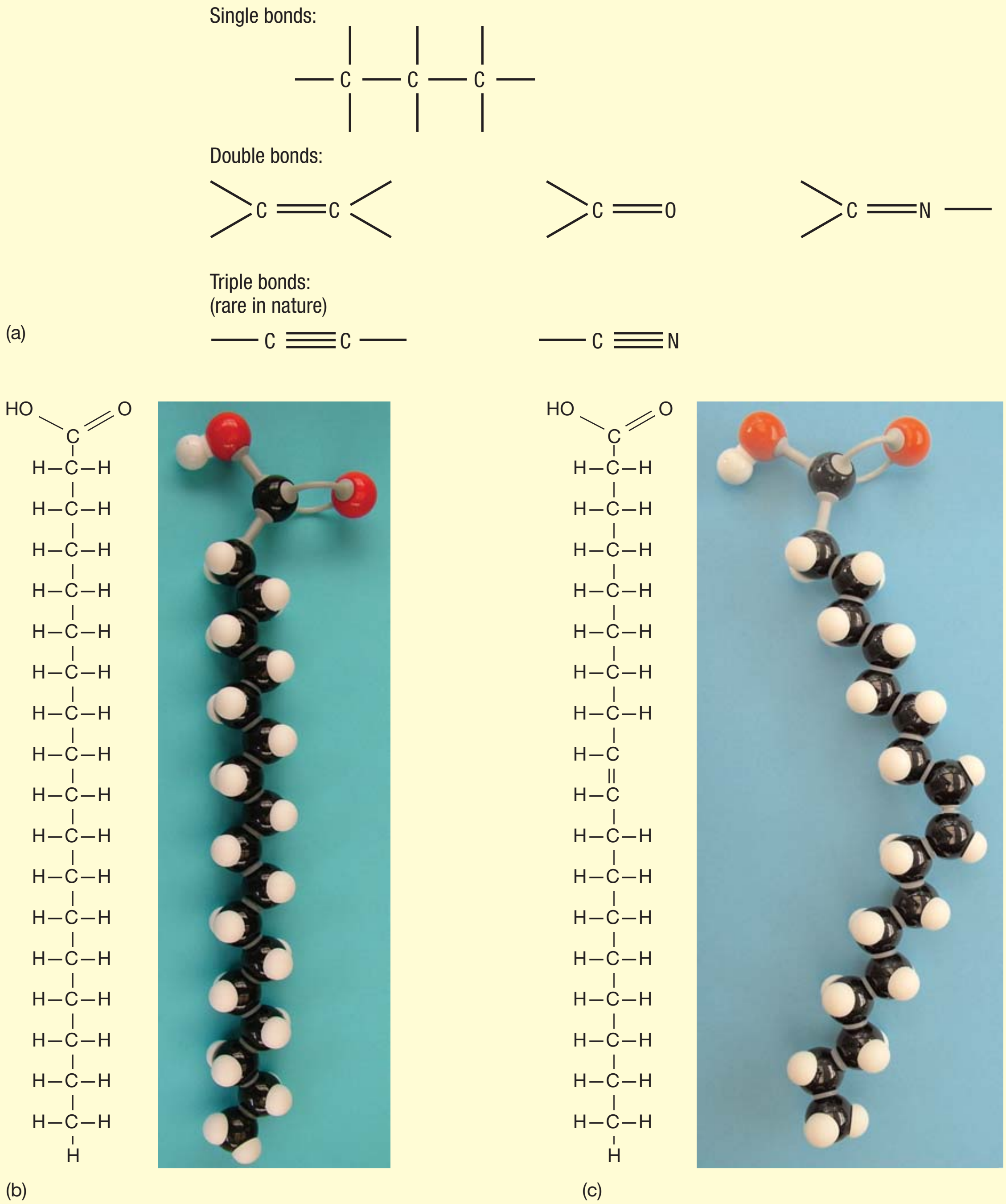


Figure 12.11 (a) Types of carbon bonding; comparison of the structure of (b) a saturated fatty acid (stearic acid) and (c) an unsaturated fatty acid (oleic acid). The structural formulae are to the left of the photographs.

SUMMARY

Carbon is the fundamental chemical of life. It:

- is a relatively small molecule and so has small mass
- has the ability to form four strong, stable, covalent bonds
- can form carbon–carbon bonds and thus large carbon skeletons of rings or chains, which may have side branches
- can form multiple covalent bonds with carbon and other elements.

Small carbon molecules form the building blocks of macromolecules. Bonds between the subunits are formed by the elimination of water (condensation or dehydration synthesis). Formation of bonds requires energy. Bonds between subunits are broken by the addition of water (hydrolysis). Enzymes are present in all these reactions and are specific for each type of subunit combination and bond.

Review questions

12.19 Carbon has a valency of 4. Why does this make it an ideal constituent of biological molecules?

12.20 How are long chains or rings of carbon molecules formed?

12.21 What is the difference between a saturated and an unsaturated carbon compound?

12.22 Define a macromolecule. Of what molecules are macromolecules composed?

12.23 How do bonds form between two monomers? What is the name of this process?

12.24 What is the name of the process whereby polymers are broken down into smaller molecules? What two things are needed for this reaction to occur?

12.2.4 Carbohydrates

Carbohydrates contain the elements carbon, hydrogen and oxygen in the ratio of 1:2:1 in the monomer. They are hydrated carbons, being composed of one water molecule to every carbon atom. Carbohydrate monomers are called **monosaccharides**, and may be triose (3 carbon atoms), pentose (5C) or hexose (6C).

There are several monosaccharides, each with the same chemical formula ($C_6H_{12}O_6$), but with the atoms spatially organised in differing ways These different arrangements of the same atoms are termed isomers. Because each will have different atoms exposed to the outside and so can take part in different chemical reactions, isomers differ in their properties.

Disaccharides are formed by a condensation reaction between two monosaccharides, with the removal of –OH from one molecule and –H from

Table 12.3 Chemical 'building blocks' of organic compounds

Smaller molecules (building blocks)	Macromolecules formed
monosaccharides (glucose = sugars) (many types but only a few are commonly used—usually only one type per molecule)	polysaccharides
amino acids (20 common types, and all may be present in one molecule)	proteins
nucleotides (sugar, phosphate and base; there are five types of bases)	nucleic acids
fatty acids and glycerol	lipids (fats and oils)

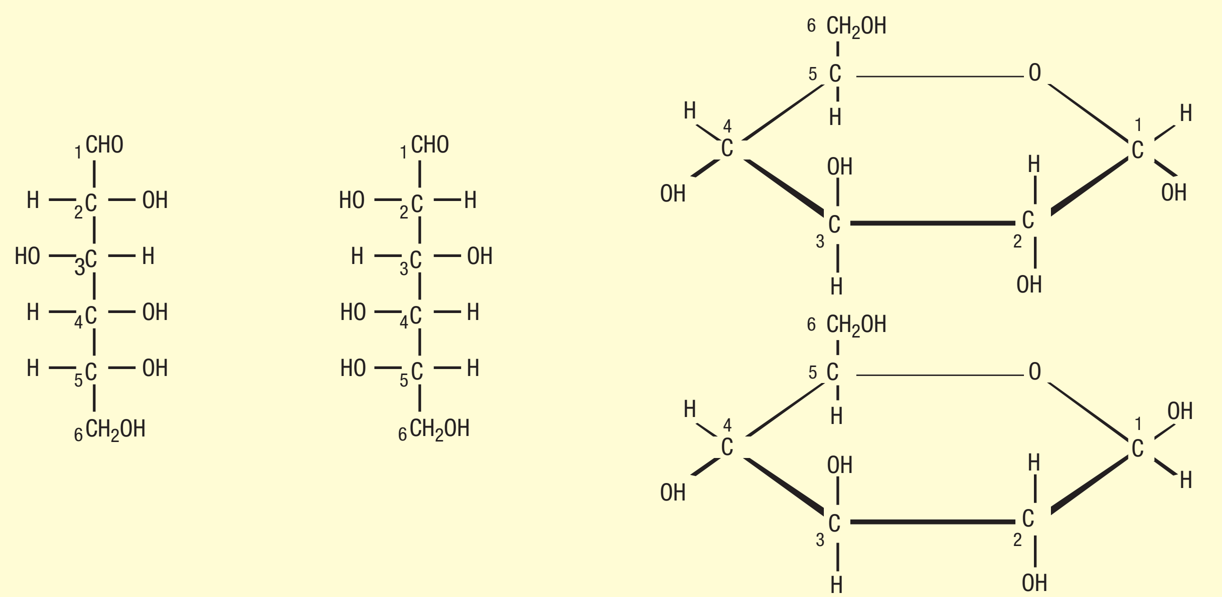


Figure 12.12 Isomers of glucose

the other. The bond formed between the two is termed a **glycosidic bond**. Further monosaccharides can be added by condensation reactions to form **polysaccharides**. The general formula for a polysaccharide is:

$$(C_6H_{10}O_5)_n\ H_2O$$

where n represents the number of monomers in the formation of the polysaccharide. $(n - 1)$ molecules of water are removed in the process. Thus the extra H_2O represents the –H and the –OH still remaining on each monosaccharide at the ends of the molecule.

Carbohydrates in living organisms

Carbohydrates are important energy sources, and can be stored in the form of polysaccharides: starch in plants and glycogen in animals. Polysaccharides may have a structural function: for example, cellulose in plant cell walls, and chitin in fungi and the exoskeletons of arthropods. Polysaccharides are good storage molecules because:

- their large size makes them more or less insoluble in water, so they do not affect the water balance of the cell
- they are able to fold into compact shapes (e.g. starch)
- they are readily converted to sugars by hydrolysis when needed.

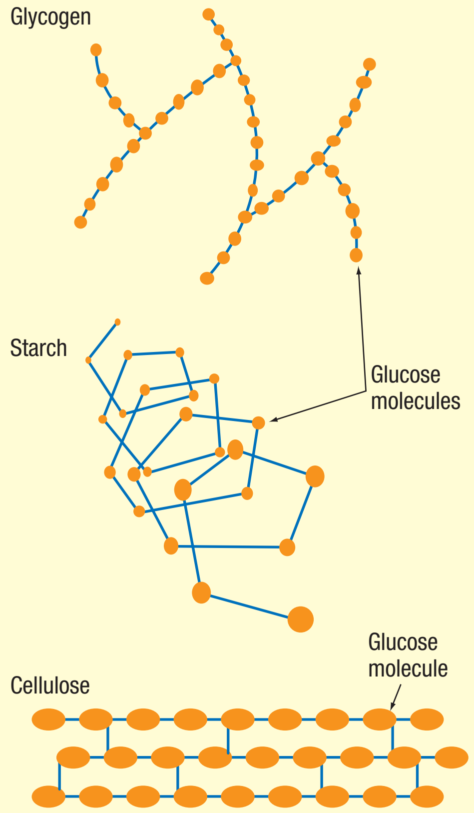


Figure 12.14 Simplified models of carbohydrates to illustrate ways in which glucose molecules can be arranged to give different structures and therefore different functions

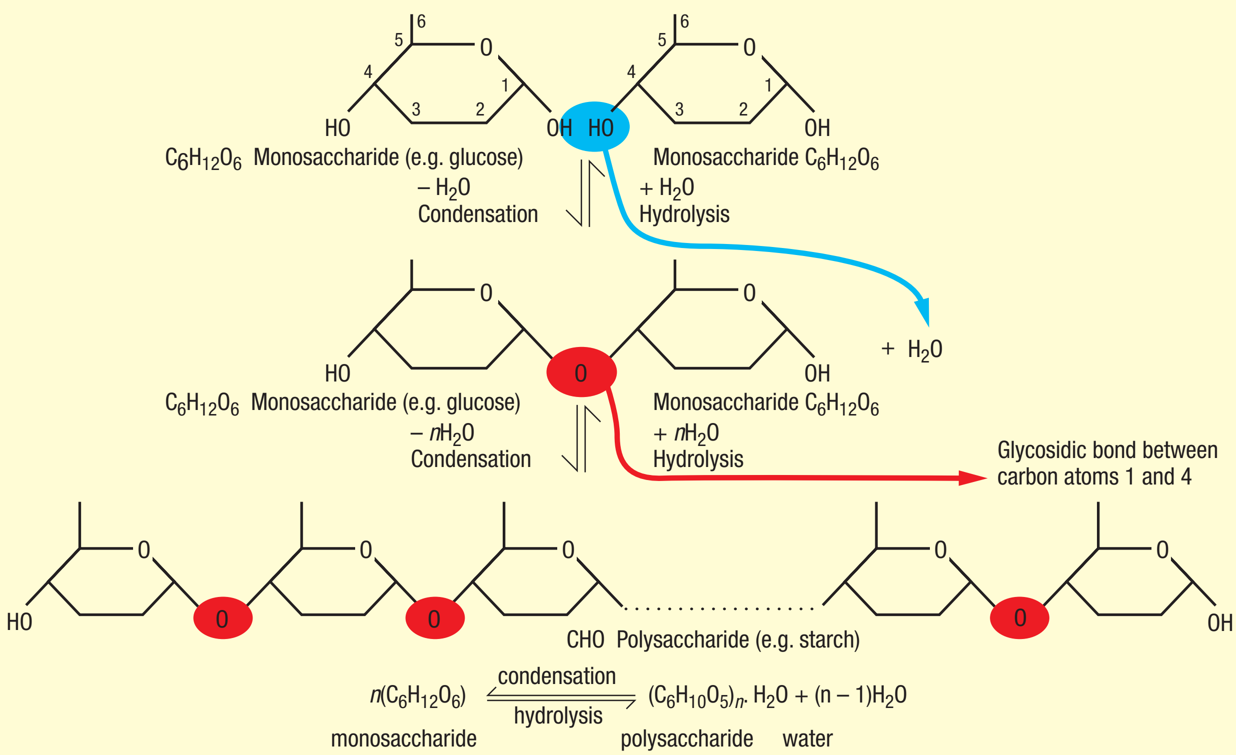


Figure 12.13 Formation of a polysaccharide

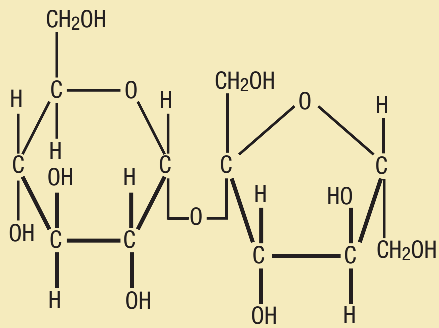
SUMMARY

Carbohydrates contain the elements carbon, hydrogen and oxygen in their monomers in the ratio of 1:2:1. The main monomer (a monosaccharide) is a hexose sugar (e.g. glucose), which may exist as many isomers, each of which has different properties. Monomers may join to form disaccharides or polysaccharides. Each bond is formed by the removal of a water molecule. Carbohydrates are important energy sources for living organisms.

Review questions

12.25 Give the general formula for a carbohydrate.

12.26 The carbohydrate illustrated below has been formed from two hexose sugars.



(a) What type of carbohydrate is this?

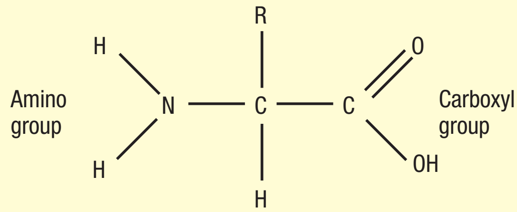
(b) What is the name of the reaction by which the two sugars joined?

12.27 Glucose and fructose can both be represented by the molecular formula $C_6H_{12}O_6$. Explain why they have different physical and chemical properties.

12.2.5 Proteins

Proteins always contain C (carbon), H (hydrogen), O (oxygen) and N (nitrogen). Other elements, such as sulfur and phosphorus, may be present. The monomer is an **amino acid**. Each amino acid has an amino group ($-NH_2$) and a carboxyl group ($-COOH$). The central carbon atom is linked to a hydrogen atom and another group of atoms, which varies, but is given the general letter 'R'.

There are about twenty different amino acids, each differing only in the composition of the R group, which may be a single atom or a large group of atoms.



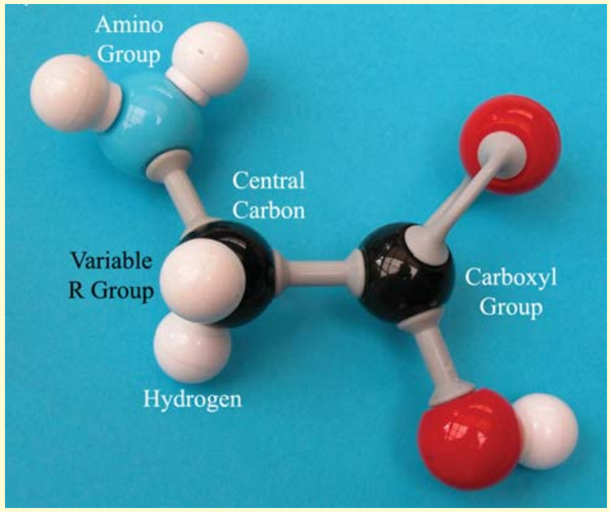


Figure 12.15 The general formula of an amino acid

A **dipeptide** is formed when two amino acids bond together by condensation. The –H is removed from the amino group of one molecule and the –OH from the carboxyl group of the other molecule. A **peptide bond** is formed between the two molecules. **Polypeptides** are formed by the continued condensation of more amino acids onto the molecule, and may be several hundred amino acid units long. A protein is a macromolecule consisting of one or more polypeptide chains which may be folded, branched and/or cross-linked at intervals.

Protein formation

The **primary structure** of a protein is the linear sequence of amino acids in the polypeptide chain. Although there are only twenty amino acids, the number of sequences of these is enormous. A typical human cell can contain 10 million protein molecules of about 10 000 different types. Each has a special function which is determined by its unique chemical nature. One small change in the primary structure of a protein may alter or destroy the way in which that particular protein functions.

As a polypeptide chain is assembled, interactions between different amino acids along the chain cause it to fold and thus form a **secondary structure**. The structure may be in the form of a helix (e.g. keratin)

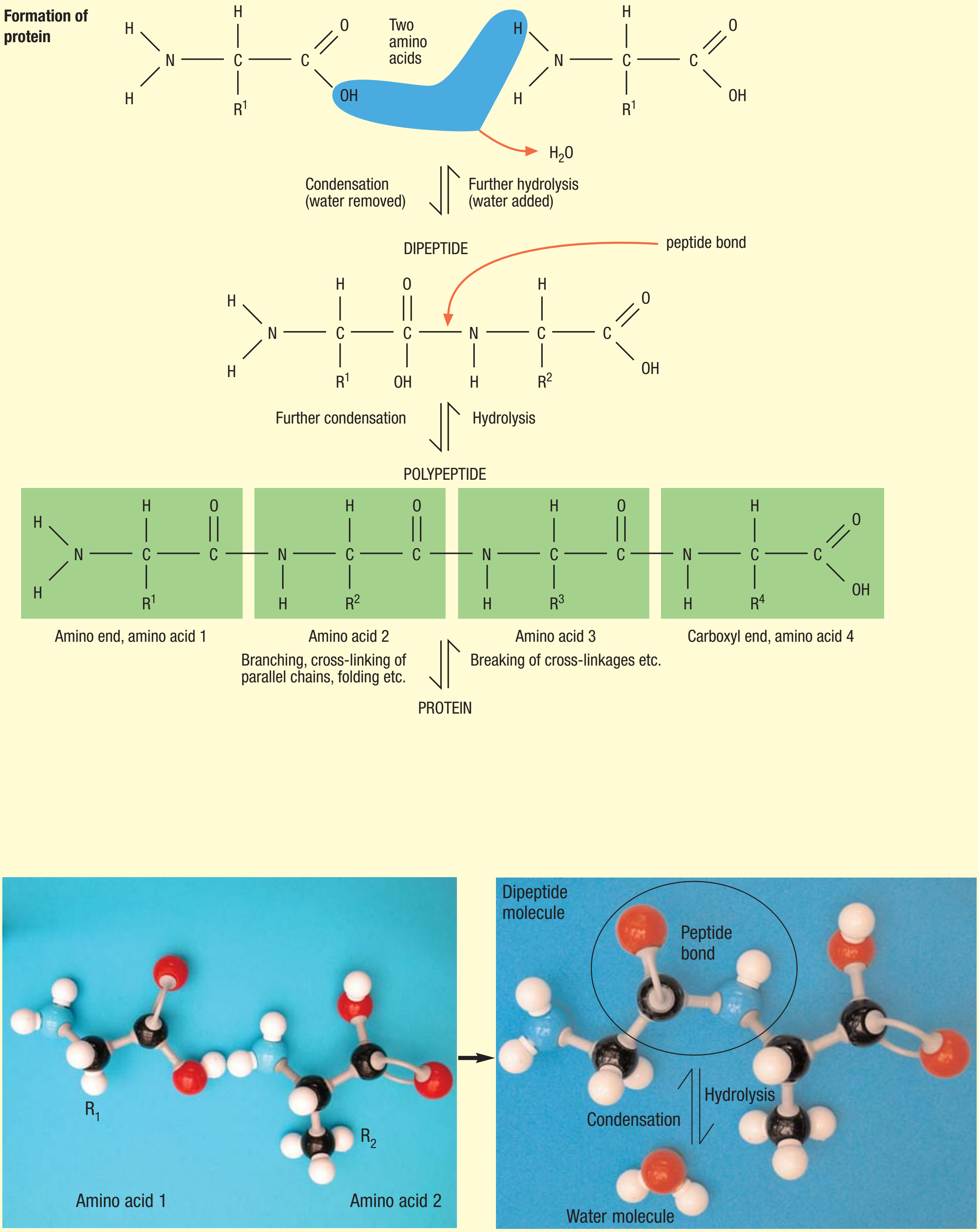
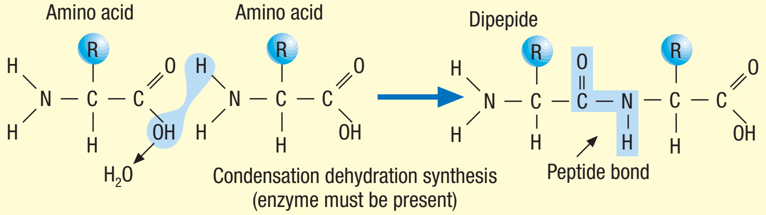


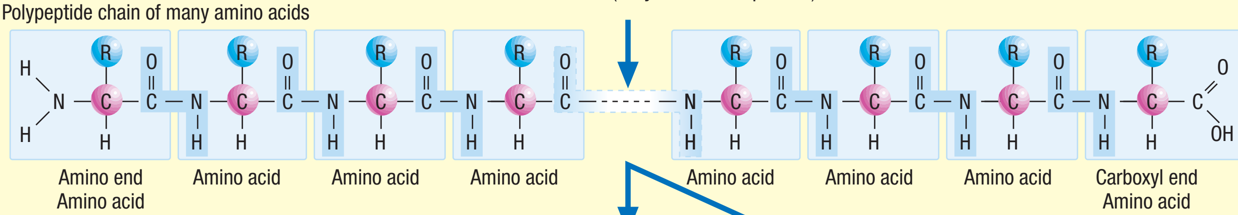
Figure 12.16 Formation of protein, and levels of protein structure

Levels of protein structure

1. Primary protein structure

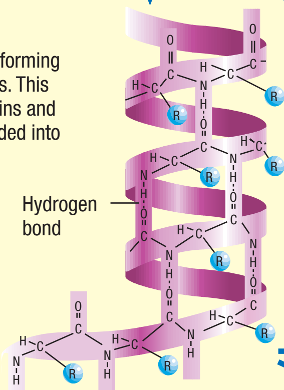
Amino acids are bonded together by peptide bonds one after the other to form a polypeptide chain. This is the primary (or first) structure of a protein. The type, position and relationship of the amino acids give rise to the unique structure, function and chemical behaviour of each type of protein.



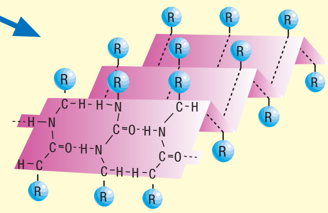


2. Secondary protein structure

Hydrogen bonds form at short but regular intervals along the forming polypeptide chain due to the type and position of amino acids. This bonding causes the secondary (or second) structure of proteins and is either *coiled* into helical patterns or several chains are bonded into *pleated sheets*.



Primary structure—polypeptide chain
Secondary structure—the helix

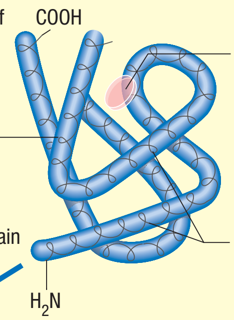


Primary structure—polypeptide chain
Secondary structure—the pleated sheet

3. Tertiary protein structure

Most polypeptide chains that have a helical or coiled secondary structure undergo further folding and bending of the chain at certain points due to the type and position of particular amino acids. The R groups of amino acids also interact to hold the chain in particular shapes and so give the protein particular functions. This further folding or coiling is the tertiary (or third) structural change of the protein.

Primary = polypeptide chain
Secondary = chain coiled
Tertiary = coiled chain is further folded



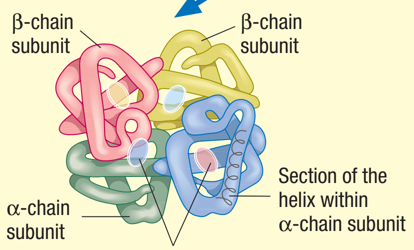
Quarternary = four peptide chains, coiled, folded and joined to form haemoglobin

Tertiary structure—the myoglobin molecule

4. Quarternary protein structure

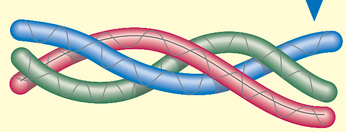
In the fourth level of protein structure two or more polypeptide chains are held tightly together by many weak links such as hydrogen bonds or covalent bonds between sulfur atoms in certain R groups.

These can be globular proteins such as haemoglobin (4 chains) and insulin (2 chains) or structural proteins such as collagen and keratin that are triple helixes.



Haem groups (total of 4 in complete haemoglobin molecule)

Primary = polypeptide chain
Secondary = coiled
Tertiary = further coiled
Quarternary = three chains, coiled into one strand



or a pleated sheet (e.g. the silk fibres of spider webs). These proteins are known as fibrous proteins, and have a structural or mechanical function.

In other proteins, the secondary structure folds back on itself to make a complex **tertiary structure** as a result of interactions between the R groups of the individual amino acids. Some pleated sheets are formed in this way, although most of these proteins have a compact globular shape. Enzymes, antibodies and many hormones are globular proteins. Their specific actions are determined by the way that folding occurs and the amino acids that are exposed on the outside of the molecule.

Some proteins are composed of several polypeptide chains, with bonds holding the chains together in special **quaternary structures**. The hormone insulin, for example, is composed of two polypeptide chains intricately bound together.

Proteins may become denatured (lose their specific three-dimensional shape and thus reactivity) by heat, strong acids and bases, organic solvents and heavy metals.

Case study 12.2: The importance of the amino acid sequence

Haemoglobin, a quaternary protein, is the pigment carried in red blood cells. It has the special property of being able to combine loosely with oxygen—picking it up from areas where oxygen levels are high (e.g. the lungs) and depositing it in areas where oxygen is low (e.g. active cells). The haemoglobin molecule consists of two pairs of polypeptide chains, each of which is combined with an iron-containing group. Each type of chain has a primary structure containing about 150 amino acids. Thus the entire haemoglobin molecule consists of 600 amino acids and four iron groups.

In the hereditary disease sickle-cell anaemia, one amino acid (glutamic acid) in each chain of one of the pairs is replaced by a molecule of a different amino acid, valine. Thus the two substituted valines create two 'sticky' areas on the surface of the haemoglobin molecule. These areas are attracted to each other and distort the shape of the entire molecule into a stiffened rod.

Red blood cells containing large proportions of these altered molecules become stiff and deformed, taking on a characteristic sickle shape. These cells are much more fragile than normal red blood cells and rupture easily. Because of their shape they tend to clog small blood vessels, creating blood clots which prevent a full supply of blood to vital organs. This results in pain, intermittent illness and often a shortened life span.

Functions of proteins

Proteins play a structural role as major components of cell membranes, connective tissues, skeletal materials and so on. Hair, feathers, horns and nails

Table 12.4 Types of proteins and their functions in living organisms

Category	Example	Type	Occurrence/function
Structural	keratin sclerotin	fibrous fibrous	skin, feathers, nails, hair, horn, silk exoskeleton of insects
Mechanical	collagen elastin	fibrous fibrous	tendons, cartilage, bones—resists stretching ligaments
Enzyme	amylase trypsin	globular globular	catalyses hydrolysis of starch to maltose catalyses hydrolysis of protein
Hormone	insulin	globular	involved in glucose metabolism
Transport	haemoglobin	globular + iron group	transports oxygen in vertebrates' blood
Protective	antibodies	globular	form complexes with foreign proteins to neutralise them
Contractile	myosin actin	fibrous fibrous	moving filaments involved in muscle contraction stationary filaments involved in muscle contraction
Storage	egg albumin	globular + non-protein group	egg white protein
	casein	globular + non-protein group	milk protein
Toxins	snake venom (enzymes)	globular	paralyse/kill prey

are all modified forms of the protein keratin. Proteins are also important body regulators. Chemical reactions and metabolic processes are controlled by enzymes, all of which are proteins. Growth and reproduction are controlled by hormones, many of which are proteins, and antibodies are proteins involved in the immune response. When other energy sources are depleted, proteins can be converted into substances that release energy for cellular activities.

SUMMARY

Proteins always contain carbon, hydrogen, oxygen and nitrogen, although other elements such as sulfur and phosphorus may also be present. The basic unit is the amino acid. Polypeptides, formed by the condensation of a sequence of amino acids, may become folded, branched or cross-linked in the formation of a protein. Proteins can be denatured by heat, strong acids and bases, organic solvents and heavy metals. Their main functions are structural and regulatory.

? Review questions

12.28 Give the structural formula for an amino acid.

12.29 There are approximately twenty amino acids. How are they similar and how do they differ?

12.30 How does a protein differ from a polypeptide?

12.31 Egg white is composed of the protein albumen. It is transparent and glue-like in consistency. When the egg is cooked, the albumen becomes rubbery and opaque. It cannot return to its original state after cooking. Explain what has happened to the albumen.

12.2.6 Lipids

Lipids are fats, oils and waxes. Fats and waxes are solid, whereas oils are liquids at room temperature. Lipids contain carbon, hydrogen and oxygen but, unlike carbohydrates, in no set ratio. They are composed of two basic units: fatty acids and glycerol. Fatty acids have the general formula RCOOH, where R is a variable group consisting of a hydrocarbon chain. This 'tail' is non-polar (does not carry an electric charge) and **hydrophobic** (*hydro* = water; *phobos* = fear). The carboxyl (acid) group (–COOH) is polar and **hydrophilic** (= water-loving).

An **ester bond** is formed by a condensation reaction which removes an –H from the glycerol and an –OH from the fatty acid. The most common lipids are triglycerides, formed when three fatty acids bond with a glycerol molecule. The fatty acids may be all the same or they may be different. The physical nature of the lipid is determined by the length of the carbon chains in the fatty acids, and whether these chains are saturated. Lipids formed from saturated fatty acids are more compact, and therefore are solids (fats, e.g. butter and lard). Lipids with one unsaturated fatty acid chain or more do not pack together and so are liquid (oils, e.g. olive oil, peanut oil).

Functions of lipids

Lipids are non-polar and thus relatively insoluble in water. They play an important role in the control of water balance in the organism. Lipids, therefore, are an important component of the membranes surrounding cells. Waxes form protective waterproof coatings on the external surface of the exoskeleton of insects, the feathers of birds and hair of mammals. Many plant surfaces, such as the leaves and fruits, are coated with a lipid cuticle which reduces evaporative water loss.

Because they store twice as much energy as an equivalent mass of carbohydrate, lipids are

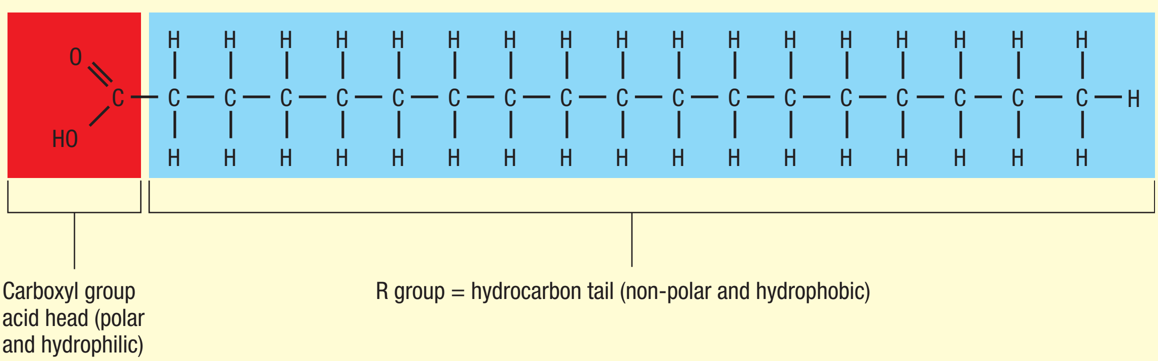


Figure 12.17 Basic structure of a fatty acid

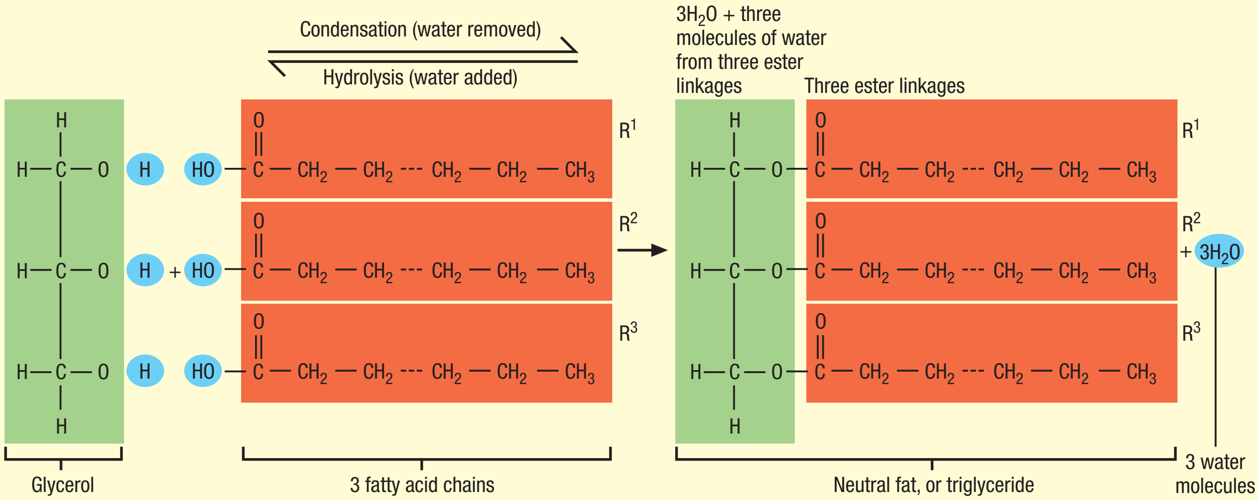


Figure 12.18 Formation of a triglyceride from three fatty acids and glycerol by three condensation reactions

important energy reserves in living organisms. In animals fat is stored in special cells, which in vertebrates are commonly found under the skin. This fat layer is especially important to animals living in cold environments. In seals and whales this 'blubber' acts as an insulator and contributes to buoyancy. Hibernating animals build up large fat reserves during summer, to provide them with energy over the cold winter months. Fat also surrounds and protects vital organs such as the mammalian heart and kidneys. Plants store oils rather than fats and these can be used as commercial sources of edible oils. Examples include coconuts, soya beans and sunflower seeds.

Water is a product of the breakdown of fat. This metabolic water is very useful to some desert animals such as the kangaroo rat and camels. Animal fats and oils such as milk, eggs, butter, cod-liver oil and liver contain the fat-soluble vitamins A and D, which are both essential to the body.

Types of lipids

Phospholipids are similar to triglycerides, except that a phosphate group plus an organic base substitutes for one fatty acid. They are important components of cell membranes. Similarly, a glycolipid is formed when a short carbohydrate chain replaces a fatty acid.

Steroids have a chemical structure unlike other lipids. They are, however, classified with them since they are insoluble in water and soluble in fat solvents. Steroids include sex hormones, adrenal cortex hormones and cholesterol. They are abundant in both plants and animals where they have many important biochemical and physiological roles. Cholesterol, a steroid, is found throughout the human body as it is an important component of cell membranes and a constituent of bile which emulsifies fats. Gallstones are cholesterol particles which have precipitated from the bile in the gall bladder.

Case study 12.3: Cholesterol and heart disease

Cholesterol is an essential molecule in animal bodies for several functions. As a component of the cell membrane, its main function is to limit uncontrolled leakage of water and soluble ions in and out of the cell. In nerve cells it prevents the outward flow of ions which would 'short-circuit' the flow of nerve impulses. On the other hand, cholesterol can lead to heart disease and strokes.

The liver regulates cholesterol levels in the body. When cholesterol is needed, the liver synthesises it from saturated fatty acids; when there is excess in the blood, the liver breaks it down. Lipids are insoluble in water, so cholesterol molecules are 'wrapped' in a layer of water-soluble proteins for transport in the blood plasma. There are two forms of these 'packages': low-density lipoproteins (LDLs) and high-density lipoproteins (HDLs). LDLs transport cholesterol to the body cells for use. HDLs carry excess cholesterol to the liver for breakdown. If too much cholesterol is eaten in meat, cheese and egg yolk, the liver is unable to get rid of the excess. This situation is made worse if too much fat is eaten, because the liver converts this to cholesterol.

This excess is taken up by cells lining the arteries. The fatty deposits trigger abnormal growth and production of fibrous materials by the cells, producing a condition known as atherosclerosis. Gradually the artery becomes more and more blocked by the growth of tissue until blood is unable to flow through the vessels. Heart attack may result from clogging of the arteries

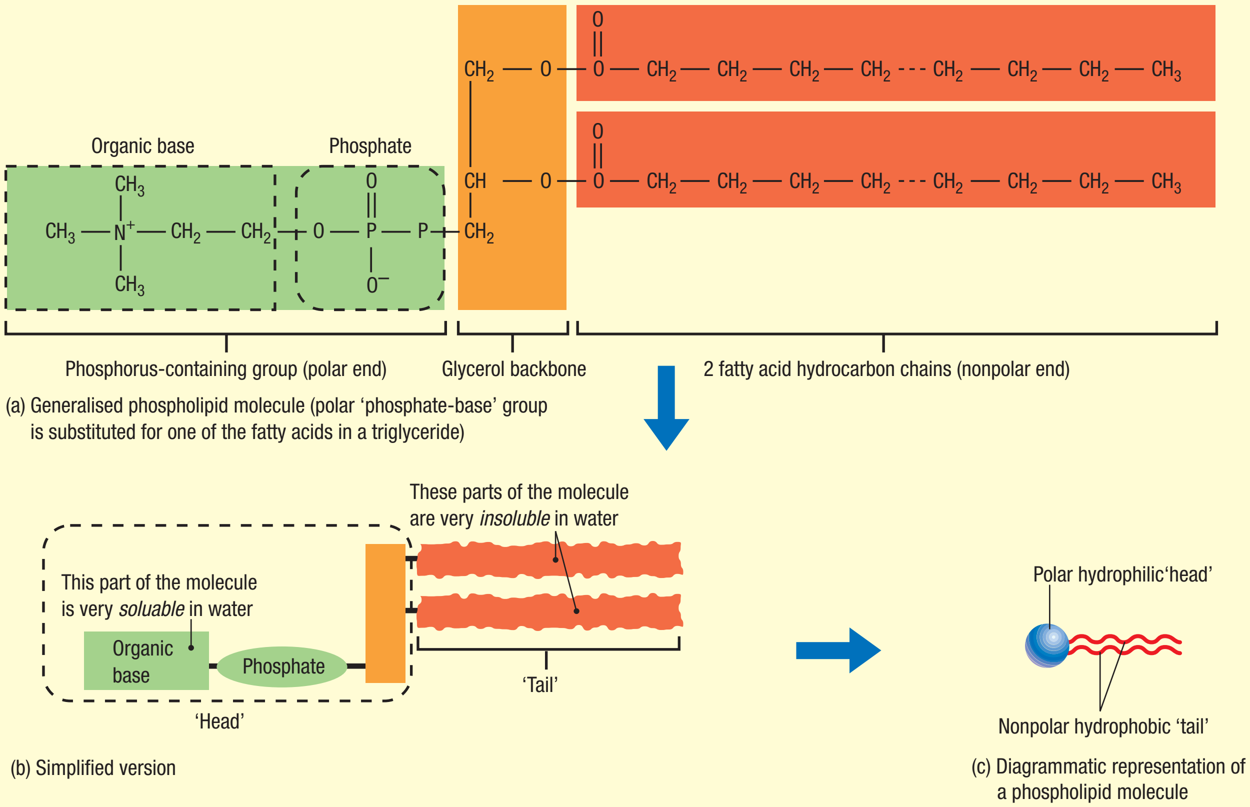


Figure 12.19 A phospholipid

which supply the heart muscles (coronary arteries). If arteries in the brain become blocked, a stroke may occur.

Heart disease may be hereditary. Normal liver cells have special receptors on their surface that take up LDLs, but in one form of heart disease these receptors are missing. The liver cells are unable to take up LDLs and so continuously produce and export cholesterol. People with this condition usually do not live past their early twenties. Other people seem to be protected because they produce large quantities of HDLs which rapidly transport excess cholesterol to the liver for breakdown. For the majority of people the risk of heart disease is related to level of exercise (which seems to increase HDLs), smoking cigarettes (which seems to decrease HDL levels) and diet.

SUMMARY

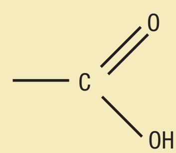
Lipids are water-insoluble carbon compounds which also contain hydrogen and oxygen, but not in a fixed ratio. The basic units are glycerol and fatty acids. They include fats, oils, waxes, phospholipids, glycolipids and steroids. They function as structural components of cell membranes, sources of energy transport and storage, insulators and chemical messengers.

Review questions

12.32 In what ways does a lipid differ from:
(a) a protein
(b) a carbohydrate?

12.33 Using a diagram, show how a triglyceride is formed. Explain why three water molecules are released in its formation.

12.34 After chemical analysis a substance was found to contain a carboxyl group:



This substance could be:
A. a carbohydrate or glycerol
B. an amino acid or fatty acid
C. a fatty acid or glycerol
D. a fatty acid, glycerol or amino acid.
Explain your answer.

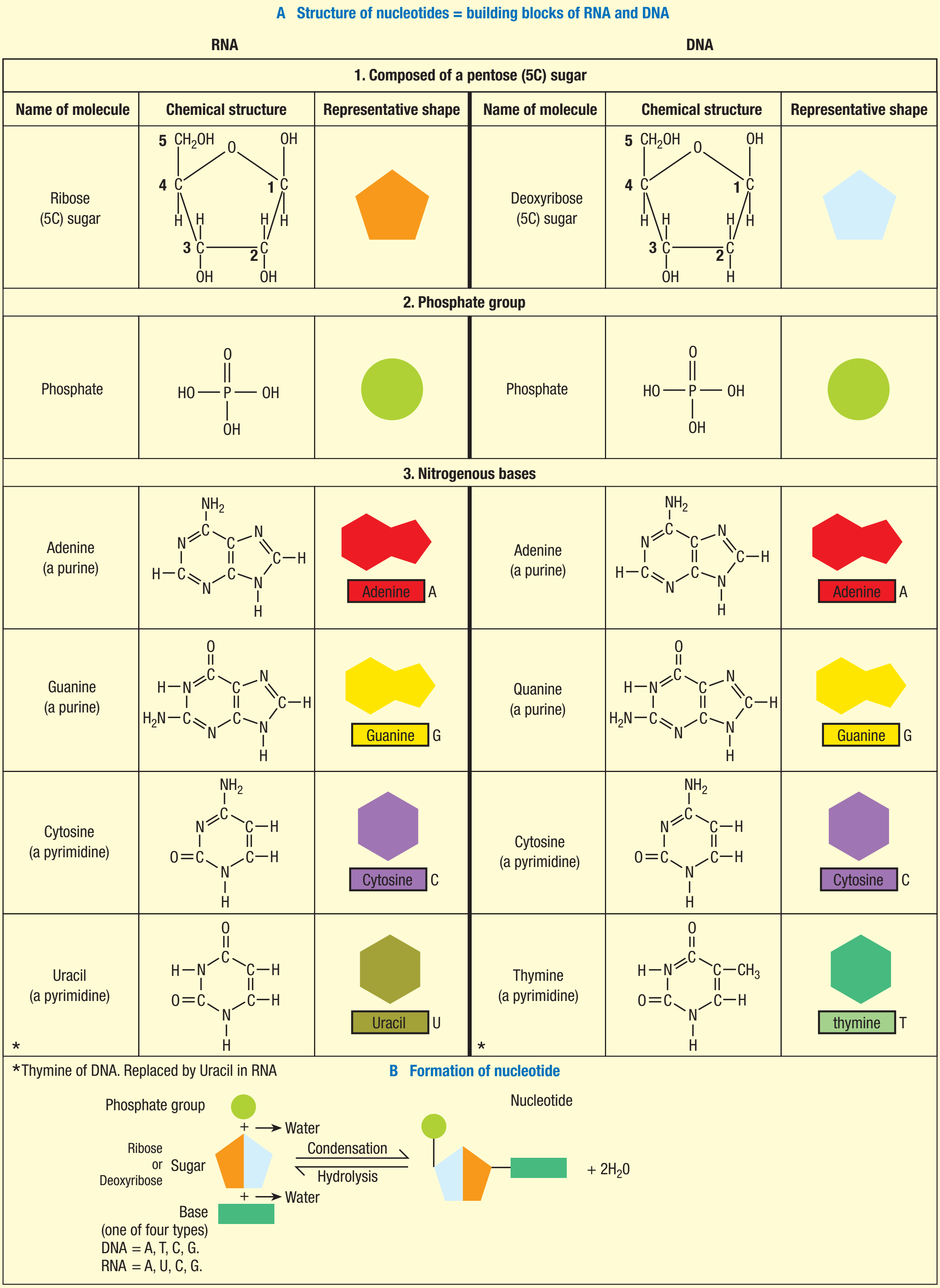
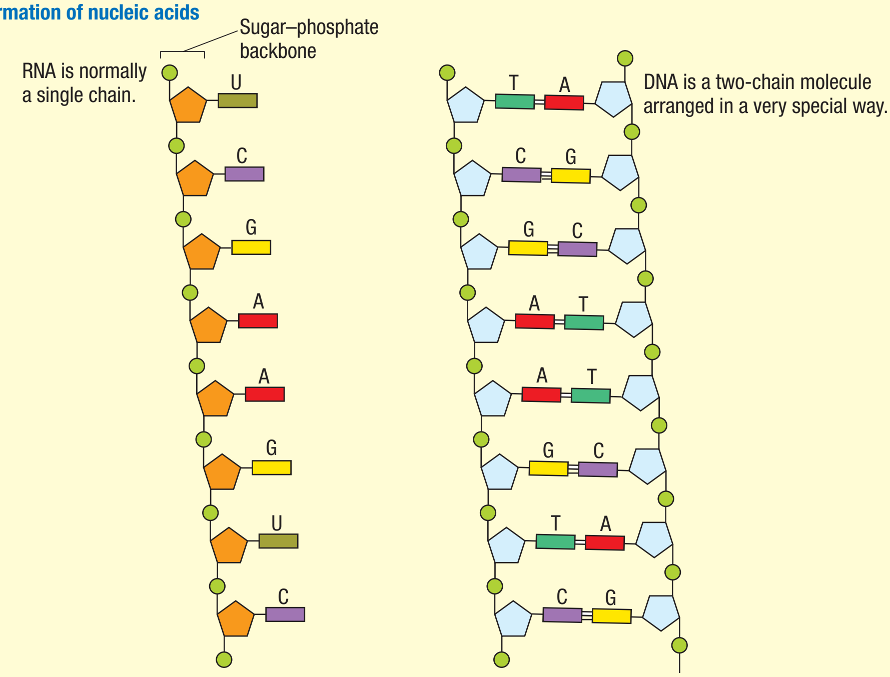
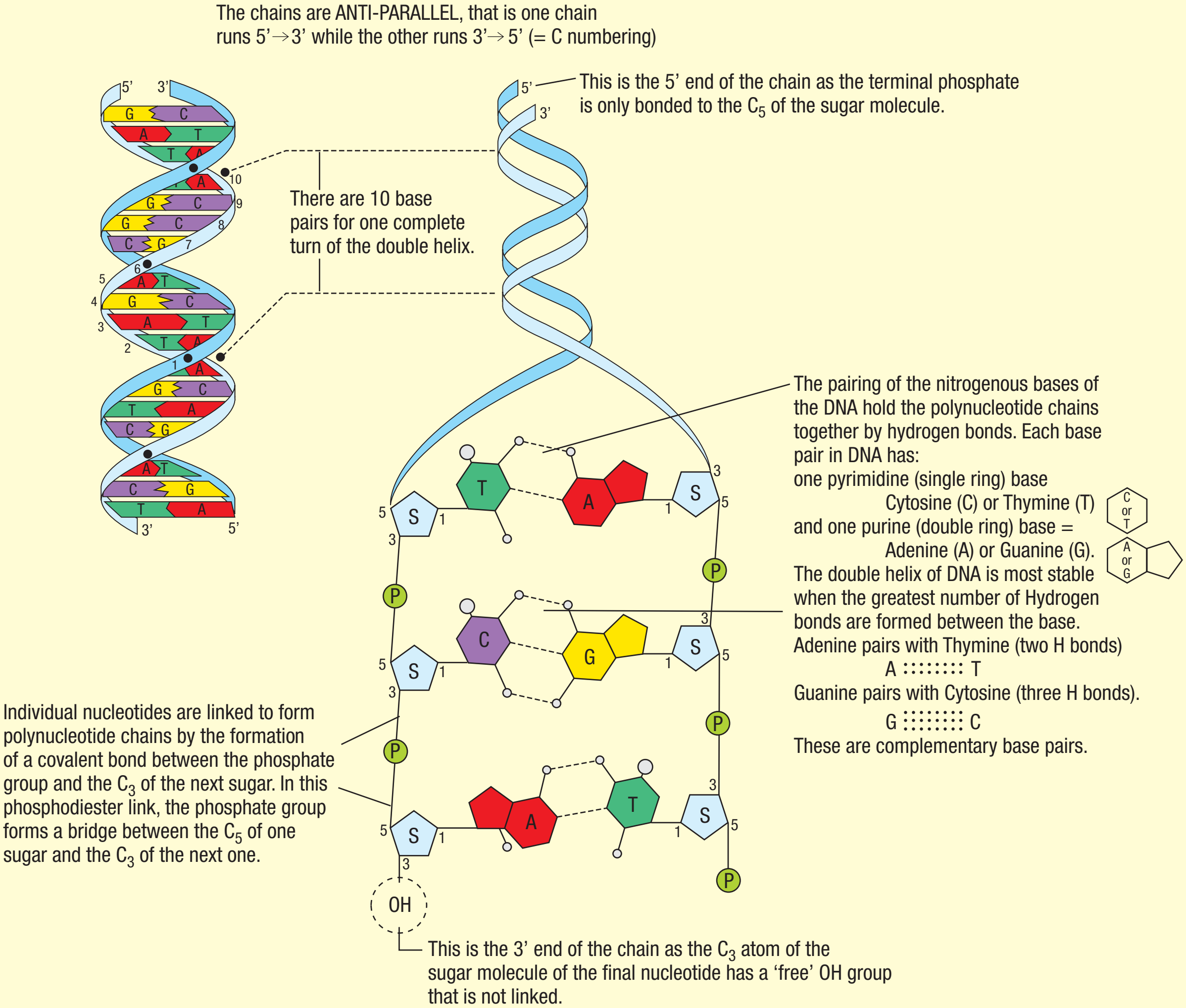


Figure 12.20 Bonding of nucleotides in the formation of nucleic acids

C Bonding of nucleotides in the formation of nucleic acids



D Structure of DNA



12.2.7 Nucleic acids

Nucleic acids are the macromolecules that make up the genetic material of all living organisms. There are two principal types of nucleic acids—**deoxyribonucleic acid** (**DNA**) and **ribonucleic acid** (**RNA**). The building blocks of nucleic acids are **nucleotides**, each of which consists of:

- a pentose sugar (5C) arranged in a ring
- an organic nitrogen base
- a phosphate.

The formation of a nucleotide involves bonding between the sugar and the base, and between the sugar and phosphate. These condensation reactions result in the removal of two water molecules. Two nucleotides join by condensation between the phosphate group of one and the sugar of the other nucleotide. Further condensation reactions result in chains, the sequences of the bases giving each chain its structural and functional properties.

DNA and RNA differ in several ways. The sugar in DNA is deoxyribose, whereas that of RNA is ribose. The RNA molecule is composed of a single chain of nucleotides, whereas that of DNA consists of two parallel chains held together by the pairing of bases between adjacent chains. This gives a ladder-like structure to the DNA molecule, which twists on its axis, forming a double helix.

There are five different types of bases found in nucleic acids. In DNA these bases are adenine, guanine, thymine and cytosine. In RNA the thymine is replaced by uracil. Each base has a particular type of structure and linking atoms. Adenine and guanine are similar in structure, and thymine, cytosine and uracil are similar. Because of their differing chemical structure, different bases form complementary pairs: they are able to link together by hydrogen bonds. Thus adenine and thymine are a complementary pair and guanine and cytosine are a complementary pair. It is thought that hydrogen bonds between these bases hold the two chains of the DNA molecule together, although this idea is currently being debated. Because only these combinations of bases can link, the two chains of the DNA molecule are always complementary chains.

Table 12.5 Comparison of DNA and RNA

Feature	DNA	RNA
Sugar	deoxyribose	ribose
Bases	adenine, thymine, guanine, cytosine	adenine, uracil, guanine, cytosine
Chains	double	single

A chromosome consists of a DNA strand and proteins. Each DNA strand is made up of huge numbers of paired nucleotides. Segments of these paired nucleotides are genes, each of which is the coded instruction for the production of a particular protein. The total amount of DNA in each cell represents the organism's genetic code. The DNA molecule is therefore responsible for transmission of the genetic code from one generation to the next and in controlling the actions of the cell through protein synthesis.

There are three major types of RNA—messenger (m), transfer (t) and ribosomal (r) RNA, all of which are involved in the translation of the genetic code into protein production by the cell.

SUMMARY

Nucleic acids are chains of nucleotides, each nucleotide being composed of a pentose sugar, a phosphate and a nitrogen base. There are five nitrogenous bases: adenine, guanine, thymine, cytosine and uracil.

DNA is a nucleic acid in the form of double helix. It stores hereditary information as a coded sequence of nucleotide bases. The sugar in each nucleotide is deoxyribose. Two complementary chains of each molecule are formed by bonding between adenine and thymine and between guanine and cytosine.

RNA is a single-chain nucleic acid. The base thymine is replaced by uracil and the sugar is ribose. RNA is responsible for the translation of the nucleotide sequence of DNA into the amino acid sequence of a protein.

? Review questions

12.35 Name the three components of a nucleotide.

12.36 List differences in structure between DNA and RNA.

12.37 What are the functions of DNA and RNA?

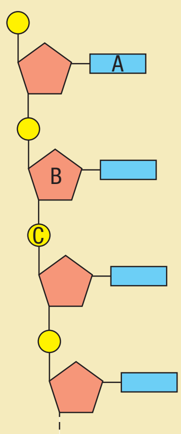
12.38 The diagram below shows part of a polynucleotide chain.

(a) Draw one nucleotide.

(b) What are the chemical groups labelled A, B and C?

(c) Which compound pairs with thymine in DNA?

(d) How are the bases of the two adjacent strands of the DNA held together?



12.3 Cellular energy

12.3.1 The laws of energy

A cell requires a constant supply of energy to grow, to reproduce, and to stay alive (maintenance). **Energy** is the ability to do work or to cause a change. There are different forms of energy, each given a different name (e.g. electrical, chemical, mechanical), but all of these can be divided into two main categories: kinetic energy (energy of motion) and potential energy (stored energy).

Energy cannot be created or destroyed (**first law of thermodynamics**) but different forms of energy can be changed into one another.

It is a basic principle of physics that all systems have a natural tendency towards increasing disorder. The more orderly an arrangement of matter is, the greater is the amount of energy required to maintain its organisation and to counteract the tendency towards disorder. Just as the structure of a house is an unnatural organisation (i.e. it is most unlikely to occur spontaneously), so too is the living cell an inherently unstable and improbable organisation. Only by constant use of energy can it maintain itself.

The molecules of many of the compounds of living cells are highly complex and are composed of many thousands of atoms bonded together. Many of these bonds, particularly C–H, are relatively rich in chemical bond energy. Thus a living organism is a storehouse of potential chemical energy which can be used, when necessary, to do work. But as this stored energy is converted to other forms, less and less remains in reserve. A source of usable energy outside the organism must be available to replenish its supply of chemical bond energy. For many organisms (heterotrophs), that outside energy source is other organisms; for other organisms (autotrophs) the source may be inorganic molecules (chemosynthesis) or sunlight (photosynthesis).

According to the first law of thermodynamics, all these energy conversions are accomplished without reduction of the total amount of energy. It might seem, therefore, that energy can be passed continuously from organism to organism and that no source of energy outside living things would be required. However, energy is constantly passed from organisms to non-living matter (e.g. heat loss from the body to the surrounding air), and is lost to the life system. The molecules of substances that leave the body retain some energy. The **second law of thermodynamics** states that every energy transformation results in a reduction of the usable or free energy of the system, and this results in the general tendency towards greater disorder.

12.3.2 Metabolism

Chemical reactions occurring in cells constitute metabolism. Metabolic processes proceed in small steps, the sum of which is called a metabolic

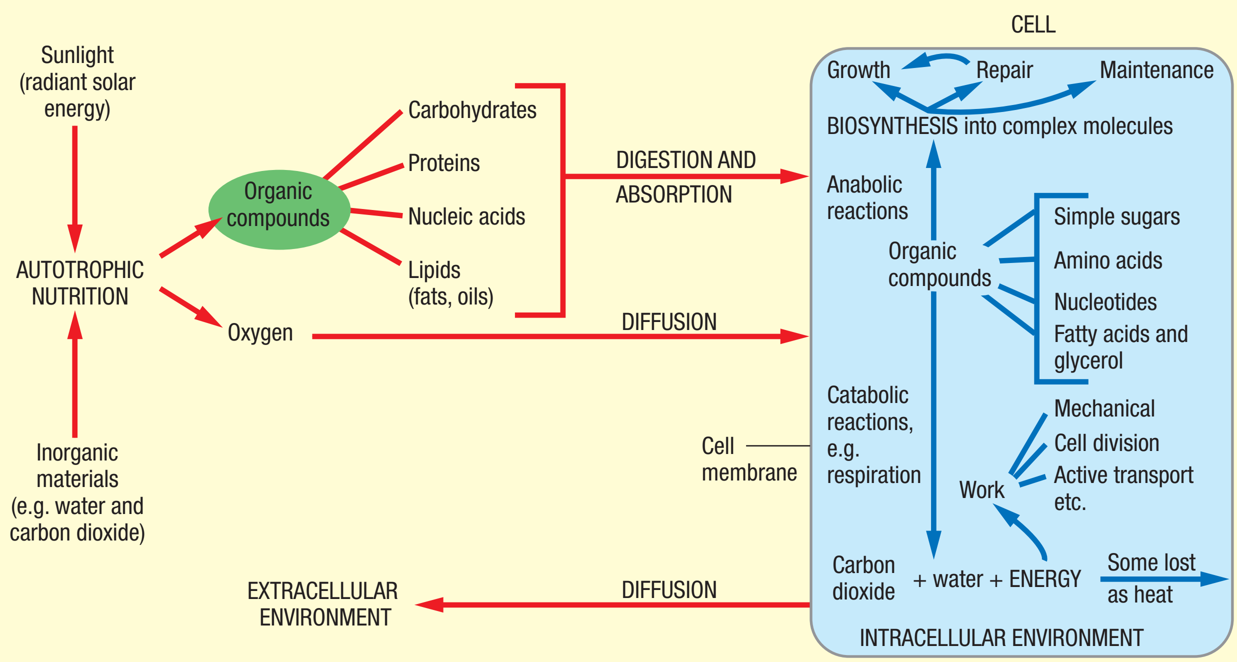


Figure 12.21 Energy transfer between the environment and a heterotrophic cell

pathway. These reactions may be synthetic (**anabolism**) or breakdown (**catabolism**). Anabolic reactions tend to absorb energy (**endergonic**), whereas catabolism tends to release energy (**exergonic**). All the catabolic and anabolic reactions occurring at any time in a cell constitute its metabolism. The energy released by catabolic reactions is required for driving anabolic reactions, for work (e.g. muscular contractions), and for maintenance purposes.

catabolism + anabolism = metabolism

simple molecules + ENERGY	ANABOLISM metabolic pathway ⇌ CATABOLISM metabolic pathway	large complex organic molecules

One of the most important metabolic pathways yielding energy is the breakdown of sugar. This is an oxidation process. As sugar is broken down, energy is liberated as carbon dioxide and water are formed. The process can be shown in simplified form by the following formula:

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

The sugar molecule contains potential energy, which is freed only when the molecule is split and new molecules formed.

Mixing sugar and oxygen does not automatically ensure that the oxidation process will proceed. The reaction must be activated, and for this to occur **activation energy** is required. For example, wood does not burn spontaneously. In order to release the great amount of energy stored in wood, it must first be heated. Whether any chemical reaction gives off energy or absorbs it, some energy must initially be added to start the reaction.

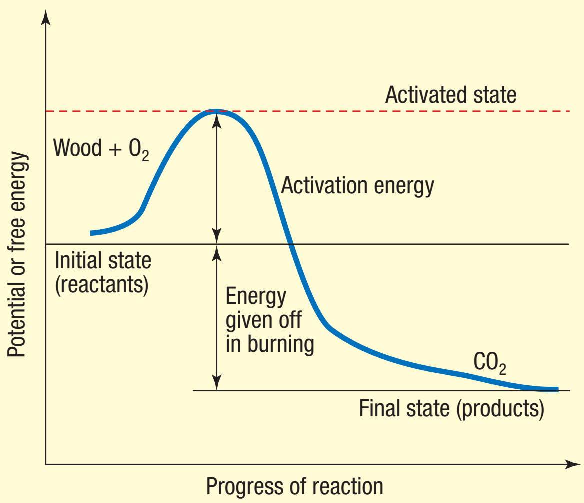


Figure 12.22 Energy relationships in a chemical reaction (e.g. burning wood)

The molecules of the reactants in any chemical reaction are in a state of continual random motion. Only when they collide and come into contact can they react. Any factor that increases the frequency of collision will increase the speed of the reaction. In general the two factors are:

- concentration of the substrate molecules
- temperature.

The more concentrated the molecules (i.e. the more densely they are packed), the more likely they are to collide and react. Raising the temperature speeds up the random motion of the molecules, thereby increasing the probability of their colliding.

Catalysts also change the rate of a reaction. The reacting molecules (the **substrate**) are absorbed onto the surface of the catalyst where, having been brought into close proximity, they react. The product leaves the surface of the catalyst, which is quite unchanged by the process and may be used again.

Many biological reactions can be made to occur more quickly by heating. Cells, however, cannot tolerate too much heat, since many biological compounds decompose at high temperatures. Catalysts, therefore, are important in metabolism. In this case the catalysts are always organic and operate in a slightly different way from the surface catalysts described. The catalysts found in living systems are called **enzymes**.

SUMMARY

Cellular activities require energy. Energy is the ability to do work or cause a change. It may be either potential (stored) or kinetic energy (energy of motion). The first law of thermodynamics states that energy cannot be created or destroyed but can be converted from one form to another. The second law of thermodynamics states that all systems have a natural tendency towards increasing disorder. In all energy transformations some energy is converted to heat energy and lost from the system.

Living cells draw primarily upon chemical energy stored in chemical bonds. Since energy is being constantly lost from the living system as heat, cells need a constant replenishment of energy. Heterotrophs gain their outside source of energy from eating other living organisms. Autotrophs utilise either sunlight (photosynthesis) or inorganic molecules (chemosynthesis) as their outside energy source.

Metabolism is the general term to describe chemical reactions in cells. Metabolic processes proceed in small steps, the sum of which is called a metabolic pathway. Synthetic pathways are termed anabolism and tend to absorb energy (endergonic).

Breakdown reactions are termed catabolism and tend to release energy (exergonic).

For most reactions to proceed, some energy input is required. This initiating energy is called activation energy. The rate of chemical reaction can be increased by:

- increase in the concentration of the substrate molecules
- increase in the temperature (but not above that at which proteins become denatured)
- the presence of a catalyst.

? Review questions

12.39 Discuss the significance of the first and second laws of thermodynamics in cell biology.

12.40 Discuss the relationship between activation energy and chemical reactions.

12.41 What factors determine whether or not a particular chemical reaction of a cell will take place?

12.42 State two factors other than temperature which influence the rate of enzyme activity.

12.4 Enzymes

12.4.1 Enzyme action

Enzymes are globular proteins which lower the activation energy required for a chemical reaction to take place. They speed up the actual rate of the reaction without altering, to any great extent, the temperature at which it occurs. The uncatalysed reaction is:

$$A + B \longrightarrow AB$$

$$\text{reactant} + \text{reactant} \longrightarrow \text{product}$$

The addition of an enzyme provides an alternative set of reactions which produce the same overall change but at a lower net activation energy:

$$A + X \longrightarrow AX$$

$$AX + B \longrightarrow AB + X$$

(where X = enzyme, A = substrate,
AX is enzyme–substrate complex,
B is reactant and AB is product)

substrate + enzyme → enzyme–substrate complex → products + enzyme
+ reactants

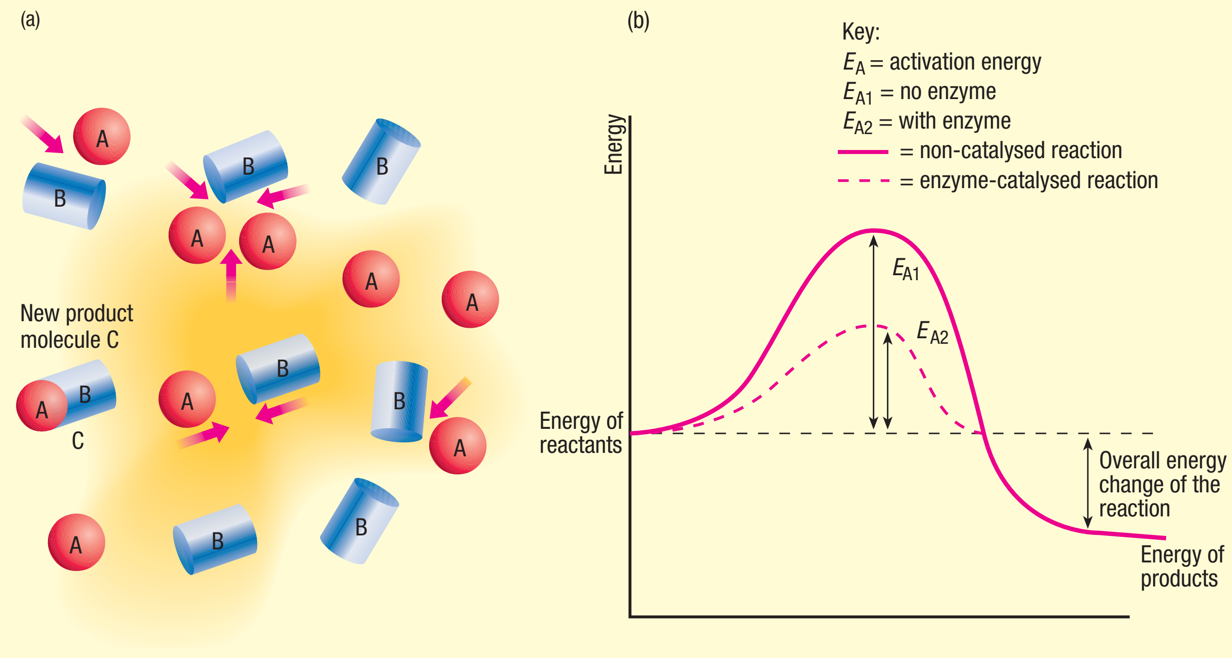


Figure 12.23 Enzymes as catalysts: (a) Molecules in constant motion, colliding with each other sometimes and occasionally reacting; only when molecules have enough energy will they collide and react. (b) Profile diagram shows that the basis of the enzyme reaction is the lowering of the activation energy.

Various hypotheses have been proposed to explain how enzymes lower activation energy for a reaction. Different reactions may utilise one or more of the following methods:

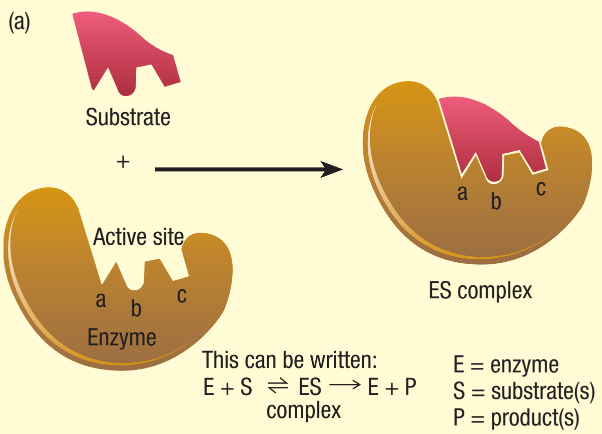
- The enzyme, when bound to the substrate, may change shape. This may place stresses on some substrate bonds, making them more easily broken.
- Substrates may form weak bonds with their specific enzymes which result in redistribution of electrons within the substrate molecule, thus making it more reactive.
- The enzyme–substrate complex may orient the substrate molecules in such a way that chemical reactions are maximised.

The overall action of enzymes can be explained by either the '**lock-and-key**' **hypothesis** or the **induced fit hypothesis**. The lock-and-key hypothesis suggests that an enzyme's function depends on its shape. Each enzyme is made up of long chains of amino acids that are folded into uniquely shaped 'globs'. An enzyme attaches to its substrate much as a lock and key fit together. The shape of the enzyme is complementary to the shape of the substrate. Because of this, the substrate molecules fit almost perfectly into the enzyme. The portion of the enzyme in contact with the substrate (**active site**) is very small in comparison with the total size of the enzyme molecule.

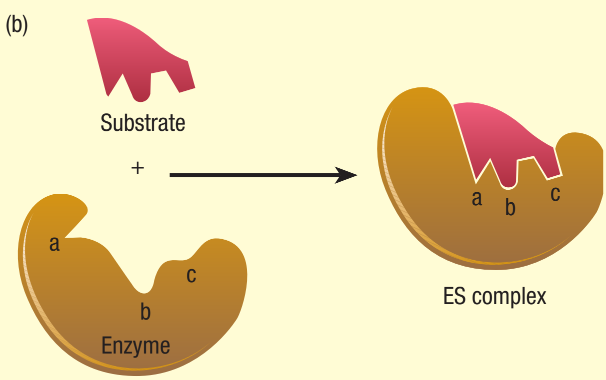
When an enzyme–substrate complex is formed it is 'activated' into forming the products of the reaction. Once formed, the product(s) no longer fit into the active site and escape into the surrounding medium, leaving the active site free to receive further substrate molecules.

It has been found that the substrate does not always fit precisely into the active site of the enzyme. Somehow the shapes of both the enzyme and substrate are modified so that a better fit between the two is induced. This process distorts the substrate so that stresses weaken critical bonds to form a transitional substrate state. In this state strong bonds can form between the substrate and the enzyme that lower the activation energy required for a chemical reaction.

Each enzyme controls only one (or one type of) reaction. The active site of any particular enzyme can accommodate only a certain shape of substrate molecule. Thus many different enzymes may be required in a multi-step reaction (e.g. respiration or photosynthesis; synthesis or hydrolysis of organic molecules).



(a) The 'lock and key' model for enzyme action



(b) The 'induced fit' model for enzyme action; the shape of the enzyme's active site is modified to accommodate the substrate

Figure 12.24 Comparison of the (a) 'lock and key' and (b) 'induced fit' hypotheses of enzyme action

Case study 12.4: A metabolic pathway—phenylalanine

The catabolism or anabolism of chemical compounds in the cell usually involves several separate reactions, each mediated by a specific enzyme. For example, in a two-step pathway enzyme A would mediate the formation of an intermediate substance from a precursor chemical. This intermediate substance would then be converted to the final substance in the presence of enzyme B. If any enzyme in a metabolic pathway is absent or faulty, the correct sequence of chemical reactions cannot occur. Different products form and some of these may be dangerous to continued existence.

When excess proteins are taken into the body, they are not stored but broken down in a series of catabolic steps. In the normal course of events the protein undergoes a series of hydrolysis reactions to release the component amino acids, one of which is phenylalanine. The liver produces the enzyme phenylalanine hydrogenase that brings about the conversion of phenylalanine to another amino acid called tyrosine. If this enzyme is

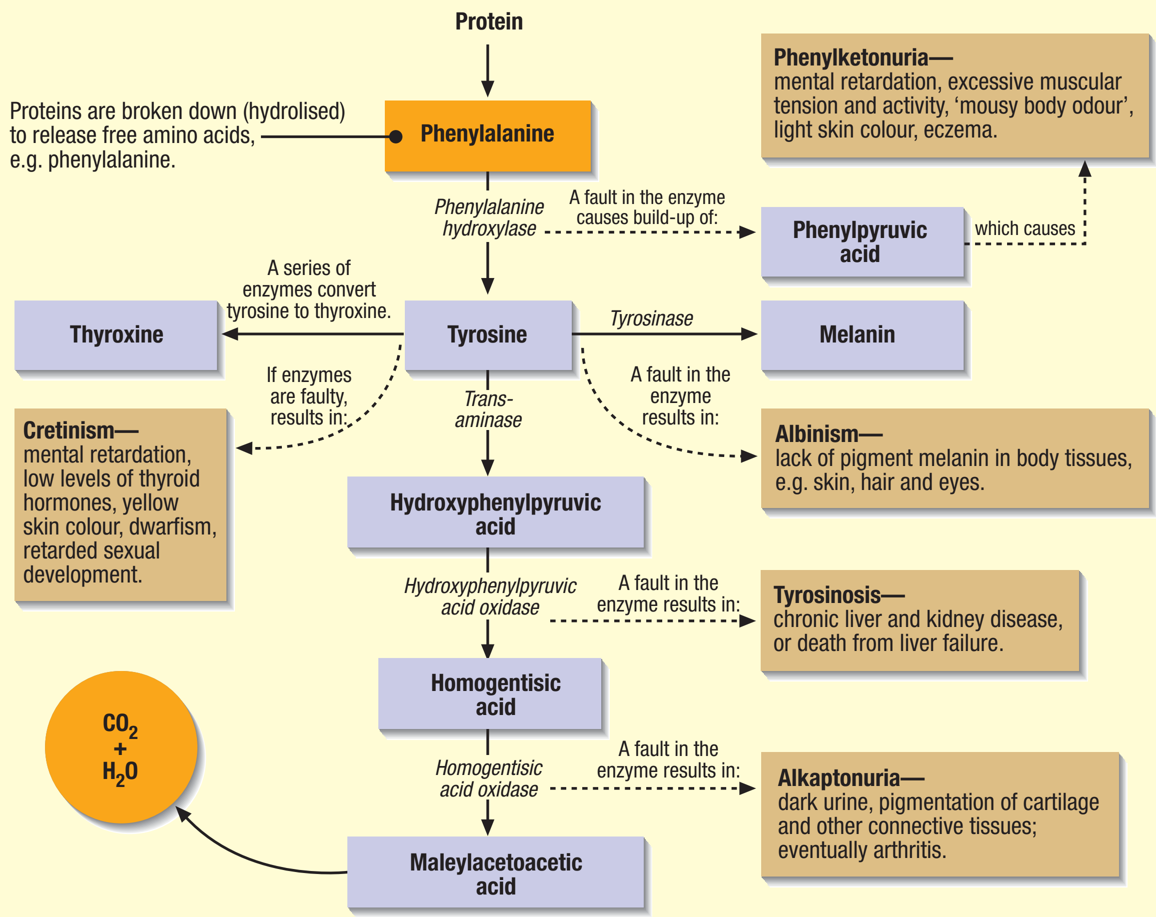


Figure 12.25 The metabolism of phenylalanine

faulty, phenylpyruvic acid is formed instead of tyrosine. A disease called phenylketonuria—with associated mental retardation, musky body odour and excessive muscular activity—results.

Tyrosine can be used in two other series of reactions—one that results in the formation of the growth hormone thyroxin, the other producing the skin pigment melanin. Each set of reactions has its own series of enzymes. If any enzyme is lacking in the first set, then thyroxine cannot be formed and, if this occurs in a developing individual, the condition known as cretinism occurs. The individual does not grow in stature and does not properly develop nervous system and reproductive system functions. Similarly, deficient enzymes in the melanin-producing pathways results in albinism, the complete lack of body pigmentation. Excess tyrosine is broken down in further reactions and the eventual products in the complete metabolic pathway are carbon dioxide and water.

Other enzymes in this metabolic pathway may also be faulty. Figure 12.25 illustrates the catabolic pathway of phelalanine and the possible inappropriate end products that result from enzyme failure at various points along the pathway.

12.4.2 Properties of enzymes

Enzymes have the following properties:

- All are globular proteins.
- They increase the rate of reaction without being used up themselves.
- Their presence does not alter the nature of the end-products of the reaction.
- A small amount of enzyme catalyses a large quantity of substrate.
- They are specific in action and generally catalyse one specific reaction or part of a reaction.
- They catalyse a reaction in either direction according to the prevailing conditions (e.g. substrate concentration).
- They reduce the activation energy required for a chemical reaction to take place.
- They are heat-sensitive, working best at an optimum temperature (30°C plants; 37°C human body). At a certain temperature above the optimum (e.g. 45°C in humans), enzymes are destroyed by denaturation and coagulation which involves a change in shape of the enzyme protein. Although the action of enzymes may be

inhibited at low temperatures (e.g. freezing), their protein structure is not altered.

- They are pH sensitive; that is, they will work only within a narrow range of the optimum pH. Each enzyme has a specific optimum pH.
- As the concentration of enzyme increases, the rate of enzyme action also increases. The rate of reaction is then limited by other factors such as number of substrate particles, pH and temperature.
- As the concentration of substrate increases, the rate of enzyme action increases to a maximum limiting value and the reverse is true.
- Enzymes are inhibited by poisons, which either compete with the normal substrate molecules for the active site (**competitive inhibition**: e.g. sulfonamide drugs), or block the active site permanently (**non-competitive inhibition**: e.g. arsenic, DDT, lead, cyanide and organophosphates).

12.4.3 Coenzymes and cofactors

Cofactors are non-protein components required by some enzymes for their efficient functioning. There are three types of cofactor: inorganic ions, prosthetic groups and coenzymes.

Inorganic ions

The activity of some enzymes is increased by the presence of inorganic ions. For example, the activity of amylase in saliva is increased if chloride ions are present. The ions may bind the enzyme and substrate together, or may serve as the catalytic site of the enzyme itself.

Prosthetic groups

These are non-protein organic molecules tightly bound to the active site. For example, the enzyme cytochrome oxidase, which is important in respiration, contains a haem (iron) prosthetic group. It takes up chemical groups from the protein part of the enzyme.

Coenzymes

These are non-protein organic groups loosely associated with the enzyme, which function as carriers for transferring chemical groups or atoms from one enzyme to another.

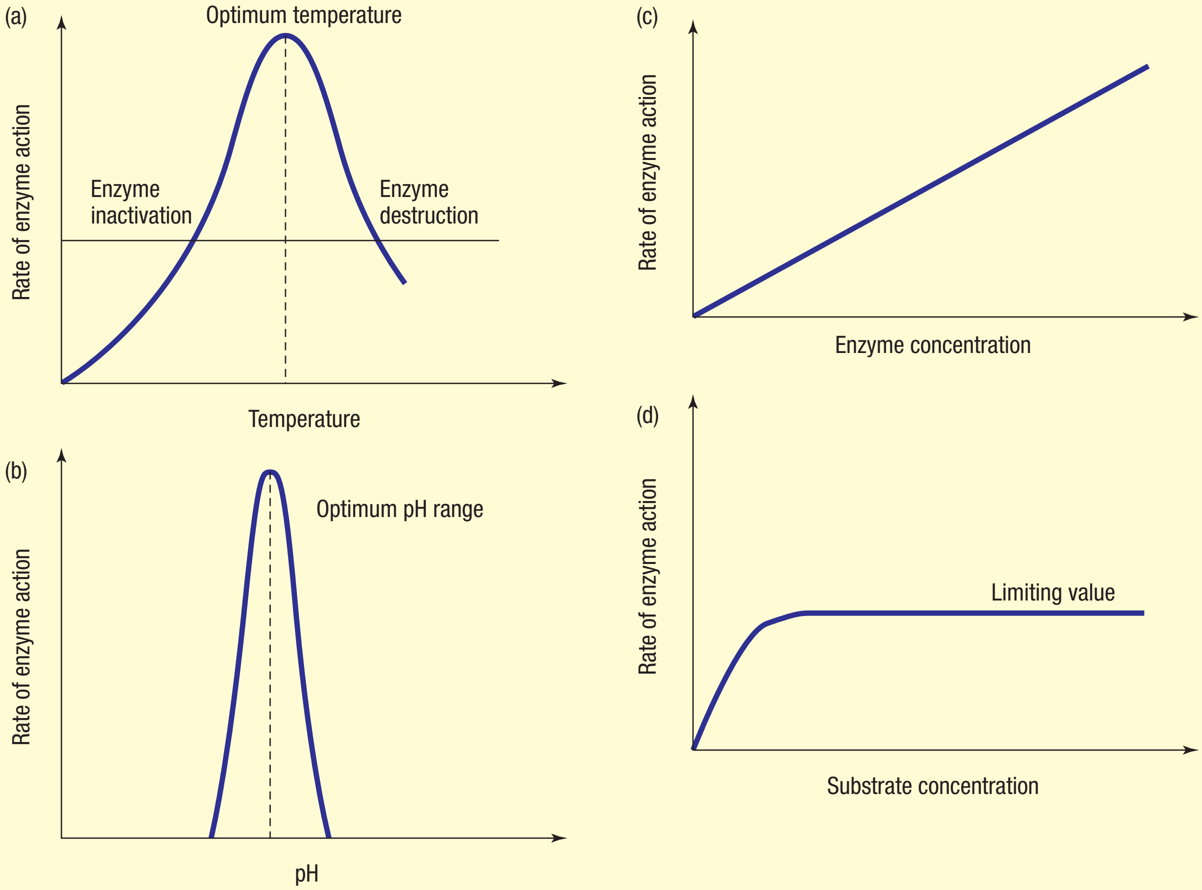


Figure 12.26 Effects on enzyme activity of: (a) temperature; (b) pH; (c) enzyme concentration; (d) substrate concentration

12.4.4 Classification of enzymes

Enzymes can be classified into two main groups: **intracellular** and **extracellular**. Intracellular enzymes occur within the cell where they control metabolism. Extracellular enzymes are produced by cells but achieve their effects outside the cell.

Normally an enzyme is named by adding the suffix *-ase* to the name of the substrate on which it acts. Thus maltase acts on maltose; lipase acts on lipids.

Case study 12.5: Biological washing powders

Many modern washing powders have a biological prefix to their trade name: for example 'BioAid' and 'BioZest'. They contain enzymes which aid in the removal of particular stains from clothing. Proteases remove blood, grass, sweat and other protein stains. Lipases remove fats and oils, and amylases remove residues of starches. Most of these enzymes are produced by genetically engineered bacteria in fermenters. The enzymes must be able to withstand the other conditions associated with detergents and washing. They have therefore been engineered to operate at high pH levels, in the presence of phosphates and other detergent ingredients, and at temperatures up to 60°C. In order to reduce the allergic responses that enzymes may create, industrial chemists have developed a method of coating the enzymes. The enzymes are then mixed with other agents to produce the detergent.

SUMMARY

Enzymes are organic catalysts that reduce the activation energy required for chemical reactions to take place. Each enzyme has a specific active site, the chemical nature of which allows joining with a specific substrate molecule. The enzyme–substrate complex is 'activated' into forming the products of the reaction. Once formed, the products no longer 'fit' the active site of the enzyme and are released into the surrounding medium, leaving the active site free to receive further substrate molecules. Both the lock-and-key and induced-fit hypothesis have been proposed to explain this process. Thus an enzyme controls only one, or one type of, chemical reaction. It increases the rate of reaction without being used up in the process. Different reactions involve different enzymes.

Enzymes are:

- globular proteins
- required in only small amounts
- specific for a particular reaction(s)
- capable of decreasing the activation energy required for the reaction
- heat sensitive
- pH sensitive
- inhibited by poisons.

Cofactors are components required by enzymes for their efficient functioning. Coenzymes are organic cofactors which function as carrier molecules, transferring chemical matter (electrons, atoms, molecules) from one enzyme to another.

Enzymes may be either intracellular or extracellular. They are named according to the type of reaction they catalyse.

? Review questions

12.43 (a) What are the characteristics of an enzyme?
(b) How is an enzyme believed to exert its effect?

12.44 Distinguish between competitive and non-competitive inhibition.

Questions 45–48 refer to the following equation:

$$\text{amino acid} + \text{amino acid} \underset{\text{enzyme B}}{\overset{\text{enzyme A}}{\rightleftharpoons}} \text{dipeptide} + \text{water}$$

12.45 During dehydration synthesis (condensation), which molecules are considered substrates?

12.46 During hydrolysis, which molecules are considered products?

12.47 Why are the arrows shown pointing in opposite directions?

12.48 According to the lock-and-key hypothesis, what is the relationship between substrate, enzyme and product in this reaction? Compare and contrast this process with the induced-fit hypothesis.

12.49 Each of the thousands of different types of chemical reaction that occur in cells requires a different enzyme. Explain why this is so.

12.50 Different enzymes have active sites which:

A. differ in composition but not shape.
B. differ in composition and shape.
C. differ in shape but not composition.
D. differ in neither composition nor shape.

12.5 Biological energy transformations

The energy released at one site of a cell is often required at another site. In biological systems special molecules are used to transport the energy from place to place, or simply to store it in a readily accessible form. **Adenosine triphosphate** (**ATP**) is the major molecule involved in this process. It is found in all living things.

The ATP molecule is composed of an adenosine unit (a complex of adenine and ribose, a 5-carbon sugar) combined with three phosphate groups arranged in sequence.

$$\text{adenosine} - \textcircled{P} \sim \textcircled{P} \sim \textcircled{P}$$

The bonds by which the second and third phosphate groups are attached are not the usual type of chemical bond, and are usually represented by the symbol ~. This bond is very weak and unstable and can be readily broken. The released phosphate can react with another molecule by the formation of more stable bonds, releasing large amounts of energy. Addition of phosphate is called **phosphorylation**.

It is often only the terminal high-energy phosphate bond that is involved in these energy conversions. The reaction, in which this bond is broken and the terminal phosphate group removed, leaves a compound called adenosine diphosphate or ADP, consisting of adenosine plus only two phosphate groups. The overall reaction can be generalised as:

$$\text{ATP} \xrightarrow{\text{enzyme}} \text{ADP} + \textcircled{\sim}\text{P} + \text{energy}$$

In a similar manner, a phosphate group from ADP can be removed, leaving behind adenosine monophosphate (AMP). (Note that AMP is one of the nucleotides of which RNA is composed.) New ATP can be synthesised from ADP and phosphate if adequate energy is available to force a third phosphate group onto the ADP.

It is the phosphate-bound energy of ATP that is used to do cellular work. Metabolism, therefore, involves enzymes and the transfer of energy. Figure 12.28 summarises these reactions.

SUMMARY

Adenosine triphosphate (ATP) is the major molecule in living organisms involved in storing energy in a readily available form, and transferring it from one site to another.

ATP consists of the nitrogen base adenine, the ribose sugar and three phosphate groups, arranged in sequence. The bonds attaching the second and third phosphate groups can easily be broken to release large amounts of energy when the phosphates form more stable bonds with other molecules. New ATP is formed from ADP and phosphate if sufficient energy is available.

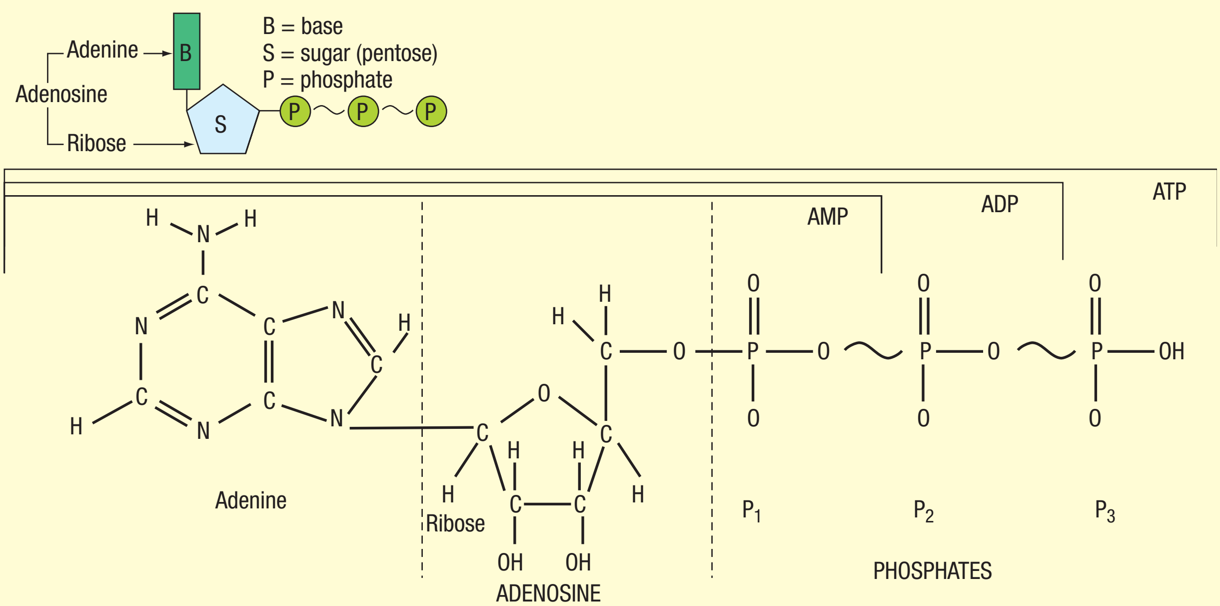


Figure 12.27 The ATP molecule

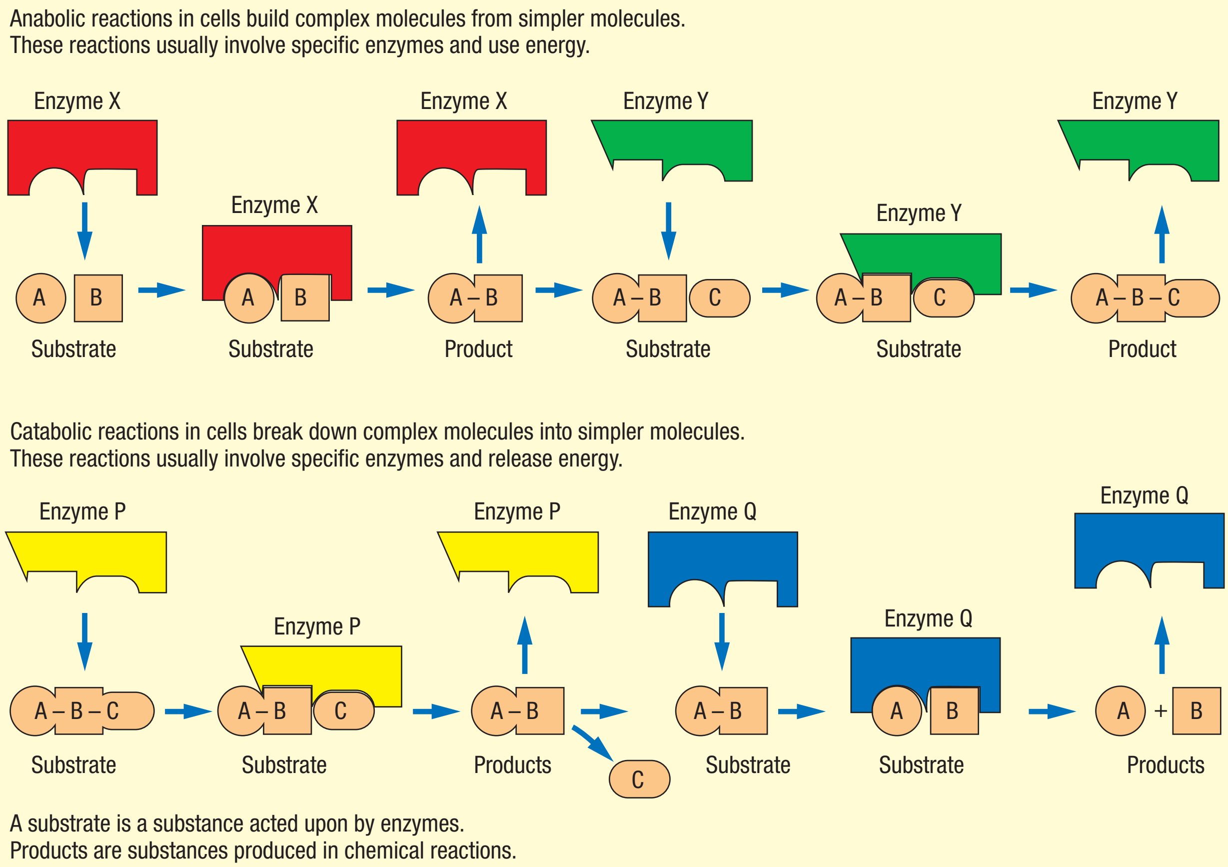


Figure 12.28 The relationships between metabolism, enzymes and energy. These represent very simple metabolic pathways.

Review questions

12.51 Discuss the features of the ATP molecule which are responsible for its function as an energy carrier in biological systems.

12.52 Distinguish between metabolic reaction and metabolic pathway. Suggest a reason for the occurrence of metabolic pathways.

EXTENDING YOUR IDEAS

1. UB Amoeboid motion requires the conversion of the cytoplasm from the sol form to a gel at the leading edge of the pseudopodium, and from gel to sol at the trailing edge of the cell. As sol converts to gel it contracts and as gel converts to sol, it expands in volume. From your knowledge of mixtures, suggest the possible mechanism involved in these conversions, and the reason for the contraction and expansion of the cytoplasm which results in movement.

2. UB Many organisms have evolved sensitive mechanisms for detecting sugars. Human sensors are on the tongue. Those for the housefly (which are about 10 million times more sensitive than the human sensors) are in the feet. When a housefly lands on droplets of sugar solution, its tubular mouthparts are automatically extended and the fly begins to feed.
   (a) Suggest reasons why the ability to detect sugars is more sensitive than detection of other organic chemicals in many animals.
   (b) Develop a hypothesis to explain the placement of sugar-sensing organs in the housefly and the human. Justify your hypothesis.

Questions 3–5 refer to the following:

Scientists studied an enzyme called enzymase. They tested the amount of product formed at different temperatures and pH levels, and their results are shown in Figure 12.29. Refer to these graphs in answering questions 3–5.

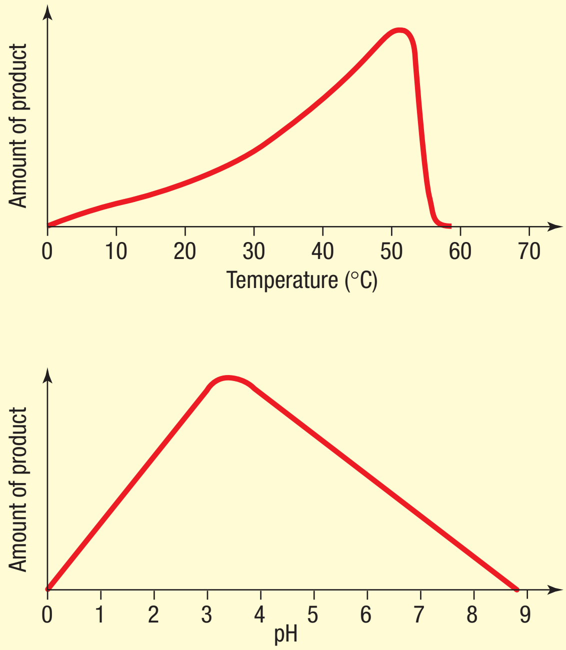


Figure 12.29

3. The enzyme functions best at which of the following temperature ranges (each given in °C)? **IB**
   A. 10–20
   B. 20–30
   C. 30–40
   D. 40–50

4. The enzyme functions best when the environment is: **IB**
   A. acidic.
   B. basic.
   C. neutral.

5. The enzyme probably does not function at 70°C because: **UB**
   A. the protein in the enzyme changes shape at that temperature.
   B. there is too little substrate at that temperature.
   C. the amount of product increases at a higher temperature.
   D. the pH is not favourable.

6. Compare and contrast carbohydrates from a structural and functional point of view. **UB**

7. Hair is composed of the protein keratin, which has a high percentage of the amino acid cysteine. Bonds can form between these amino acids. If there are few bonds, the hair is straight. If there are many bonds, the hair is curly. When hair is permed, it is first treated to break the bonds. This makes the hair more flexible so that it can be set into the desired shape with rollers. The hair is then treated to form new bonds which will hold that shape. **UB**
   (a) Explain why 'perms' must be renewed to maintain the desired hair characteristics.
   (b) Suggest how curly hair could be straightened.

8. The formula of a carbohydrate is $C_{30}H_{52}O_{26}$. How many monosaccharides are in this molecule? Explain your answer. **UB**

13 Cell structure

The basic unit of structure and function in living organisms is the cell. With the development of microscopes in the nineteenth century, the structure of living matter was better understood. This resulted in the formulation of the **cell theory**, which states that:

- all living matter is composed of cells and cell products
- all cells arise from pre-existing ones.

The cell is a self-perpetuating chemical system. In order to maintain its chemical integrity it must be physically separated from the environment and yet capable of exchanging material with it. The **cell membrane** forms this boundary. The efficiency of exchange decreases with an increase in size of the cell (the surface area:volume ratio decreases), so there is an upper limit to how large a cell can grow. Most cells, therefore, can be seen only when viewed with a microscope. The shape of the cell is generally spherical. Modification of some cells for particular functions can result in different cell shapes.

The living contents of the cell, and its membrane, are called **protoplasm**. Division of labour occurs within the protoplasm of eukaryotic cells, with minute subcellular structures having particular functions. These structures are called **organelles**. The largest organelle is the **nucleus** which is enclosed by a membrane and contains, among other chemicals, DNA and RNA. The protoplasm included in the nucleus is called the **nucleoplasm**. The rest of the protoplasm contained within the cell membrane is called the **cytoplasm**.

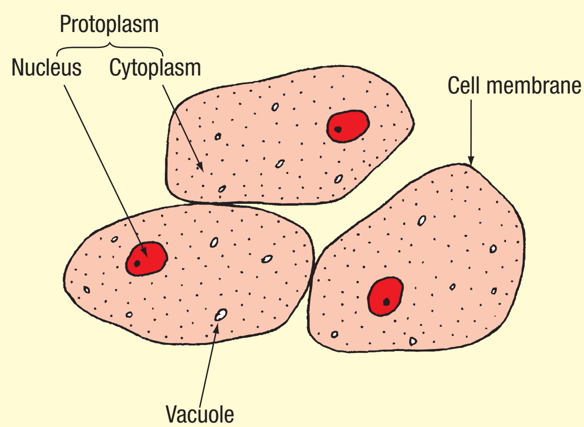


Figure 13.1 Generalised animal cells as seen through the light microscope

The cytoplasm consists of an aqueous mixture of chemicals in which are suspended a variety of organelles and other inclusions such as insoluble waste or storage products. Due to the very small size of many organelles, it was not until after the development of the electron microscope that scientists were able to determine their structure. The electron microscope is able to magnify objects up to about 500 000 times compared with the 2000 times of the light microscope.

Plant and animal cells are basically similar in structure, although plant cells have a **cell wall** surrounding the entire cell and some specialised organelles such as chloroplasts, and a large central vacuole.

13.1 The cell membrane

13.1.1 Functions of the cell membrane

The cell membrane is a selectively (or differentially) permeable barrier which controls the movement of substances into and out of the cell. Some substances, because of their very small size, can diffuse through very easily (e.g. water); others (e.g. large protein molecules) are prevented from moving through the membrane.

The cell membrane:

- helps in the active transport of materials across it
- provides a certain degree of mechanical support to the cell
- helps the cell maintain its shape
- acts as a receptor for certain extracellular materials (e.g. hormones) and thus maintains the specificity of the particular cell type.

13.1.2 Chemical structure of the cell membrane

The cell membrane is very thin—about 7.5 nm in width (1 nm = 10^{-9} m). The basic structure of the membrane is a bilipid layer; that is, it consists of two thin sheets of polar phospholipids. A polar lipid has a head region that is hydrophilic (water-loving) and a tail region that is hydrophobic (water-hating).

The phospholipid layer has to be double because it is surrounded on either side by a water-based mixture (the extracellular fluid and the cytoplasm).

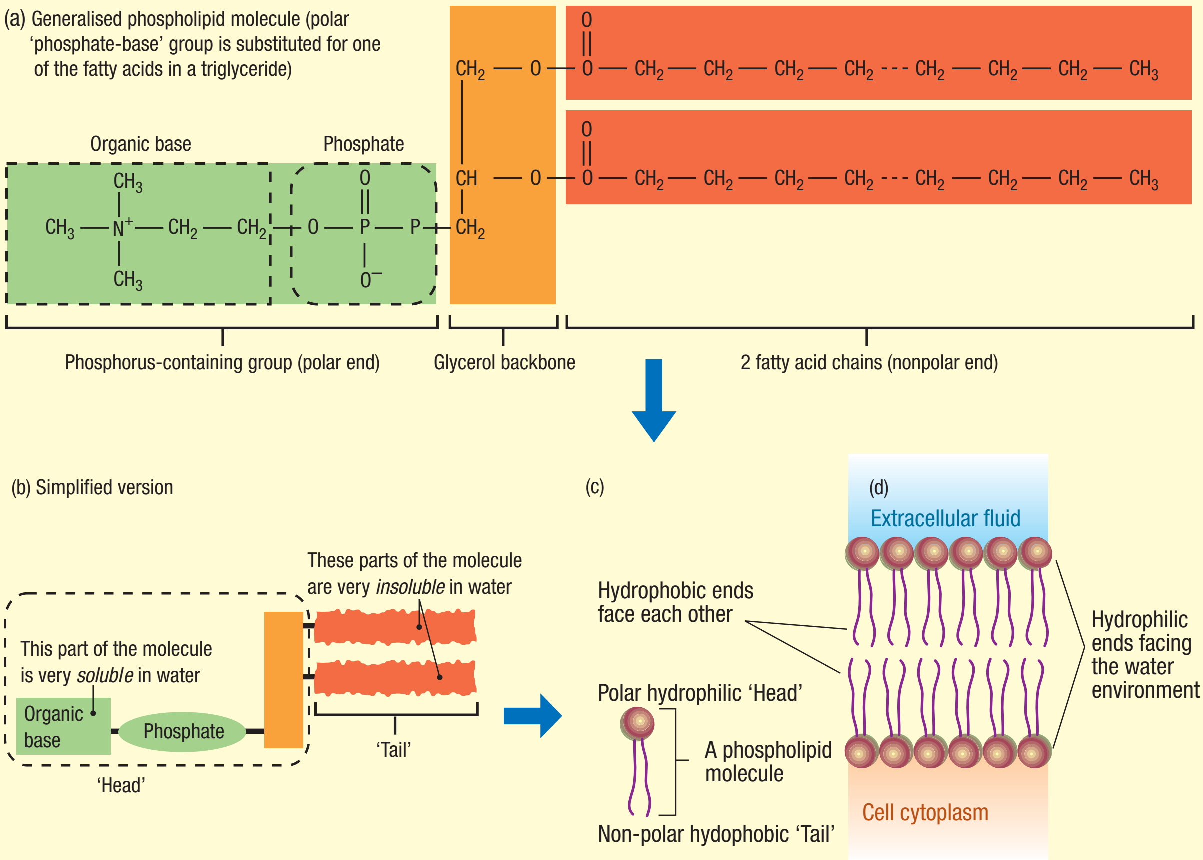


Figure 13.2 (a) Generalised phospholipid molecule; (b) simplified version; (c) phospholipid molecule; (d) arrangement of phospholipid bilayer

This also dictates the orientation of the individual molecules. The hydrophobic tails repulse water, so the phospholipid molecules automatically arrange themselves so that the hydrophobic tails are sandwiched between the heads.

As with all molecules, the phospholipid molecules move about. However, their polarity restricts their movement mainly to the lateral plane.

A great deal of energy is required to move the phospholipid molecules from one layer to the other, since the hydrophilic head must pass through the hydrophobic tail region. The tails must come into contact with water in this action. As a result, 'flip-flop' movement is very rare.

The phospholipid bilayer, according to the **fluid mosaic model**, is regarded as a dynamic structure in which proteins can float—some moving about freely while others are fixed in position by microfilaments running into the cytoplasm.

Some proteins, known as **integral proteins**, penetrate either part of the way into the membrane or all the way through it. These proteins interact extensively with the hydrocarbon tails of the membrane lipids and can be released only by detergents or organic solvents. Other proteins are on the periphery of the membrane or to the outer surfaces of integral proteins and are called **peripheral proteins**. These peripheral proteins are weakly bound to the membrane or other proteins. These bonds are easily disrupted by adding salts or changing the pH.

Usually the integral proteins have a hydrophobic portion which interacts with the phospholipids, and a hydrophilic portion facing the aqueous contents of the cell at the membrane surface. Some of the proteins (of which thousands may occur in membranes) may be purely structural in function. Others act as carrier molecules in transporting specific substances through the membrane. It is thought that hydrophilic channels occur within integral proteins or between adjacent protein molecules. The channels allow the passage of some water-soluble substances, otherwise excluded by the phospholipid molecules, through the membrane.

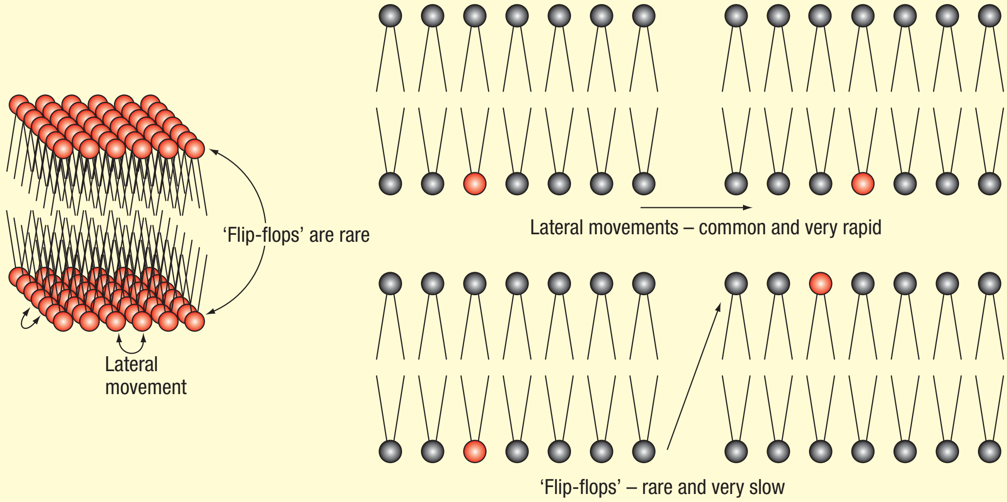
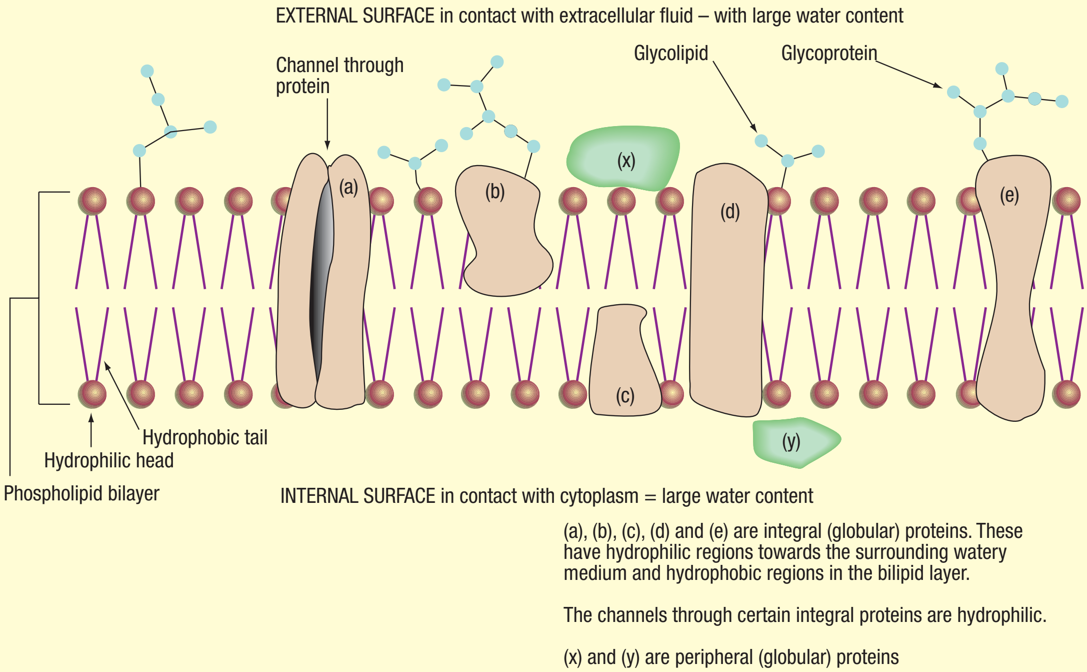


Figure 13.3 Movement of phospholipids within the membrane



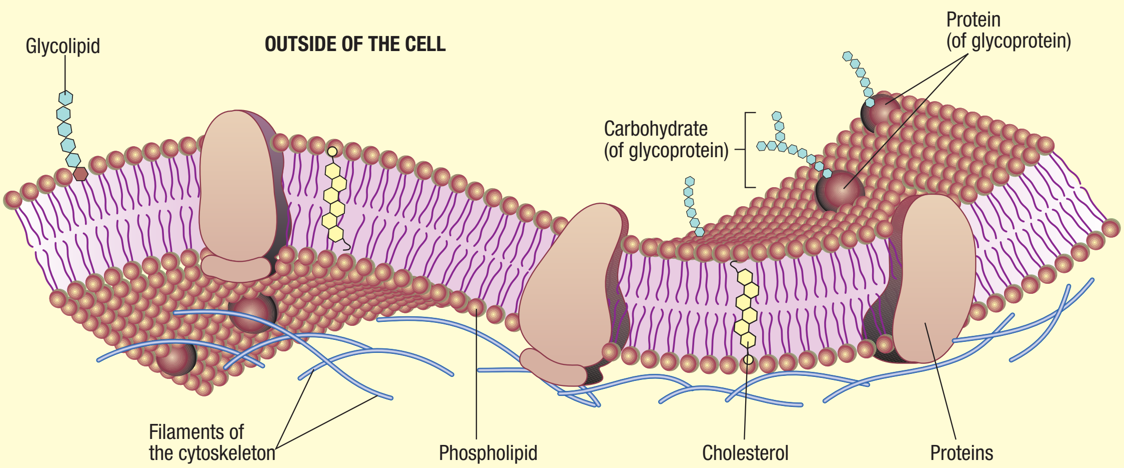


Figure 13.4 The fluid mosaic model of the cell membrane

Other membrane proteins may act as enzymes, specific receptor molecules or electron carriers. Glycoproteins and glycolipids are also present in the membrane. They have branching carbohydrate portions on their free surfaces. These 'antennae' are made up of a number of sugar residues and have a range of precisely defined patterns. They are important as recognition features:

- Sugar recognition sites of two neighbouring cells may bind to each other, causing cell-to-cell adhesion. This results in particular orientations of cells and formation of tissues.
- Glycoproteins act as antigens in the immune response.
- Various control systems rely on recognition sites. For example, hormones and other chemicals bear recognition sites which enable them to be taken up specifically by cells that have the complementary sites.

13.1.3 Variations in membrane properties

Differing types of phospholipids in the membrane affect such properties as its fluidity and permeability. In turn, these properties affect the ease with which membranes fuse with each other, and the activity of membrane-bound enzymes and transport proteins.

The variations in membrane properties of different cells can be attributed to differences in:

- lipid composition and thus fluidity
- integral proteins and thus 'channel' sizes
- peripheral and integral proteins and thus
  — recognition sites
  — carrier molecules
  — enzymes attached.

SUMMARY

The basic unit of structure and function in living organisms is the cell. The cell theory states that:

- all living matter is composed of cells and their products, and
- all cells arise from pre-existing cells.

The cell is bound by a membrane which consists of a phospholipid bilayer, through which integral proteins are inserted and on which peripheral proteins and other chemicals, such as sugars, are bound. The phospholipid molecules are composed of a hydrophilic (water-loving) head and a hydrophobic (water-hating) tail. The tails are attracted together to avoid the watery solutions of cytoplasm and intracellular fluid. Different cells have membranes with different chemical composition, and this changes their properties.

The functions of the cell membrane are to:

- control movement of substances into and out of the cell
- help in active transport of materials across it
- provide a certain degree of mechanical support to the cell
- help maintain the cell shape
- act as a receptor for extracellular material and thus maintain the integrity of each type of cell
- maintain each cell as an integral structure.

? Review questions

13.1 What is the cell theory?

13.2 Why must the cell membrane consist of a bilayer of phospholipids?

13.3 What functions do proteins perform in the cell membrane?

13.4 What are some of the factors that determine whether a particle will pass through a cell membrane?

13.5 Relate the structure of the cell membrane to the fact that cells vary in their ability to allow different types of molecules to pass through them.

13.6 List functions of the cell membrane.

13.7 Why are recognition sites on the outside of the cell membrane significant to living things?

13.2 Movement of chemicals in and out of cells

The membrane phospholipid bilayer is a major barrier which is impermeable to the usual water-soluble substances such as ions, glucose, amino acids and many others. Lipid-soluble substances such as oxygen, nitrogen and alcohols dissolve in the phospholipids and diffuse rapidly through the cell membrane as if it were not there. Even though water is highly insoluble in the membrane phospholipids, it is readily able to penetrate the phospholipid layer as well as pass through the protein channels. The reason for this is not certain, but it is believed that the water molecules are sufficiently small, and their kinetic energy sufficiently great, for them to penetrate the lipid portion before the hydrophobic 'tails' can stop them.

The very fluid nature of the cell membrane ensures that it is in constant motion, so small molecules can pass between the lipid molecules. Thus at any particular point in time there are 'pores' in the membrane that will allow small molecules such as water and urea to pass through.

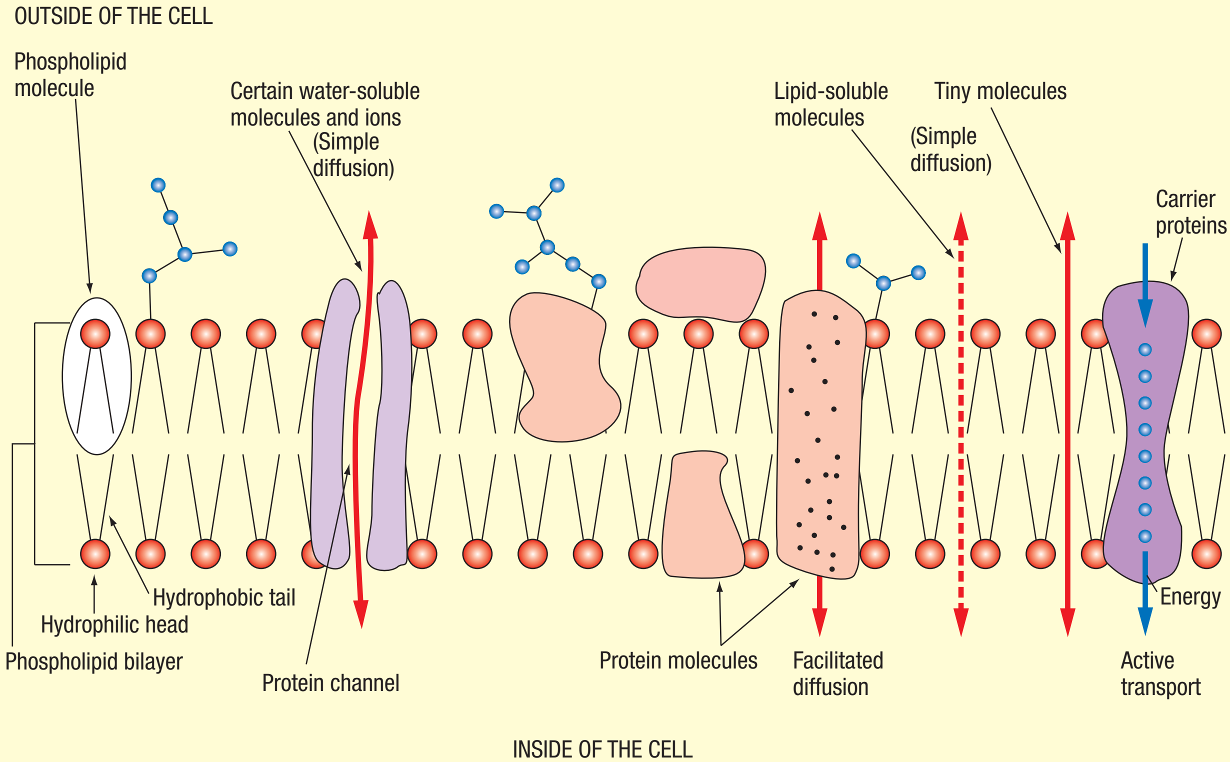


Figure 13.5 Transport pathways through the cell membrane, and the basic mechanisms of transport

The phospholipid bilayer is impermeable to ions because of their electrical charges, and to glucose and amino acids because of their larger molecular diameters. These molecules must enter the cell through the channels in the integral proteins.

Various materials must move in and out of cells so that biological activities can take place in the cell. The cell membrane allows some solute molecules or ions, but not others, to move freely through it. It is selectively permeable. A permeable membrane allows the free movement of all molecules in both directions; often a selectively permeable membrane allows solvent molecules and excludes the solute molecules.

Three important ways that materials move into and out of cells are:

1. Passive transport
   - (a) diffusion — (i) simple
     - (ii) facilitated
   - (b) osmosis
2. Active transport

13.2.1 Passive transport

Diffusion is the process by which molecules or ions of liquids or gases tend to spread out from regions of their higher concentration to regions of their lower concentration. This results from their random movement (Brownian motion). Eventually, the molecules become more or less evenly distributed throughout the space they occupy. For example, a sugar cube (solute) placed in water (solvent) will dissolve and slowly spread throughout the solution. Diffusion through the cell membrane may be divided into two separate processes: **simple diffusion** and **facilitated diffusion**.

Simple diffusion

Simple diffusion is the free and unaided movement of molecules or ions through the cell membrane. For example, oxygen molecules (solute) dissolved in water (solvent) will be in constant random motion, causing an even dispersion of them through the solvent. If the concentration of oxygen molecules outside a cell is higher than that inside the cell, a **concentration gradient** will exist. Oxygen molecules are soluble in both water and lipids, and can therefore pass freely through the cell membrane. Oxygen and water molecules will pass through in both directions, but the number of oxygen molecules passing into the cell will initially be greater: there will be a net flow into the cell. As the concentrations on both sides of the membrane become equal, the number of molecules passing from each direction will become the same. At this point **dynamic equilibrium** has been reached. The number of molecules entering the system equals the number of molecules leaving.

Facilitated diffusion

Sometimes, specific molecules in the cell membrane make possible the passage of a substance to which the membrane is normally impermeable. This is facili-

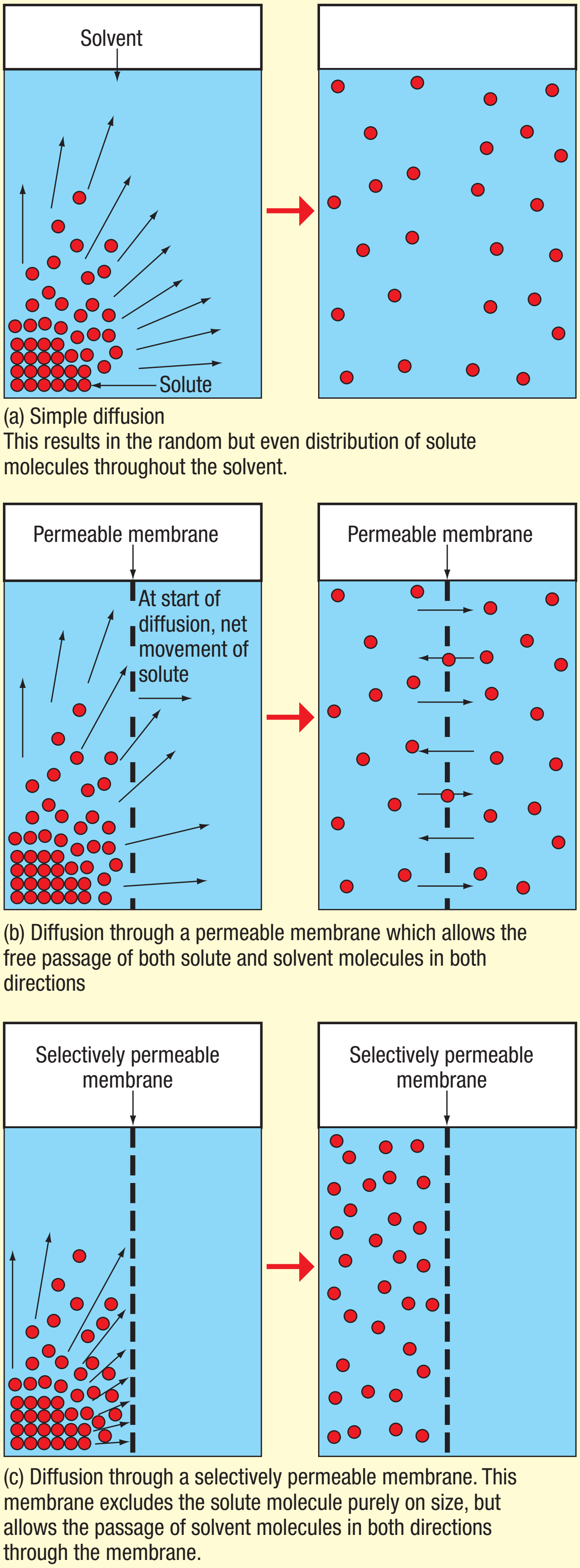


Figure 13.6 Diffusion, and the effect of different types of membranes

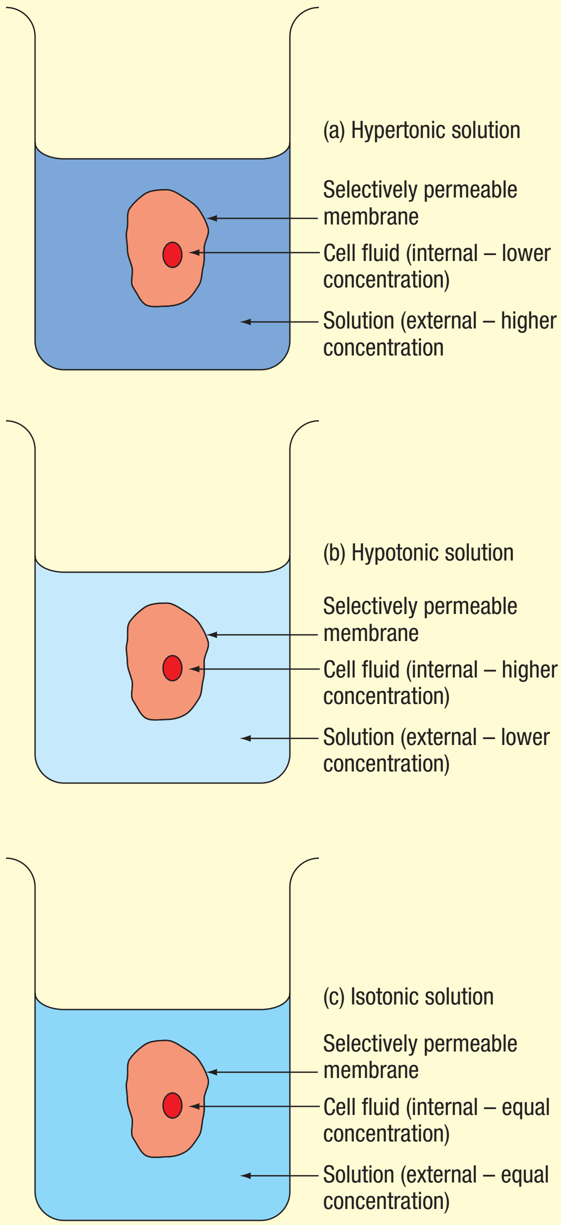


Figure 13.7 Types of solution

tated diffusion. The molecules are carried across the cell membrane by (globular) proteins which collect them on one side of the membrane, diffuse across it and deposit them on the other side of the membrane. For example, glucose molecules are insoluble in the phospholipid bilayer of the cell membrane and are too large to pass through. However, the glucose plus its protein carrier is soluble in lipids and can diffuse across. No energy is expended in this process.

Osmosis

Osmosis occurs when there is a concentration gradient across a selectively permeable membrane which is impermeable to the solute. In this case only the solvent molecules move across the membrane. The solvent molecules move from a region of their high concentration to a region of their low concentration through a selectively permeable membrane, because the dissolved substances cannot. In biological systems the solvent is water.

Osmotic/water potential is the capacity of a solution to lose water molecules through a selectively permeable membrane. It depends upon the concentration of the solute in the solution (e.g. the cytoplasm of a cell), compared with the concentration on the other side of the membrane (e.g. extracellular fluid). If the solute concentration in the cell is high compared with its surrounding medium, the solution in the cytoplasm is said to be **hypertonic**, and its osmotic potential is low. If the concentration in the cell is low, the solution in the cytoplasm is **hypotonic**, and its osmotic potential is high. When the concentration inside and outside the cell is the same, the solutions are said to be **isotonic**.

If the osmotic or water potential of a cell is low, there will be a net flow of water into the cell by osmosis. If it is high, there will be a net flow of water out of the cell by osmosis. In the isotonic condition the same amount of water leaves the cell as enters.

When a cell is placed in a strong sugar solution, the sugar cannot diffuse through the cell membrane. There is a net flow of water out of the cell (high osmotic potential) to a region of low osmotic

Table 13.1 Relationship between solute concentration and osmotic potential in cells

	Solute concentration in the cell	Osmotic potential
Hypertonic:	greater than the medium	low
Hypotonic:	less than the medium	high
Isotonic:	the same as the medium	nil

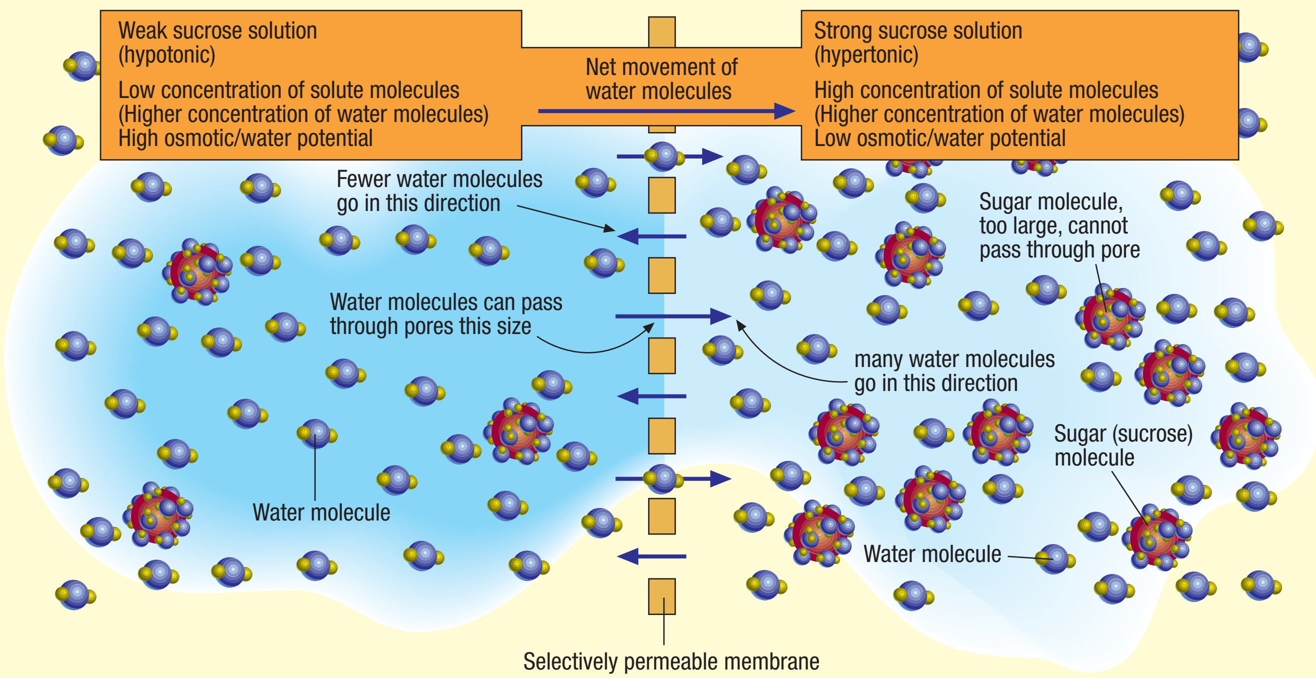


Figure 13.8 The process of osmosis

potential, until the concentration on both sides of the cell is equal, or isotonic.

When plant cells are placed in a hypertonic solution, the cell wall remains rigid but the protoplasm shrinks away from it, because the fluid of the vacuole is reduced in volume by osmosis. Shrinkage of the cytoplasm away from the cell wall is known as **plasmolysis**. If these cells are then placed in distilled water or a hypotonic solution, water will enter the cytoplasm and the vacuole and restore the cell to its normal state. The cell is now **deplasmolysed**.

When water enters a plant cell by osmosis the volume of the total cell contents increases and exerts a **turgor pressure** against the rigid cell wall. When this is at a maximum, no net movement of water into the cell can occur. The cell is fully turgid.

A similar phenomenon takes place in animal cells (e.g. red blood cells or single-celled protists such as *Amoeba*). Because they lack a cell wall, the entire cell shrinks and shrivels in a hypertonic solution (**crenation**), and in a hypotonic solution it expands, stretching the cell membrane, which may burst. Red blood cells which rupture due to osmosis are said to be **haemolysed** since the red pigment haemoglobin is released into the surrounding liquid.

13.2.2 Active transport

Active transport is the energy-consuming transport of molecules or ions across a membrane against a concentration gradient or an ionic gradient. Energy is required because the substance must be moved against its natural tendency to diffuse in the opposite direction. Movement is unidirectional. In contrast, diffusion is reversible, depending on the direction of the concentration gradient. Active transport of materials out of cells is termed **exocytosis**; the active movement of materials into the cell is termed **endocytosis**. Active transport may involve:

- carrier molecules in the membrane; or
- formation or breakdown of membrane-bound 'packages' of matter. These packages are membrane-bound vacuoles formed by the processes of phagocytosis or pinocytosis.

The membrane may actually engulf particulate matter (**phagocytosis**) or extracellular fluid and its contents (**pinocytosis**). Phagocytosis (cell eating) involves the extension of the cell membrane around a solid particle outside the cell. The membrane fuses around the particle and, in doing so, forms a vacuole which becomes incorporated into the cytoplasm.

Pinocytosis (cell drinking) occurs by infolding the cell membrane to form a channel. The liquid material enclosed in the channel is pinched off in a vacuole as the membrane fuses at the surface.

Exocytosis of materials in vacuoles involves the vacuole again fusing with the cell membrane and then opening up to the external environment to expel the contents.

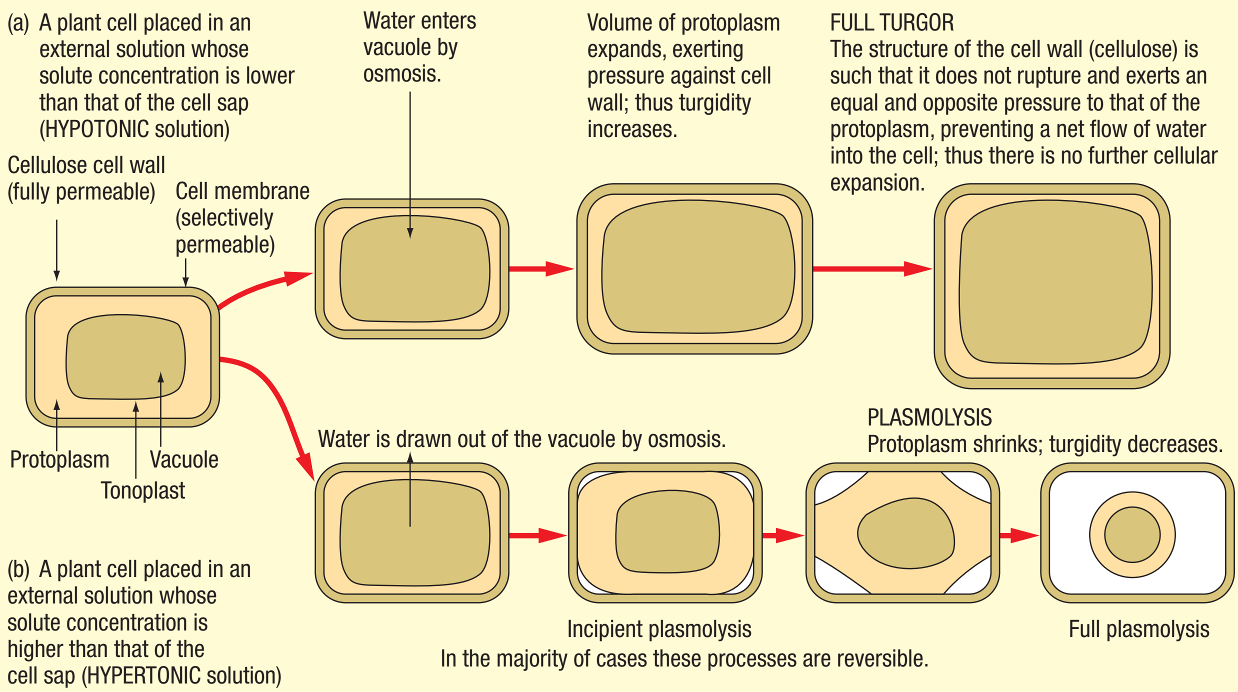


Figure 13.9 Plasmolysis and turgidity in plant cells

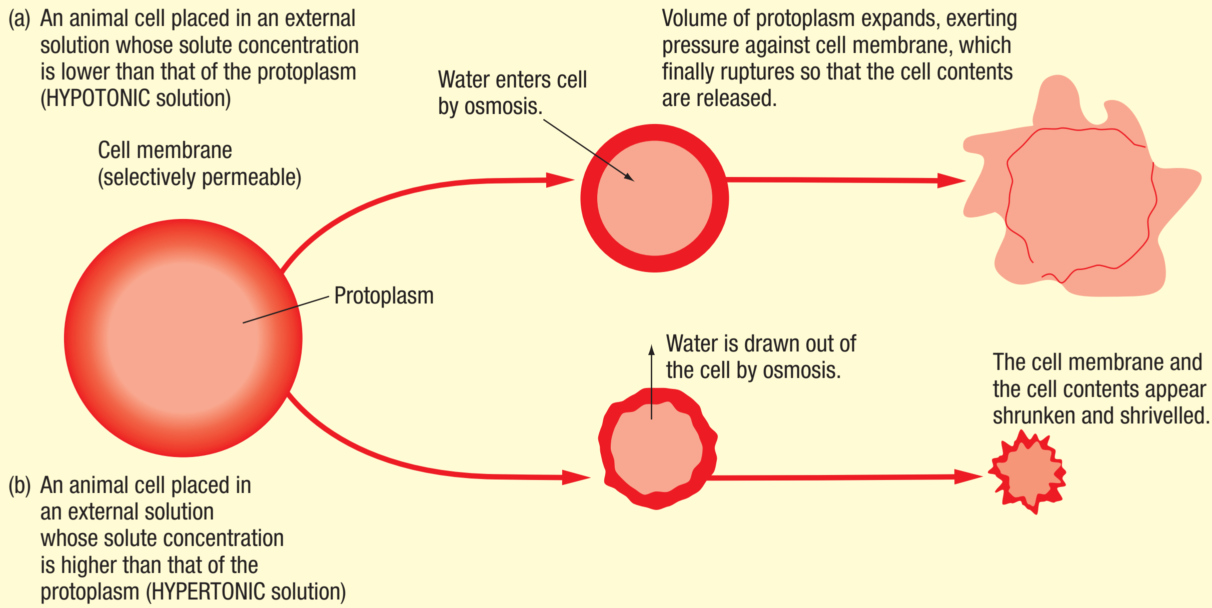


Figure 13.10 Crenation and haemolysis in red blood cells

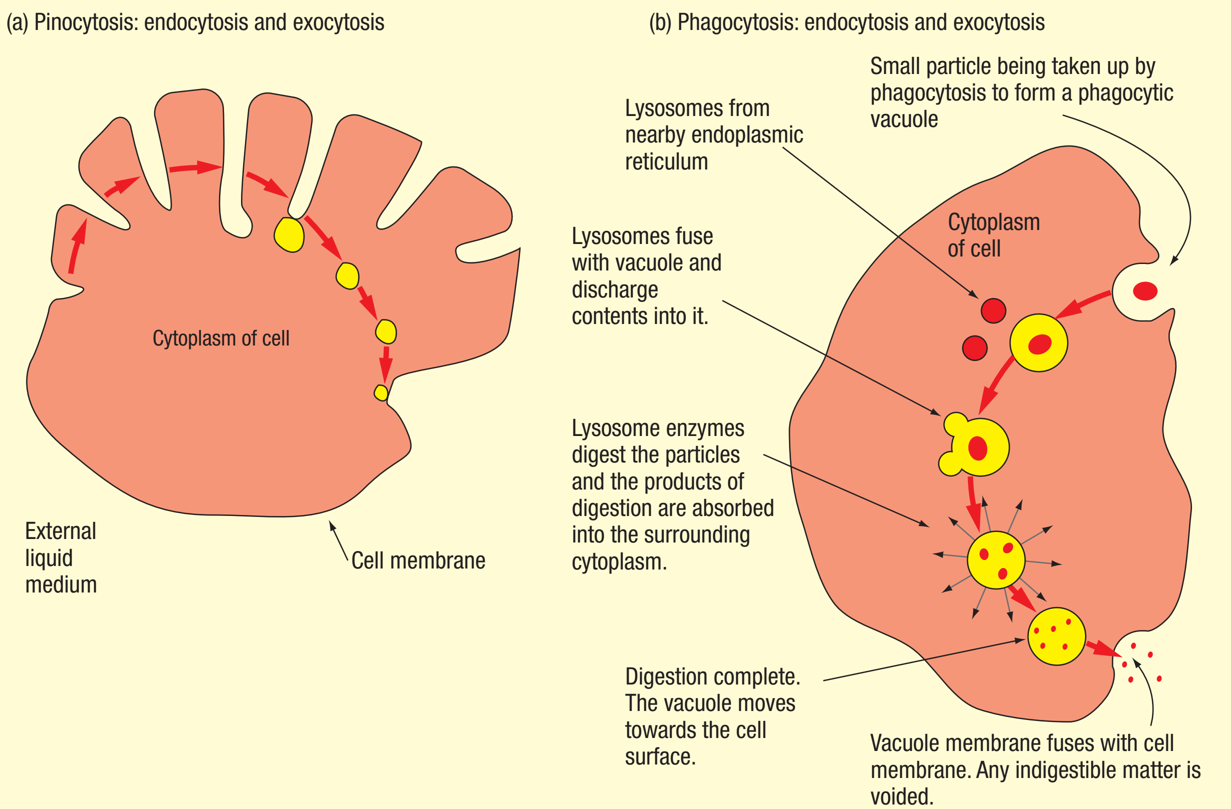


Figure 13.11 The sequence of events in pinocytosis and phagocytosis

SUMMARY

The cell membrane is a selectively permeable structure.

- Small fat-soluble molecules pass through the lipid bilayer readily.
- Water consists of small molecules that can slip through the moving membrane molecules.
- Small water-soluble molecules and mineral ions can pass through integral protein channels.

The passage of large molecules is blocked by the membrane.

Diffusion is the passage of solutes from a hypertonic solution (high concentration) to a hypotonic one (low concentration) through a selectively permeable membrane. Substances with molecules that are very small compared with the phospholipid molecules of the cell membrane, and lipid-soluble molecules, can diffuse through the membrane; but this can be overridden by an energy-requiring mechanism. Other substances may pass through the membrane via the integral protein 'channels'. Facilitated diffusion is the transport of substrate molecules through the membrane by special enzyme-like carrier molecules.

Osmosis is the passage of the solvent (water) from a hypotonic to a hypertonic solution through a selectively permeable membrane which is impermeable to the solute(s) in this solution.

Diffusion, facilitated diffusion and osmosis are forms of passive transport of materials. Energy is not required for these processes to occur, whereas energy is expended in active transport. Active transport is the movement of materials against a concentration or ionic gradient and may involve carrier molecules, phagocytosis or pinocytosis.

? Review questions

13.8 What is meant by the terms 'passive transport' and 'active transport'?

13.9 Distinguish between a permeable and a selectively permeable membrane. Give an example of each.

13.10 Explain what is meant by dynamic equilibrium between two solutions separated by a selectively permeable membrane.

13.11 Define diffusion. How does it differ from facilitated diffusion?

13.12 Compare and contrast diffusion and osmosis.

13.13 Animal cells placed in a hypotonic solution swell and burst. Plant cells placed in a hypotonic solution swell only to a particular point and do not rupture.
- (a) What process is involved in the swelling?
- (b) Explain why animal cells rupture but plant cells do not.
- (c) What is the name given to this action in plant cells?

13.14 In what ways is active transport achieved?

13.15 In what ways are phagocytosis and pinocytosis:
- (a) similar
- (b) different?

13.3 Cell structure

13.3.1 Organelles in eukaryotic cells

The cells of eukaryotic organisms (all organisms apart from bacteria and cyanobacteria, which are prokaryotic) contain membrane-bound organelles. Most of these structures are not normally visible under the light microscope but can be viewed with the electron microscope.

Organelles found in both plant and animal cells

Nucleus

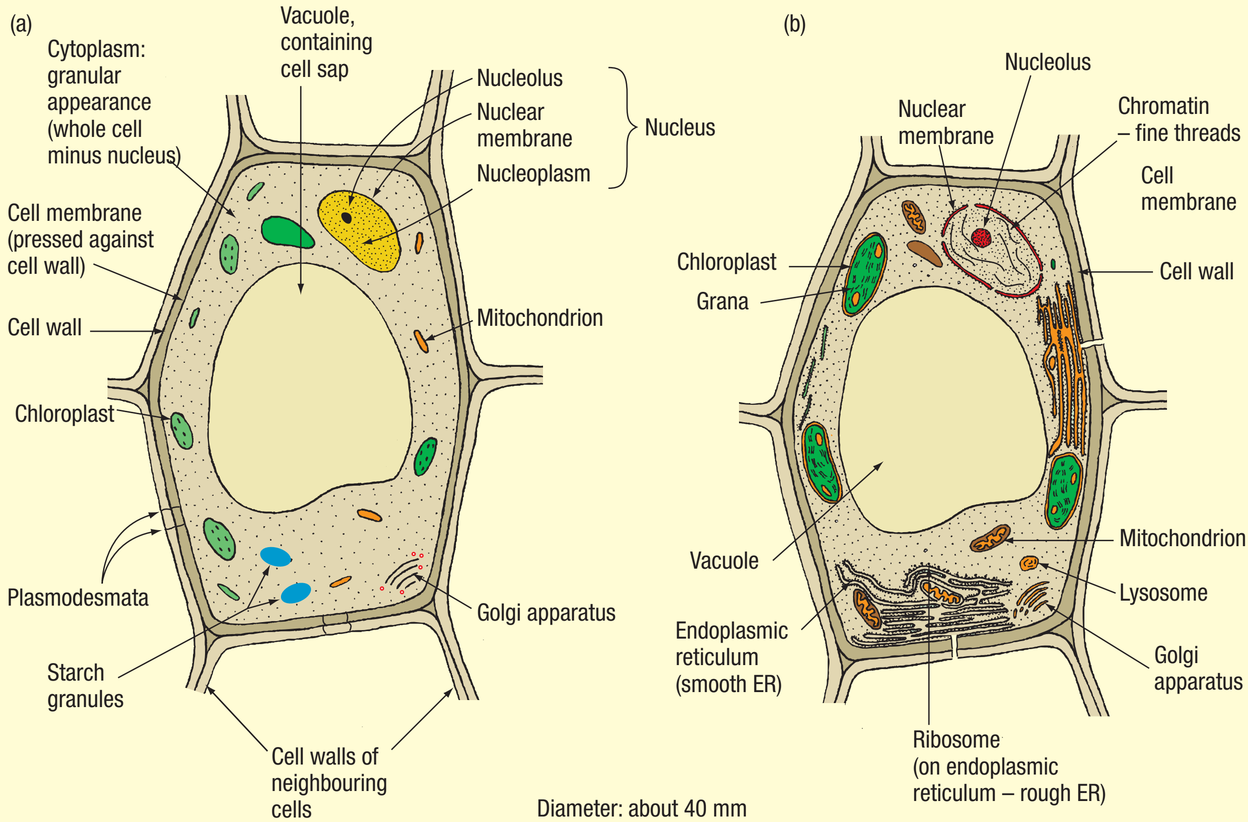
The total contents of the nucleus are called **nucleoplasm**. The nucleus controls cell activity through DNA, which operates by directing protein synthesis and cell division. In the non-dividing cell the DNA forms a diffuse network of threads called **chromatin**. These condense during cell division into **chromosomes**. The nucleus is surrounded by a double membrane, with pores that allow passage of some materials into and out of the nucleus. The nucleus contains the **nucleolus**, which is composed of proteins, DNA and RNA, and which produces ribosomes.

Endoplasmic reticulum

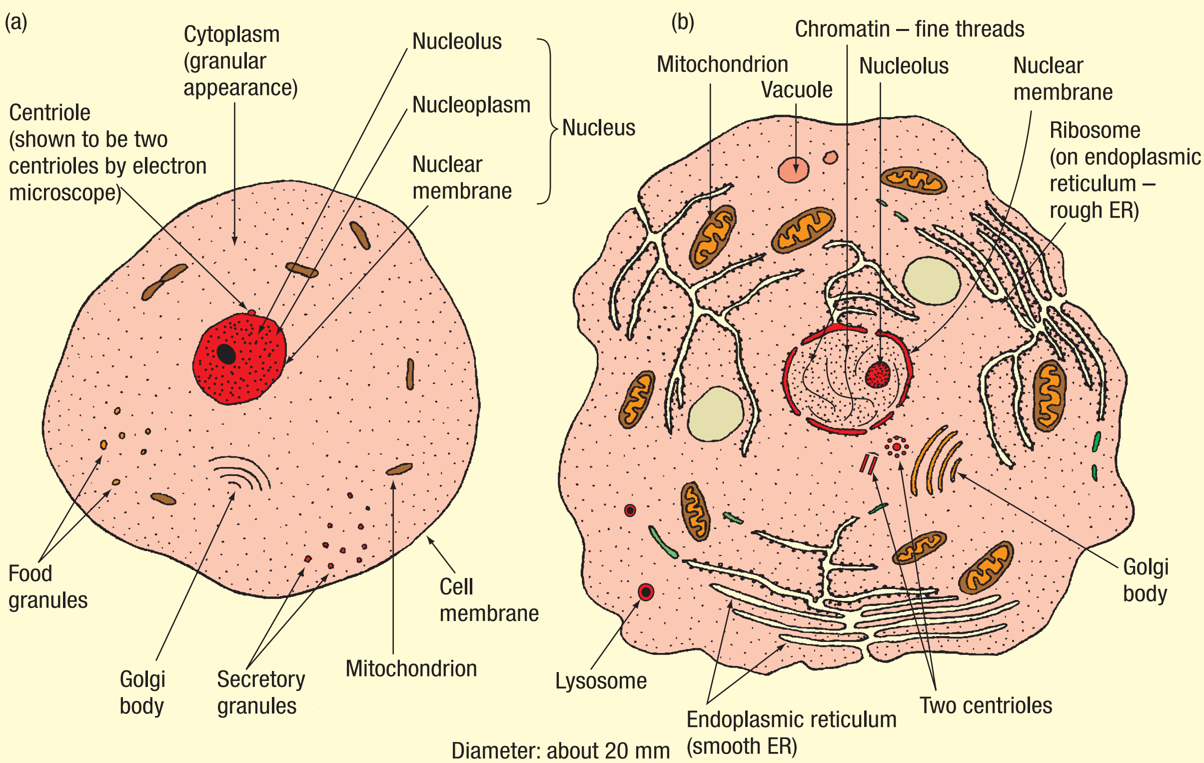
Endoplasmic reticulum (ER) is a network of flattened, membrane-bound sacs or **cisternae** continuous with both the nuclear and cell membranes. Smooth ER is responsible for the synthesis of lipids and steroids, and transport of materials within the cell and between the cell and its surroundings. It also detoxifies drugs and some metabolites. Rough ER has **ribosomes** on the membrane surfaces which are involved in the synthesis of proteins. Transport of proteins occurs in their cisternae.

Mitochondria

Mitochondria (singular *mitochondrion*) are cigar-shaped and bound by a double membrane. The inner membrane is folded into **cristae**, which increase the surface area for attachment of enzymes. The membranes enclose a **matrix**. The cristae and matrix provide different sites for various stages of aerobic respiration and thus the production of ATP. Mitochondria contain special mitochondrial DNA and ribosomes which control their enzyme production, and allow them to replicate themselves.



A. Plant cell viewed with (a) light microscope and (b) electron microscope



B. Animal cell viewed with (a) light microscope and (b) electron microscope

Figure 13.12 Plant and animal cells

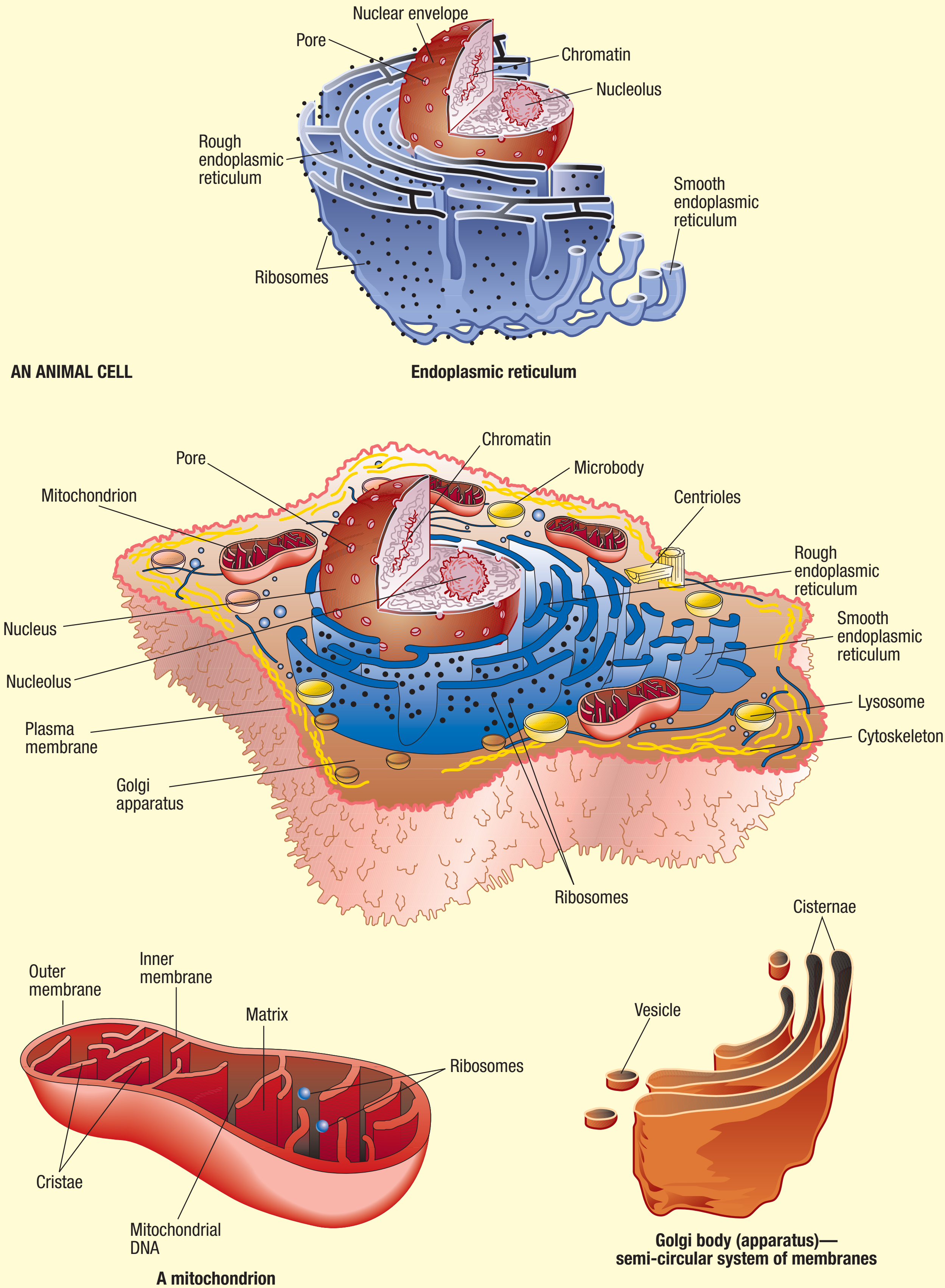
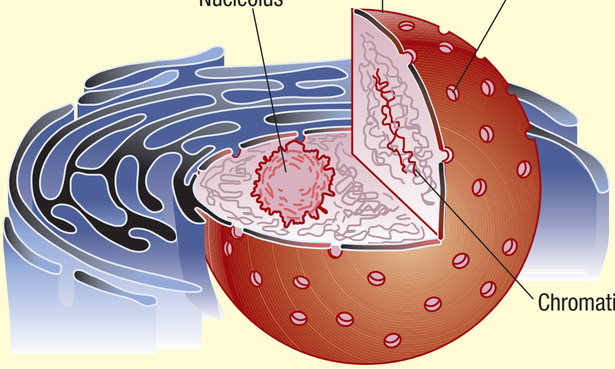
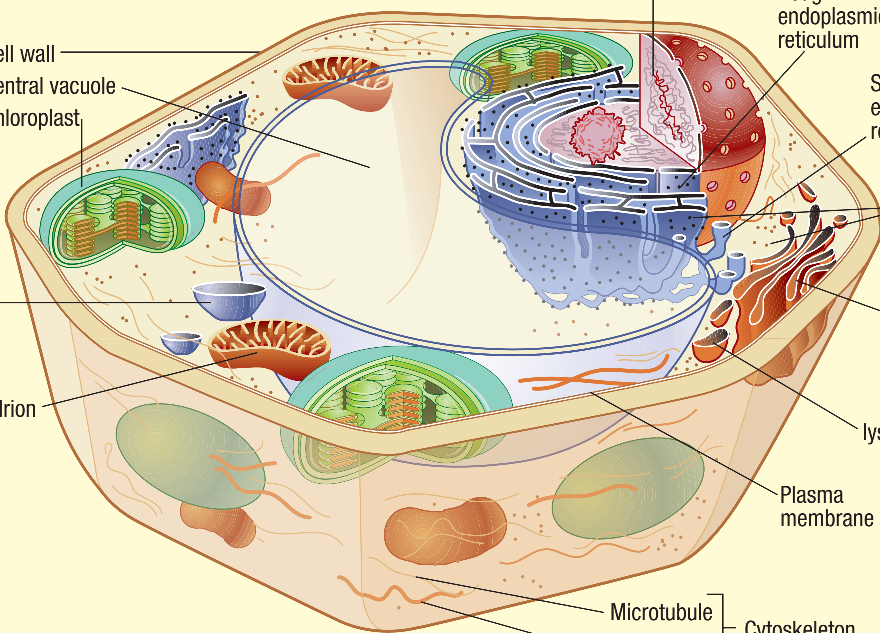


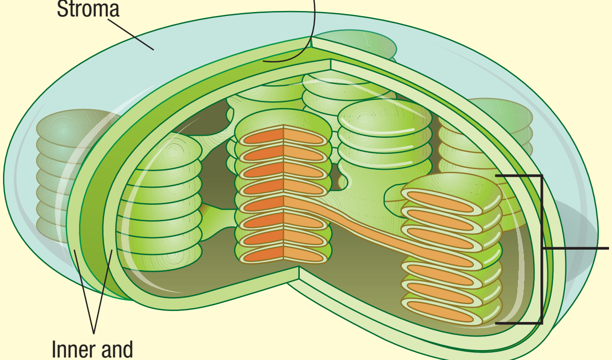
Figure 13.13 Animal and plant cell organelles



A cell nucleus

A PLANT CELL





A chloroplast

Golgi apparatus

This structure is composed of a stack of flattened membranous sacs or cisternae which are continually being formed at one end and budded off as vesicles at the other. They are closely associated with the endoplasmic reticulum, receiving the enzymes, proteins, lipids, glycoproteins and polysaccharides synthesised there, enclosing them in membranes and releasing them either into the cytoplasm or outside the cell. Thus they serve as collecting, sorting, processing and distribution centres.

Lysosomes

A **lysosome** is a simple spherical sac containing digestive enzymes. It can fuse with food vacuoles to bring about digestion of their contents. Unwanted cell contents are broken down (autophagy) by lysosomes. They can also cause complete breakdown of damaged cells (autolysis) and so are sometimes termed 'suicide sacs'.

Centrioles

Centrioles consist of a set of two cylindrical bodies adjacent to the nucleus. They are involved in flagella and cilia formation and in cell division in animals. In general, they are found only in animal cells, but some algae also have centrioles.

Organelles found only in plant cells

Cell wall

This is a non-living wall, composed of cellulose, and enclosing the cell membrane. It may be secondarily thickened with the chemical lignin. The cell wall provides mechanical support and protection. It allows turgor pressure to develop in hypotonic media without osmosis causing the cell to rupture. A **middle lamella** between the walls of adjacent cells cements neighbouring cells together. At points between the cells, the cell wall and membrane break down to provide fine cytoplasmic links between cells called **plasmodesmata**. These allow rapid movement of materials from cell to cell.

Plastids

These are double-membraned organelles of varying shape. Three types are common. **Chromoplasts** are non-photosynthetic, containing red, yellow and orange pigments which provide colour to flowers, fruit and leaves. **Leucoplasts** are colourless and involved in starch storage. **Chloroplasts** are large, consisting of a fluid matrix or **stroma** and flattened stacks of membranous discs called **grana**. They contain chlorophyll and function in photosynthesis. Like mitochondria, they also contain DNA and ribosomes and can replicate themselves.

Vacuole

A large central vacuole contains cell sap and is responsible for storage of substances and osmotic control of the cell.

Cytoskeleton

Organelles are not scattered randomly throughout the cytoplasm. The nucleus generally takes a central position in the cell, with the Golgi bodies and endoplasmic reticulum clustered around it. Chloroplasts are usually oriented with their grana facing the light source. Many organelles move within the cytoplasm in an ordered fashion. The orientation and movement of organelles within the cytoplasm results from their interactions with the **cytoskeleton** —a framework of protein filaments. There are three main elements of the cytoskeleton: **microfilaments**, **microtubules** and **intermediate filaments**.

Microfilaments

Microfilaments are fine strands of the globular protein actin. They are able to bind with other proteins, and in so doing are able to hold organelles in position within the cytoplasm. Interactions of actin microfilaments with another protein, myosin, bring about general movement of the cytoplasm, organelles and the cell as a whole. Muscle cells have a high content of both of these proteins. The sliding action of actin and myosin results in contraction and relaxation and thus movement.

Some cells in animals (e.g. lining the intestine and kidney tubules) have minute finger-like projections of the membrane. These **microvilli** increase the cell surface area massively without increasing volume to any great extent. Since they usually occur in large numbers and appear like the bristles of a brush, cells bearing microvilli are said to have a **brush border**. Actin microfilaments allow them to contract. The combined actions of increased surface area and movement facilitate uptake of materials into the cell.

Microtubules

Microtubules are hollow cylinders of the protein tubulin. Being more rigid than microfilaments, they provide greater mechanical support for the cell. In plant cell walls microtubules provide the framework along which cellulose is laid down. Microtubules also provide routes along which materials in the cytoplasm can move, assisting transport within cells. During cell division microtubules form the spindle fibres which attach to chromosomes and draw them apart.

Cilia (short) and flagella (long), are cellular projections covered by the cell membrane. They are composed of an exact array of microtubules. The sliding of adjacent pairs of these tubules causes the projections to move. Cilia and flagella can thus bring about movement of a cell or of a liquid over the cell's surface.

Intermediate filaments

Intermediate filaments are composed of a variety of fibrous proteins, and range in size between that of the microfilaments and microtubules. These filaments are strong, stable and resistant to stretching, thereby providing mechanical support for the cell.

13.3.2 Comparision of prokaryotic and eukaryotic cells

The prokaryotes (bacteria and cyanobacteria) are the most ancient cells. They are smaller than eukaryotic cells and have a simpler structure. Bacteria have a semi-rigid cell wall of murein surrounding the cell membrane, but they lack distinct membrane-bound organelles and a cytoskeleton. The genetic material is bound into a single circular DNA molecule floating within the cytoplasm. Smaller segments of DNA are called plasmids. Although many ribosomes are present, they are not attached to any other structure and differ chemically from those of eukaryotes. The enzymes for respiration are attached to the inside of the cell membrane. (A mitochondrion is similar to a whole bacterial cell.)

Some bacteria have flagella. The flagellum, however, is outside the cell membrane and composed of helically coiled protein fibrils projecting from a 'motor' embedded in the membrane.

Case study 13.1: Commercial use of cellulose

Cellulose is the major consituent of plant cell walls. Wood comes from the central, dead part of tree trunks. The xylem cells have died, because lignin has been embedded in their cellulose cell walls. The lignin stengthens the cell walls, providing rigidity to the flexible cellulose. Plant waste products can be deposited in the central cavities left behind when the cells die. Wood can support buildings for years and is more widely used in construction of buildings, bridges, furniture and tools than all other materials put together.

The stems of the papyrus reed were used by the Egyptians to construct boats, sails, mats, cloth cords and paper as early as the fifth century BC. Papyrus scrolls were produced by cutting the stem of the reed into longitudinal strips. These strips were laid side-by-side to the required width. Another layer of shorter strips was then laid on these, at right angles. This sheet was then soaked in water, which possibly dissolved glutins in the stalks and cemented the strips together as the glutins dried. Finally the sheet was hammered and dried in the sun. Papyrus was used as a writing material in Europe up until the fifth century AD. Although the reed is very light when dried, the cellulose components are very strong. Thor Heyerdahl demonstrated this when, in 1970, he constructed a papyrus boat, the *Ra II*, from ancient designs and sailed it from Morocco to Barbados.

True paper-making was developed by the Chinese in about AD 105, using the macerated bark of trees, hemp waste, old rags and fish nets. Today the fibres are pulped either mechanically or chemically to release the cellulose fibres. In high-quality papers the lignin, which can cause discolouration, is chemically removed. The pulp is washed to free it of soluble impurities and screened to remove insoluble matter such as knots, dirt and unpulped fibres. Bleaching removes any unwanted colours in the pulp, after which the pulp is beaten. This shortens the fibres and mashes them to create hair-like fibrils which absorb water and become slimy. The whole mass of pulp can then be spread on wire frames and rolled, to press out water and enmesh the fibrils to form paper. Different types of paper are produced according to the particular plant material used.

Cellulose is used in the manufacture of a variety of textiles. Linen, produced from the flax plant (*Linum usitatissimum*), is one of the oldest textile fibres known. The fibres are obtained from

Table 13.2 A comparison of eukaryotic plant and animal cells

Feature	Plant cell	Animal cell
Cell wall	rigid, cellulose; may be lignified	none
Vacuoles	large: up to 80% cell volume	small if present
Centrioles	absent	present
Chloroplasts	present in photosynthetic cells	absent
Granules	starch	glycogen
Cilia	absent	present in certain cells or cell types

Table 13.3 Comparison of eukaryotic and prokaryotic cells

Structure	Eukaryotic cells	Prokaryotic cells
Cell wall	absent in animals; present in plants (cellulose) and fungi (chitin)	present (murein)
Cell membrane	present	present
Nucleus	surrounded by membrane	not surrounded by membrane
Chromosomes	multiple, composed of nucleic acid (linear DNA) and protein	single, composed only of nucleic acid (circular DNA)
Ribosomes	present	present but are different chemically
Membrane-bound organelles:		
ER	present	absent
Golgi body	present	absent
lysosomes	present	absent
mitochondria	present	absent
vacuoles	present	absent
chloroplasts	present in plants	absent
Cytoplasmic streaming	may occur	does not occur
Flagella	complex—microtubules	simple, with no microtubules (extracellular, i.e. not enclosed by the cell membrane)
Nitrogen fixation	does not occur	does occur

the bark of the stalks. This is removed by a process called retting, in which the stalks are subjected to partial decomposition by bacteria. The fibres, after mechanical separation from the wood, can then be spun and woven. Hemp fibres from the plant *Cannabis sativa* are prepared in a similar manner. These fibres are used to produce a range of textile materials from fine fabrics to coarse ropes.

The seed hairs of the cotton plant (*Gossypium*) are almost pure cellulose and therefore do not need the same preparation as the stalks of flax and hemp. Cotton, therefore, supplanted linen and hemp as a fabric material.

In recent years there has been added interest in the production of hemp. Genetically engineered crops of *Cannabis* species which do not produce the narcotic drug in its shoots are currently being grown in Tasmania. Unlike cotton plants, they are not subject to pest attack and can grow in less fertile soils with lower water content. Thus they are a more 'environmentally friendly' crop than cotton. Also, since the whole stalk produces usable fibre, it is a more productive crop than cotton, from which only the seed head is utilised (Figure 5.13, page 117).

Cellulose can also be processed into a wide range of products such as thickeners for paint, stabilisers in foods and cosmetics, adhesive tapes and dialysis membranes.

SUMMARY

Eukaryotic cells are distinct from prokaryotic cells in having a 'division of labour' of the cytoplasm into membrane-bound organelles. Each organelle has a specific structure related to its function. For example:

- The nucleus contains DNA in the form of chromosomes and controls the cell's activities.
- Ribosomes, the sites of protein synthesis, are manufactured in the nucleolus of the nucleus and transported to the cytoplasm, where they attach to part of the endoplasmic reticulum or may remain free in the cytoplasm.
- Endoplasmic reticulum without ribosomes (smooth ER) is involved in the formation of steroids and lipids.
- The Golgi apparatus is responsible for the processing and packaging of polysaccharides and glycoproteins. Products leave the Golgi apparatus in membranous sacs, either remaining in the cell as lysosomes or fusing with the cell membrane to be secreted outside the cell.
- Mitochondria are the powerhouses of the cell, and are responsible for the production of ATP in aerobic respiration.

The cytoskeleton maintains the position of the organelles within the cell, providing a support framework and movement of both the cytoplasm and the cell as a whole.

Plant cells, unlike animal cells, are surrounded by a rigid cell wall of cellulose, and contain a large central vacuole filled with cell sap, and chloroplasts which are the sites of photosynthesis.

Review questions

13.16 Give the main functions of the following cell parts. Indicate the kind(s) of cells in which they are usually found.

(a) cell wall
(b) centriole
(c) chloroplast
(d) endoplasmic reticulum
(e) Golgi body
(f) lysosome
(g) microtubules
(h) mitochondrion
(i) nucleolus
(j) nucleus
(k) ribosome
(l) vacuole

13.17 Why are enzymes contained within a lysosome instead of being free in the cytoplasm?

13.18 Distinguish between rough and smooth endoplasmic reticulum.

13.19 Plant cells can usually be distinguished from animal cells because only plant cells possess:

A. cell walls and mitochondria.
B. Golgi bodies and central vacuoles.
C. cell walls and central vacuoles.
D. chromosomes and mitochondria.

13.20 What structural differences are there between prokaryotic and eukaryotic cells?

13.4 Cells in multicellular organisms

In unicellular organisms, the cell must perform all life functions. In order to operate efficiently, cells cannot grow too large. The ratio of surface area to volume decreases with increased size, and the rate of diffusion therefore decreases. Thus for an organism to become larger it must increase its number of cells. In multicellular organisms, the cells are specialised for particular functions. Specialisation leads to the inclusion of some structures in particular cell types and the loss or decrease of others.

13.4.1 Organisation of cells in multicellular organisms

Junctions between cells

Cells of multicellular organisms must remain linked together in some way. Animal cells are often bound together by a non-cellular matrix. This is composed of fibres interspersed in the intercellular fluid. There are also physical connections between cells.

Tight junctions involve the fusing of cell membranes of adjacent cells by proteins on each membrane surface. This fusion is so tight that even small molecules cannot pass through the intercellular space.

Anchoring junctions can be of several types. They may form localised thickenings where filaments penetrate the membranes of both cells. Contractile bundles of actin may pass from the cytoplasm of one cell to another, forming an elastic connection between the cells. Other cells have a very sticky, complex sugar on their surfaces which glues the cells together. Between the cell walls of plants is a thin layer of polysaccharides (pectins) which cements adjoining cells.

Tissues, organs and systems

In most multicellular organisms cells are arranged in **tissues**, which are groups of cells specialised to perform a specific function. This involves structural changes to the individual cells. Thus cells engaged in energy-requiring activities such as movement will have many more mitochondria than those which do not require much energy. Cells specialised for production of enzymes will have a large number of both mitochondria and ribosomes.

Sometimes the specialisation for function results in a different cell shape. Tissues that line parts of an animal are called epithelium. Cells on the outside of the organism tend to be flat: this type of tissue is called squamous epithelium. Stability and binding is provided by this shape and thus underlying tissues are protected. The cells of other epithelial tissues may be column-shaped or cuboidal. They may have cilia or microvilli on their border or they may include secretory, goblet-shaped cells.

Organs are composed of more than one tissue, forming a structural and functional unit such as the heart, stomach or liver of an animal. **Systems** are composed of different organs working together for one main function: for example, the excretory system. Plants do not have true organs and systems, but they are composed of tissues. These may be composed of several different types of cells forming tissue systems (e.g. the tissues involved with conducting organic matter through the plant—the phloem). For convenience, these compound tissues are often referrred to as 'organs' or 'systems'. Thus the leaf is often called an organ, and the tissues composing the root or stem may be referred to as a system. Figure 13.14 summarises the structure of an individual multicellular organism.

The organism cannot survive if the operations of the constituent parts are not coordinated, so communication among the cells of tissues, between organs and thus between systems, is essential. This is essentially achieved by means of chemical signals. Substances transported out of one cell travel to another cell, causing some change in the recipient. Sometimes the chemical signal is very specific to a particular tissue. In these cases, the cells have special recognition sites on their membranes. Only cells with the specific recognition site will respond to that chemical.

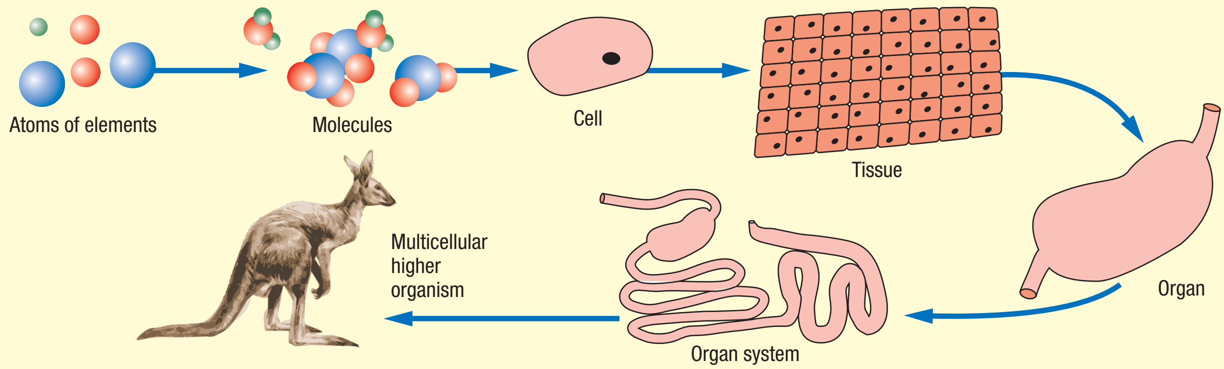


Figure 13.14 Multicellular organisms all share the same basic structural hierarchy.

Table 13.4 Comparison between plant and animal tissues in relation to function

Function	Flowering plant	Vertebrate animal
Digestion of food	no comparable tissue	glandular tissue
Connecting parts and packing spaces	parenchyma	connective tissue
Food storage	parenchyma	fatty connective tissue
Protective surfacing	epidermis, bark	epithelium
Support	xylem, sclerenchyma and collenchyma fibres	cartilage and bone
Food production	chlorenchyma	no comparable tissue
Production of new cells for growth and repair	cambium and meristem	no localised tissues
Production of sex cells	germinal tissues in anthers and ovaries	germinal tissues in testes and ovaries
Transport	non-cellular sap xylem tissue—tracheids and vessels (water) phloem tissue—sieve tubes (organic molecules)	blood, combination of epithelium muscle and connective tissue forming a system of tubes
Coordination	meristematic tissues	nerve tissue and glandular tissue
Locomotion	no comparable tissue	muscle tissue

Special **gap junctions** between animal cells can aid communication between cells by permitting the direct passage of ions and small molecules between them. Direct communication between plant cells occurs through **plasmodesmata**—strands of cytoplasm linking one cell with the next and thus unifying the entire plant.

The presence of the cell wall around plant cells limits movement of the cell, and restricts direct cell-to-cell communication to the plasmodesmata. As a consequence, locomotion in plants is not possible. This determines the strategies that are employed by the plant in carrying out its life functions. These strategies are explored in Chapters 15 and 16.

Animal cells are more flexible and can achieve some degree of movement within their matrix. As a result, locomotion of the whole body can occur. Communication between cells is also more effective. Since they lack cell walls (and thus turgidity), however, animals must have some form of support structure as they increase in size.

SUMMARY

The size of a cell is limited by the ability of the nucleus to control cytoplasmic activities, and by the efficient movement of mate-

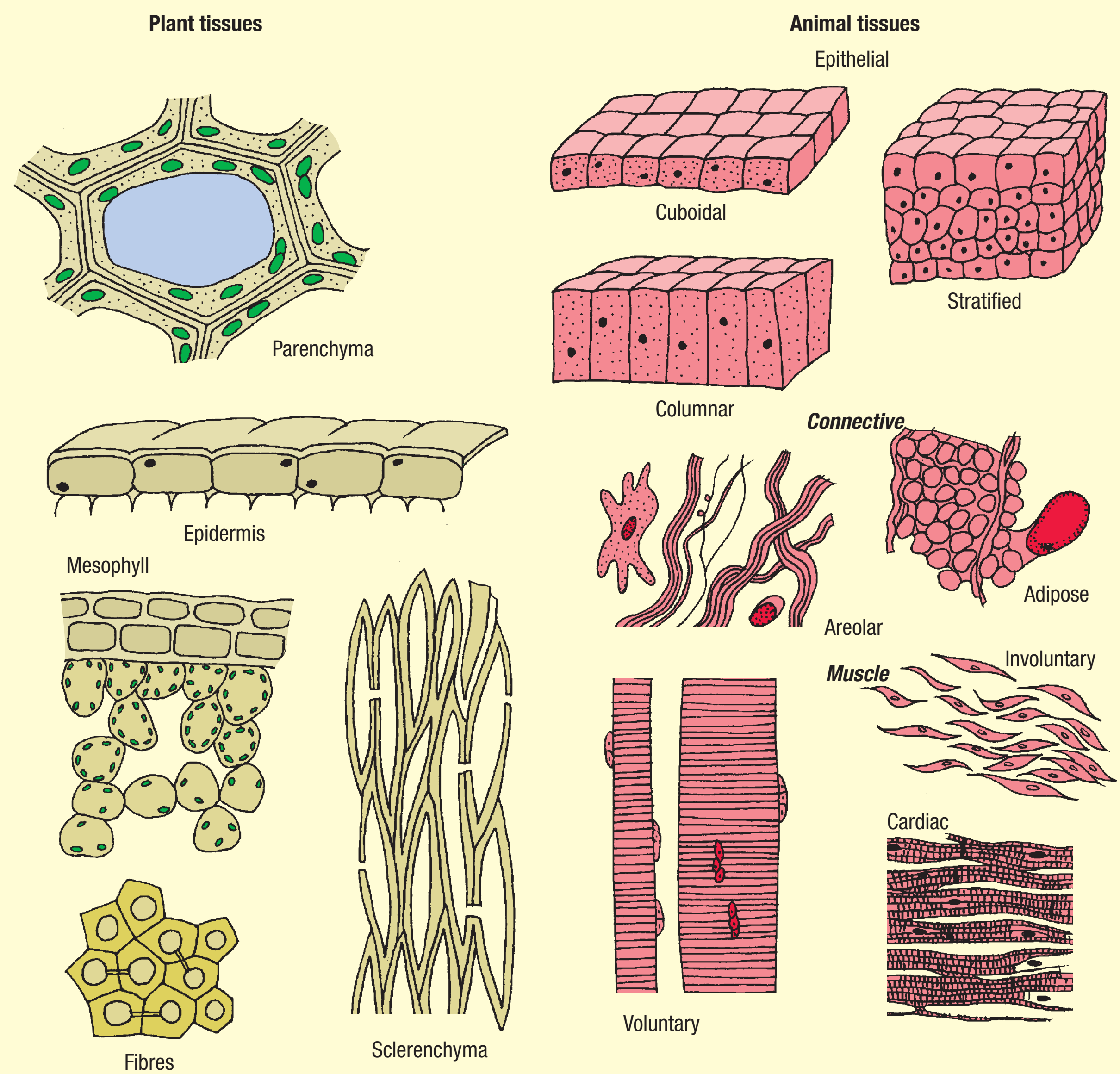


Figure 13.15 Some typical plant and animal tissues

rials into and out of the cell. Increase in the size of an organism results from increase in the number of cells.

Cells of multicellular organisms must stay together. In plants this is achieved by joining adjacent cell walls together with pectins, and by the cytoplasmic bridges between cells (plasmodesmata). In animals a variety of junctions are found between cells as well as the sticky intercellular matrix which binds cells together.

Multicellular organisms show division of labour between cells. The different functions of each cell type often result in slightly different structures between cells. Cells performing a specific function are termed tissues. In animals, tissues form organs and organs are arranged into systems. In plants tissues are arranged into tissue systems.

All cells in the organism must communicate in order to coordinate the activities of the whole body. This communication is achieved by chemical signals.

Characteristics of plants and their tissue systems are directly related to the presence of a cell wall surrounding their cells. While providing turgor pressure, the walls limit the amount of cell movement.

? Review questions

13.21 How does the the ratio of surface area to volume influence cell size?

13.22 Define the following terms:
- (a) tissue
- (b) organ
- (c) system
- (d) tissue system.

13.23 How do cells in tissues:
- (a) remain together
- (b) communicate?

13.24 In what ways does the cell wall influence the structure and functions of a plant?

EXTENDING YOUR IDEAS

1. UB Jane's mother tells her that plants like salts and water. So Jane mixes up a big batch of water and table salt and pours it into her mother's potted plants. All the plants are dead and their tissues dried up after two days. Explain why the plants died.

2. UB Radishes are often used to decorate salads. Small concentric cuts are made around the radish which is then placed in cold water for a period of time. The radish takes on the appearance of a 'rose'. Explain the mechanisms behind this phenomenon.

3. UB What factors might influence the smallest possible size of a cell?

4. IB The surface area of a cube = 6 x ℓ^2, where ℓ is the length of one side.
   The volume of a cube = ℓ^3.
   The surface area of a cylinder (both ends included) = $(2\pi r \times \ell) + 2(r^2)$, where r is the radius, $\pi = 3.14$ and ℓ is the length.
   The volume of a cylinder = $\pi r^2 \times \ell$.
   Showing the working for all calculations, calculate surface area, volume, and the ratio of surface area to volume:
   (a) of a cube where ℓ is
      (i) 1 μm long
      (ii) 3 μm long
   (b) of a cylinder where r = 0.5 μm and ℓ is 1 μm.

   Discuss, referring to the calculations above, the most efficient size and shape for a cell.

5. UB The electromicrograph (photograph produced from an electron microscope) in Figure 13.16 shows a cell organelle, labelled A.
   (a) Name this organelle. Give reasons for your identification.
   (b) Would this organelle be found in a plant or animal cell, or both?
   (c) What is the function of this organelle?

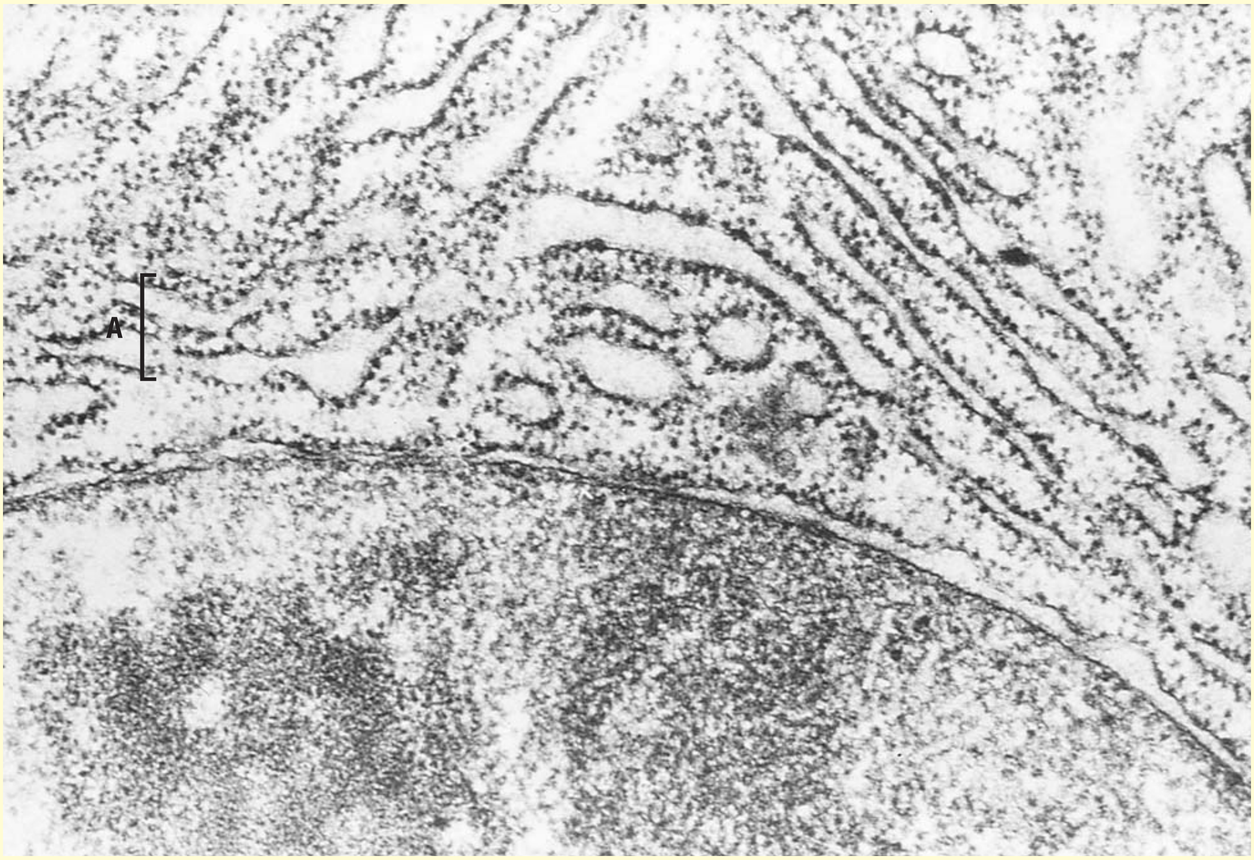


Figure 13.16

6. The electromicrograph in Figure 13.17 shows part of a typical cell of a certain tissue.

UB

(a) Identify the structure labelled X.

(b) Is this from plant or animal tissue? Give reasons for your answer.

(c) Where in the organism would you expect to find this tissue?

Figure 13.17

14 CELL FUNCTIONS

In order for cells to perform life functions they require energy to do metabolic work. This energy is held in the chemical bonds of the organic molecules of which they are composed. Thus cells are energy converters. They take in energy, store it, release it from chemical bonds when required and use it to synthesise the chemicals needed to sustain life. One of the major types of chemicals the cells produce are enzymes, which regulate all of the chemical reactions of the cell. Energy is also used in cell division. Cell division can occur through two different processes—mitosis or meiosis—depending on the role of the division in the life of the cell or multicellular organism. For the majority of organisms, energy that is used to drive these cell functions originates from certain wavelengths of solar energy that are converted to chemical bond energy by cells of photosynthetic organisms.

14.1 RESPIRATION

Energy is released by cell respiration. All cells must perform cell respiration to survive. This generally involves the oxidation of sugar in a series of small steps, each controlled by an enzyme. The energy is stored in the ATP molecule for further use by the cell or transported to other cells within the organism. Some steps in the process are endergonic (energy-requiring); several are exergonic and release energy for the formation of ATP. Cell respiration may occur either in the absence or presence of oxygen. The sugar is able to be broken down into smaller molecules when oxygen is present (**aerobic respiration**) than when oxygen is absent (**anaerobic respiration**). As a consequence more energy is released. Thus in aerobic respiration there is usually an overall gain of thirty-six ATP molecules during the respiration of one glucose molecule.

Aerobic respiration occurs in three stages in eurkaryotic cells: glycolysis, the citric acid cycle and the electron transport chain.

Glycolysis (= splitting of glucose) occurs in the cytoplasm, and is an anaerobic process. No oxygen is required. In a series of steps involving the energy from two ATP molecules:

- each glucose molecule is converted to two pyruvate molecules
- there is an overall gain of two ATP molecules.

If no oxygen is present in the cell, anaerobic respiration continues so that the pyruvate is converted to:

- lactic acid in animal cells
- ethyl alcohol and carbon dioxide in plant cells.

If oxygen is present in the cell, aerobic respiration occurs. Pyruvate and oxygen enter the mitochondrion, where the pyruvate is completely

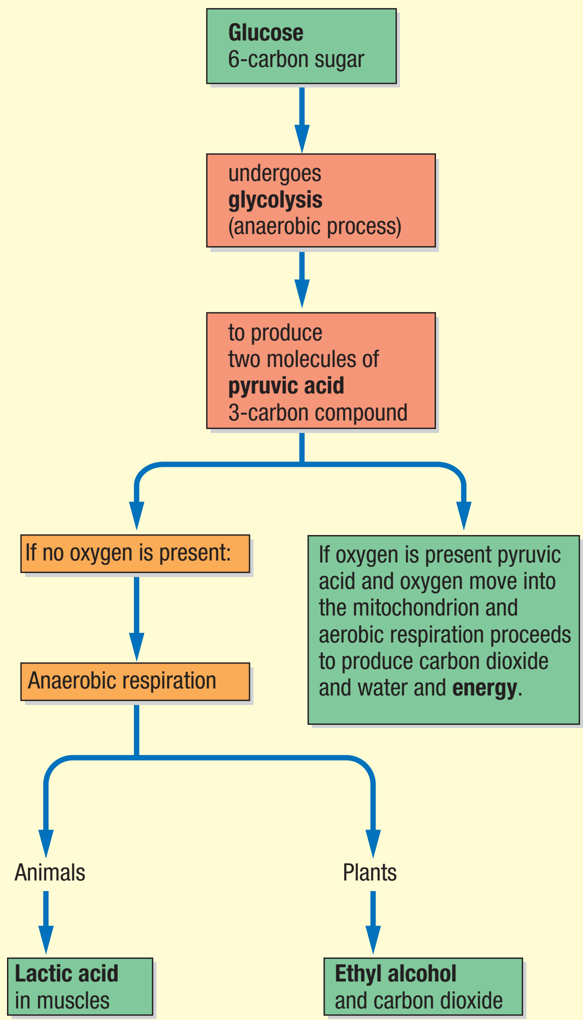


Figure 14.1 The aerobic and anaerobic respiration pathways

broken down to release carbon dioxide, water and thirty-four further ATP molecules in the citric acid cycle and electron transport chain. The oxygen is needed to remove hydrogen released in the citric acid cycle, so that this cycle can continue.

14.1.1 The biochemistry of aerobic respiration

The mitochondrion is a double-membraned cell organelle with the inner membrane deeply folded to form a series of cristae (shelves), which increase the surface area of the membrane. The whole structure is either spherical (e.g. in liver cells) or cigar-shaped, thus providing a high surface area to volume ratio for the efficient uptake and release of materials.

The outer membrane controls the passage of materials into and out of the mitochondrion. The inner membrane, however, is impermeable to ions and so an electrochemical gradient can be established across the membrane. This provides a source of potential energy which is used by the mitochondrion. The inner surface of this membrane contains the enzymes responsible for ATP production.

The matrix within the mitochondrion contains ribosomes, circular DNA molecules and the enzymes required for many of the steps in aerobic respiration.

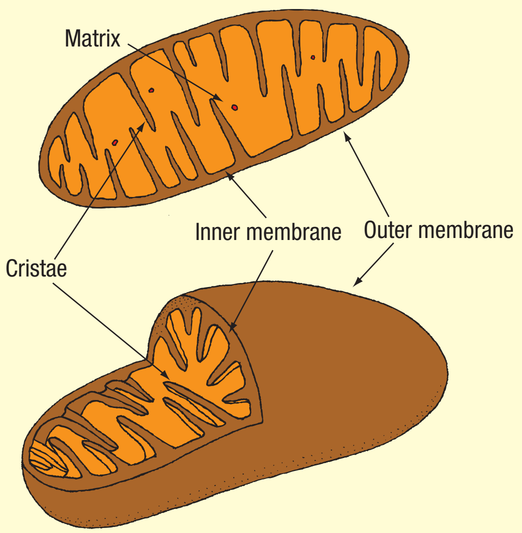


Figure 14.2 The structure of the mitochondrion

Glycolysis is carried out by all living organisms. The initial steps require two ATP molecules to activate the process and during glycolysis:

- a 6-carbon glucose molecule is converted to two 3-carbon pyruvate molecules
- Four ATP molecules are formed (a net gain of two ATP as four ATP molecules are produced but two ATP were needed as activation energy)
- Four hydrogen ions and eight electrons are transferred to the coenzyme NAD^+ (nicotinamide adenine dinucleotide) to form two NADH plus $2H^+$.

If oxygen is present then the pyruvate leaves the cytoplasm, entering the mitochondrion by passing through the outer membrane, the outer compartment and the inner membrane into the inner compartment (the matrix of the mitochondrion). Here the enzyme-activated steps of aerobic respiration occur.

Forming acetyl CoA

A molecule of carbon dioxide is removed from each pyruvate, and so two carbon dioxide molecules are released as a waste product. The remaining 2-carbon fragment is added to coenzyme A to form acetyl coenzyme A (acetyl CoA). In this process another two molecules of NAD^+ are used to produce a further two molecules of NADH plus $2H^+$. Acetyl CoA then enters the citric acid cycle.

The citric acid cycle

This cycle has several different names—the citric acid cycle, the Krebs cycle and the tricarboxylic acid (TBA) cycle, or a combination of these.

The citric acid cycle involves the formation of citric acid from the combination of acetyl CoA with a 4-carbon compound, and the subsequent breakdown of this 6-carbon compound to release:

- Eight hydrogen atoms which form:
- three NADH + $3H^+$ and 1 $FADH_2$ (FAD—flavin adenine dinucleotide—also accepts hydrogen atoms)
- one ATP molecule
- two carbon dioxide molecules
- the original four carbon compound

for each acetyl CoA molecule.

Since two of these molecules are formed as a result of the breakdown of one molecule of glucose, the output from the Krebs cycle is:

- 6 NADH + $6H^+$
- 2 $FADH_2$
- 4 CO_2

Altogether, six water molecules are used in the reactions.

Electron transport chain

The twenty-four hydrogen atoms formed in the previous steps (four from glycolysis, four from the formation of acetyl CoA and sixteen from the citric acid cycle, and carried as NADH, H^+ and $FADH_2$) are used in the electron transport chain. Twelve pairs of electrons are transferred from these molecules to a coenzyme chain (a series of specialised proteins embedded in the inner membrane of the mitochondrion). This inner membrane divides the mitochondrion into two compartments. The electrons, which have high potential energy, release bundles of energy as they pass from one specialised protein to the next, and this energy is used to drive the freed H^+ from the inner compartment to the outer mitochondrial compartment through these proteins and so are concentrated there. The hydrogen ions (H^+) flow back into the inner compartment through ATP synthesases protein channels. This flow back process drives the formation of ATP from ADP + ~ P. In many types of cells this results in the formation of thirty-two ATP molecules. The 2NADH and $2H^+$ produced during glycolysis cannot enter the mitochondrion unless they are shuttled across the membrane by coenzymes.

When the electrons reach the end of the transport chain, they have low-energy potential and are combined with twelve pairs of hydrogen ions that have flowed back into the inner compartment. The twenty-four hydrogen atoms combine with six oxygen molecules to form twelve water molecules. There is a net gain of six water molecules as six water molecules were used in the citric acid cycle.

Thus respiration can be summarised as:

$$C_6H_{12}O_6 + 2ATP + 6H_2O + 38ADP + 38\text{~}P + 6O_2 \longrightarrow 2ADP + 2\text{~}P + 6CO_2 + 12H_2O + 38ATP$$

For each glucose molecule there is the release of $6CO_2$, $6H_2O$ (as wastes) and thirty-six ATP molecules (as a chemical energy transfer molecule).

Fats and amino acids can also be used as energy sources, after first being converted to acetyl CoA which can enter the Krebs cycle. The breakdown of fats for respiration occurs when there is no more glycogen (in animals) or starch (in plants) available to convert to glucose. When all fat reserves have been depleted, the organism will then convert proteins for respiration.

A simplified flowchart of aerobic respiration is shown in Figure 14.4 on pages 350–1.

14.1.2 Anaerobic respiration

Some organisms can derive adequate energy from anaerobic respiration alone. In general, two types of anaerobes are recognised. Complete anaerobes live permanently in oxygen-deficient conditions and so are completely independent of oxygen for respiration. In some cases they may be poisoned by even small concentrations of oxygen. Examples include certain bacteria and some parasites.

Partial anaerobes thrive in the presence of oxygen, but resort to anaerobic respiration if oxygen

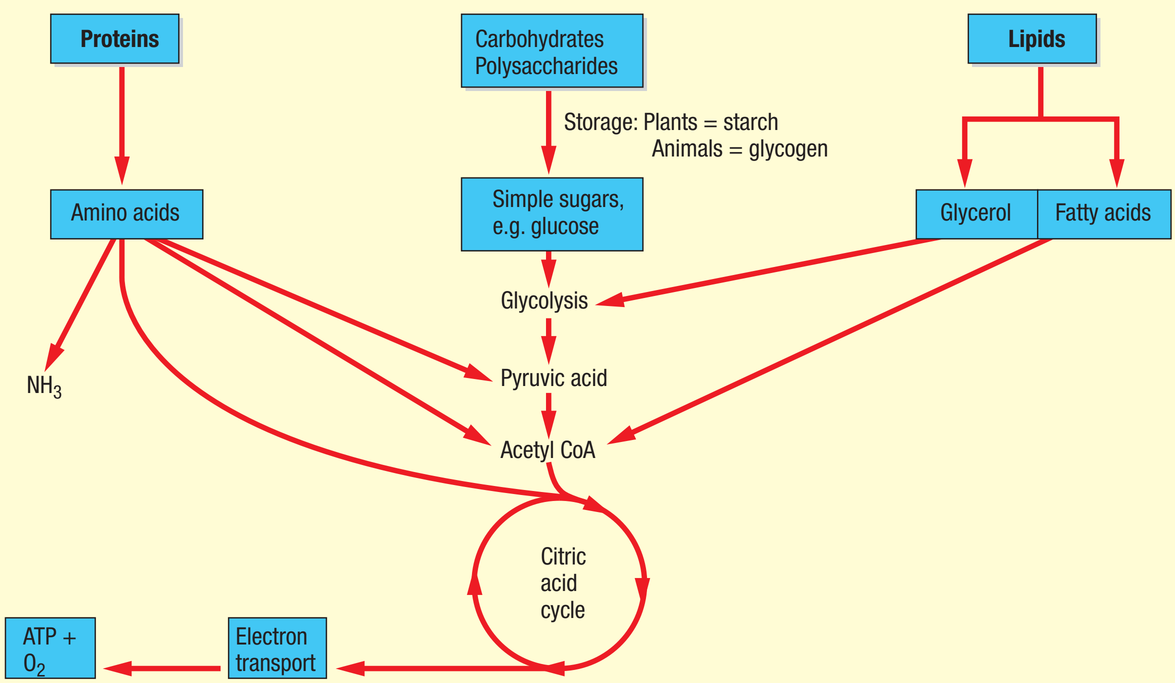


Figure 14.3 Respiration of carbohydrates, lipids and proteins

(a)

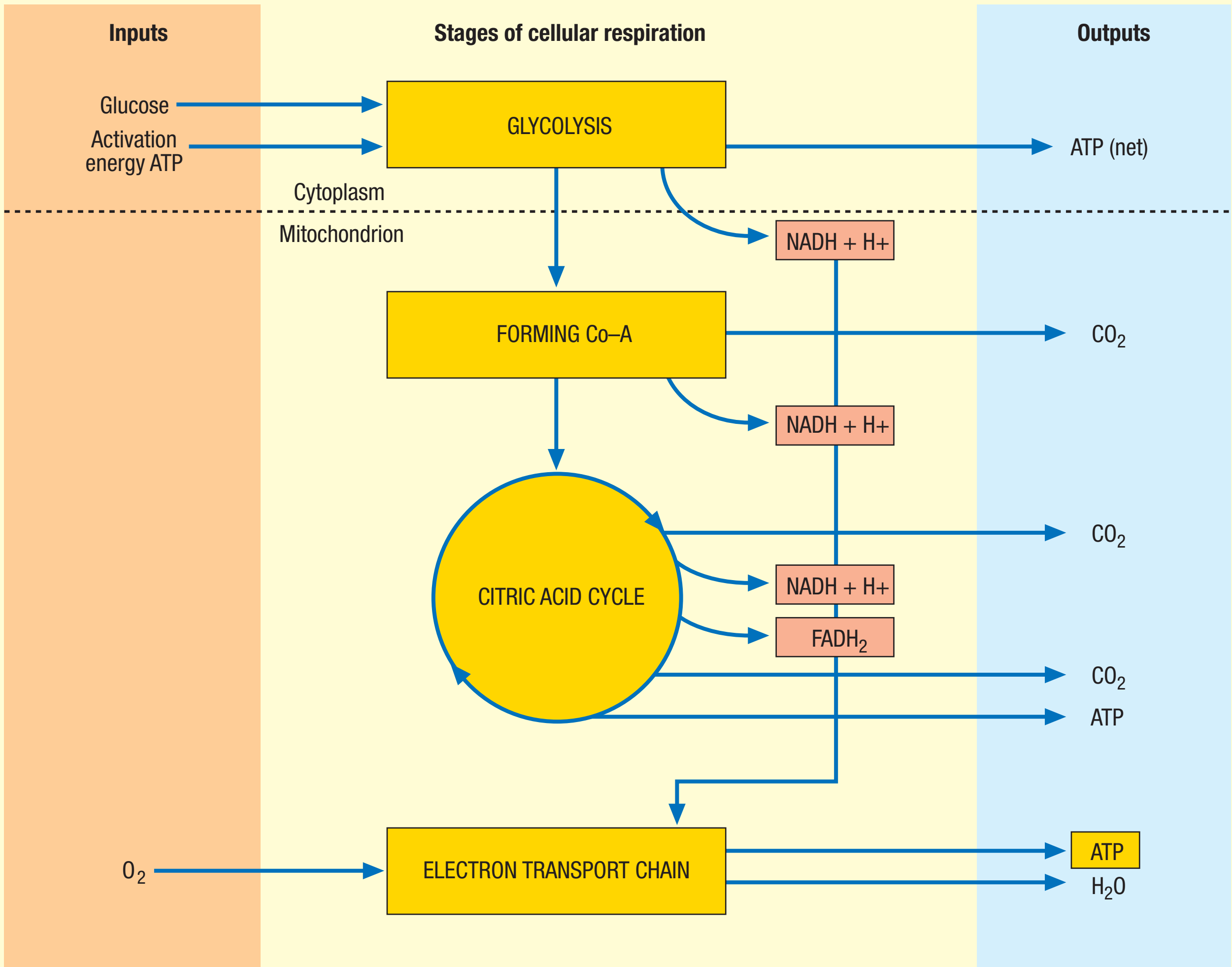
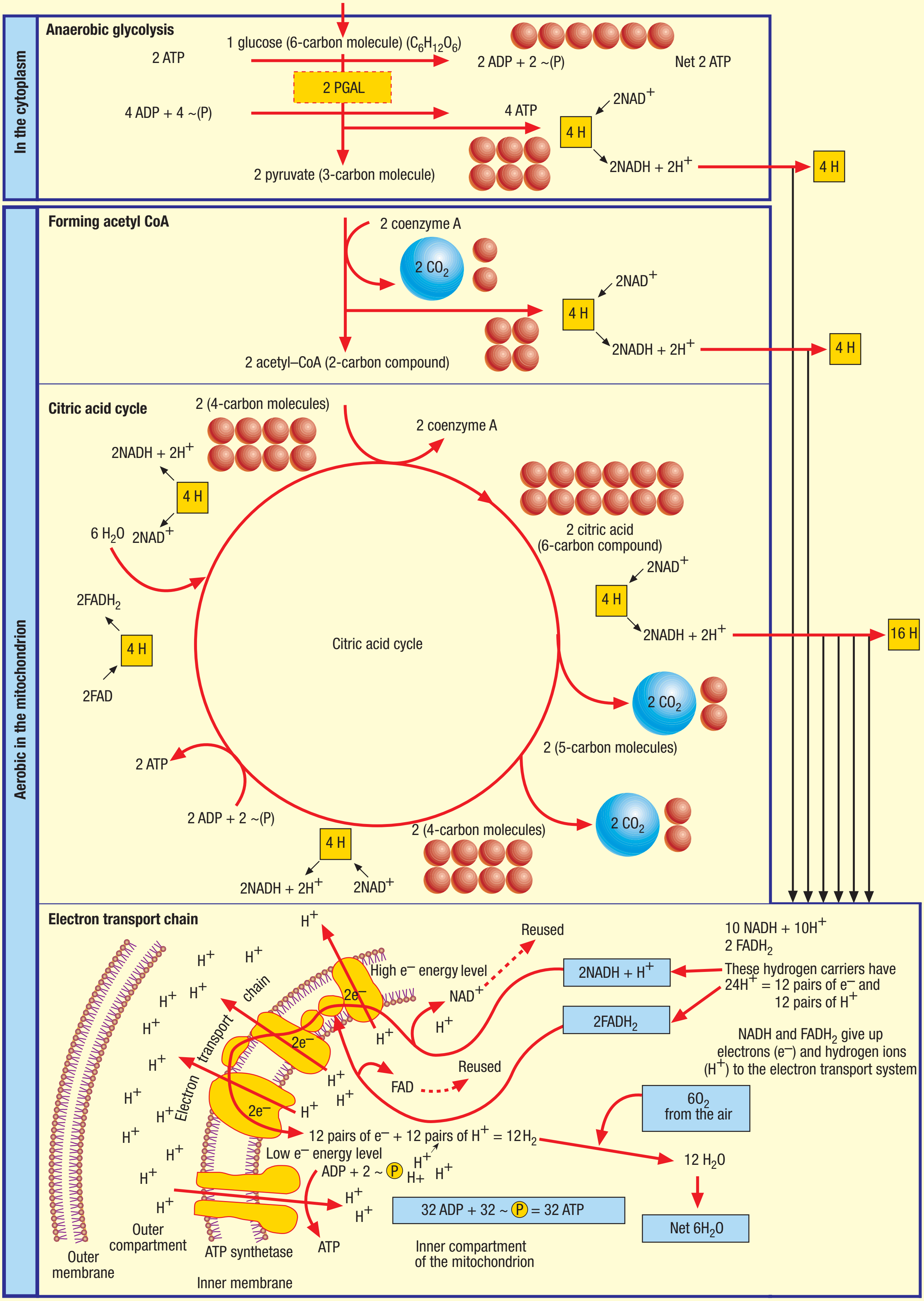


Figure 14.4 (a) and (b) Simplified flow charts of aerobic respiration

(b)



Polysaccharides (carbohydrates)
In the cytoplasm
Anaerobic glycolysis
1 glucose (6-carbon molecule) ($C_6H_{12}O_6$)
2 ATP
2 ADP + 2 ~(P)
Net 2 ATP
2 PGAL
4 ADP + 4 ~(P)
4 ATP
$2NAD^+$
4 H
$2NADH + 2H^+$
2 pyruvate (3-carbon molecule)
4 H
Aerobic in the mitochondrion
Forming acetyl CoA
2 coenzyme A
2 CO_2
$2NAD^+$
4 H
$2NADH + 2H^+$
4 H
2 acetyl–CoA (2-carbon compound)
Citric acid cycle
2 (4-carbon molecules)
2 coenzyme A
$2NADH + 2H^+$
4 H
6 H_2O
$2NAD^+$
2 citric acid
(6-carbon compound)
$2NAD^+$
4 H
$2NADH + 2H^+$
16 H
$2FADH_2$
4 H
2FAD
Citric acid cycle
2 CO_2
2 (5-carbon molecules)
2 ATP
2 ADP + 2 ~(P)
4 H
$2NADH + 2H^+$
$2NAD^+$
2 (4-carbon molecules)
2 CO_2
Electron transport chain
H^+
Reused
10 NADH + $10H^+$
2 $FADH_2$
$2NADH + H^+$
These hydrogen carriers have
$24H^+$ = 12 pairs of e– and
12 pairs of H^+
High e– energy level
NAD^+
2e–
2e–
2e–
Electron transport chain
$2FADH_2$
NADH and $FADH_2$ give up
electrons (e–) and hydrogen ions
(H^+) to the electron transport system
FAD
Reused
$6O_2$
from the air
12 pairs of e– + 12 pairs of H^+ = 12H_2
12 H_2O
Low e– energy level
ADP + 2 ~ (P)
32 ADP + 32 ~ (P) = 32 ATP
Net $6H_2O$
ATP
Outer compartment
ATP synthetase
Inner compartment
of the mitochondrion
Outer membrane
Inner membrane

is absent or in short supply. Most organisms that respire anaerobically belong in this category. Examples include worms living in the mud at the bottom of stagnant pools or oceans, and diving mammals such as whales which can stay under water for long periods. The length of time an organism can survive without oxygen varies—a matter of minutes for humans, while some lower organisms and plants can respire anaerobically for much longer periods.

If a person undergoes vigorous exercise, more energy is required than can be supplied aerobically. This is because the breathing and circulatory systems cannot operate fast enough to sustain an adequate supply of oxygen. Oxygen from a special muscle storage molecule, myoglobin, is first used as the supply from the blood is depleted. The muscle fibres then provide energy anaerobically and produce lactic acid. Lactic acid is a metabolic poison and cannot be accumulated in large amounts.

When exercise is completed the lactic acid must be either broken down into carbon dioxide and water or reconverted to carbohydrate. Oxygen is needed for these processes. Panting for a period of time after exercise increases the uptake of oxygen into the bloodstream. The amount of oxygen needed to get rid of the lactic acid is called the **oxygen debt**. 'Stiffness' of muscles occurs because lactic acid accumulates in sufficient amounts to cause muscle fibre damage before it is broken down.

The products of anaerobic respiration in plants are ethyl alcohol and carbon dioxide, which they cannot use and cannot reconvert to carbohydrate. Nor can alcohol be broken down further in the presence of oxygen. As it is toxic, it must not be allowed to accumulate. While many plants can indulge in anaerobiosis for a short period of time (e.g. germinating seeds or roots in waterlogged soil), they must revert to aerobic respiration before the ethyl alcohol levels reach toxic levels and cause death. Thus very few plants can be complete anaerobes.

The yeasts (fungi) used in wine production are eventually killed by the ethyl alcohol that they produce in anaerobic respiration. Different yeasts have different tolerances to ethyl alcohol and wines therefore vary in alcohol content according to the yeast used in their fermentation.

SUMMARY

Cells require energy to perform their life functions. Since there is a constant loss of energy from cells in the form of heat, energy must be replaced, used in endergonic reactions, stored as chemical bond energy and released as required. Cells are energy converters.

Cellular respiration releases energy from organic molecules to ATP. Carbon dioxide and water are waste products. There are three phases in the complete metabolic pathway. Glycolysis is an anaerobic process which occurs in the cell cytoplasm. A glucose molecule is converted to two molecules of pyruvate, releasing a net of two ATP molecules and hydrogen which becomes attached to carrier molecules.

If oxygen is present, pyruvate can enter the mitochondrion, along with the oxygen. Pyruvate is completely broken down to carbon dioxide and water, releasing a further thirty-four ATP molecules.

If oxygen is not present, the pyruvate is converted to lactic acid in animals and ethyl alcohol and carbon dioxide in plants. Both lactic acid and ethyl alcohol are metabolic poisons which result in cell damage and death if allowed to accumulate. Anaerobic respiration results in the net production of only two ATP molecules—the rest of the energy is stored in the many chemical bonds of the large end-product organic molecules.

Table 14.1 Aerobic and anaerobic respiration

Anaerobic respiration	Aerobic respiration
Occurs in cytoplasm of the cell.	Occurs in mitochondria of the eukaryotic cell.
Oxygen not required.	Oxygen required.
Glycolysis: glucose converted to pyruvic acid and two ATP molecules. This is a very low energy yield.	Pyruvic acid converted to carbon dioxide, water and a further thirty-four ATP molecules in the Krebs cycle and electron transfer chain processes. This is a very high energy yield per glucose molecule.
A very energy-inefficient process.	A very energy-efficient process.
Pyruvic acid in the absence of oxygen cannot enter the mitochondrion and is converted to lactic acid (animals) or ethyl alcohol and carbon dioxide (plants).	Pyruvic acid with oxygen present can enter the mitochondrion and thus the Krebs cycle and electron transfer chain.

Review questions

14.1 Write an equation to describe respiration.

14.2 Give a concise account of how energy is made available to cells.

14.3 What are the distinguishing features between the processes involved in glycolysis and the citric acid cycle?

14.4 (a) In which part of the respiration process is the most energy released?
(b) Describe the process of this energy release.

14.5 Discuss the circumstances in which:
(a) carbohydrate,
(b) fat and
(c) protein
are the substrates for cell respiration;
and the circumstances in which:
(d) carbon dioxide,
(e) ethyl alcohol and
(f) lactic acid
are the end products of respiration.

14.6 Compare and contrast aerobic and anaerobic respiration.

14.7 Distinguish between a complete and a partial anaerobe.

14.2 Synthesis of proteins

The specific function and structures of any particular cell in a multicellular organism are controlled by the DNA in the cell nucleus. This is achieved through the production of proteins (e.g. structural proteins, enzymes, hormones).

A gene is a segment of DNA, and one gene generally controls the synthesis of one protein. A segment of DNA 'unzips' to expose the nucleotide bases of a particular gene. A length of 'messenger RNA' (mRNA), consisting of complementary bases, is formed at this site and detaches. This process is called **transcription**. The messenger RNA leaves the nucleus and attaches to ribosomes on the endoplasmic reticulum.

Within the cytoplasm are other short lengths of RNA molecules: transfer RNA (tRNA). Each tRNA collects a specific amino acid and carries it to the appropriate, complementary position on the mRNA. Adjoining amino acids link together. This releases the tRNA to pick up and transport more amino acids to locations on the mRNA. The process continues until the end of the mRNA is reached. The interaction between the mRNA, ribosomes and tRNAs in the production of the polypeptide chain is termed **translation**. At some point the mRNA is destroyed and no more of that polypeptide is produced.

The polypeptides move away from the ribosome. Some of these need the addition of other molecules to complete the formation of specific proteins. This is achieved in the Golgi apparatus. The completed protein will then be released, either to the cytoplasm (e.g. hydrolytic enzymes in membrane-bound lysosomes) or excreted to the exterior of the cell (e.g. hormones, extracellular enzymes). Other polypeptide chains do not need additional molecules added and will fold to form a protein.

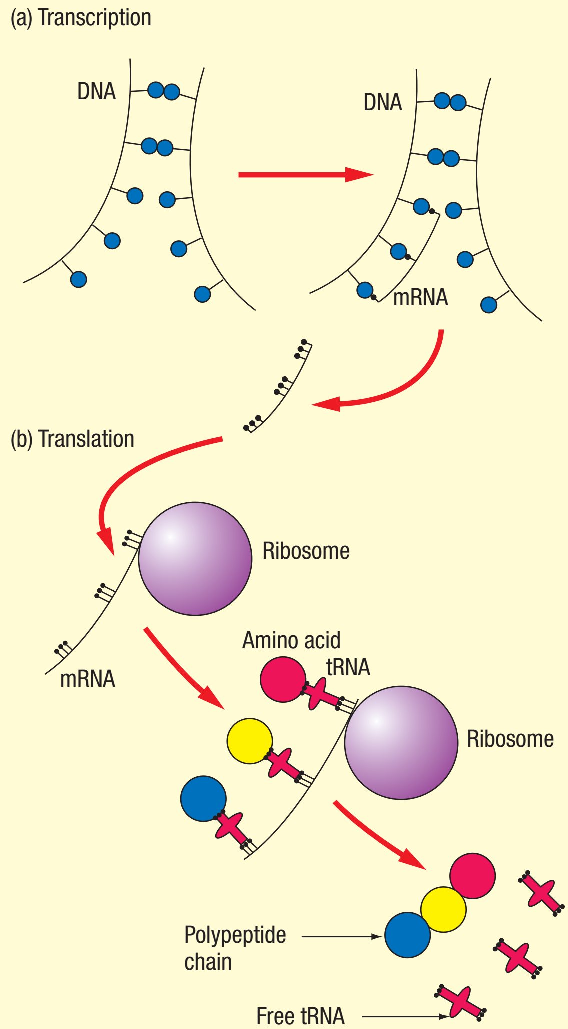


Figure 14.5 Transcription and translation

The production of proteins can be likened to manufacture in a factory:

- The blueprint (DNA) defines the product.
- A copy of this plan (mRNA) is transferred to the assembly line (ribsomes) where raw materials are conveyed (tRNA) to complete the desired article (polypeptide chain).
- The article is then packaged for distribution (Golgi apparatus).

Protein synthesis will be revisited in Chapter 21.

SUMMARY

Protein production controls all cell activities, forming structural components, chemical signals and enzymes which regulate all chemical reactions. Protein production is controlled by a set of encoded messages on the DNA. The message for a particular protein is translated from the DNA onto a mRNA molecule which leaves the nucleus and attaches to a ribosome. tRNA picks up appropriate amino acids from the cytoplasm and places them in the correct sequence on the mRNA. Bonds form between each amino acid to form a polypeptide chain. When each chain is completed, it is released from the ribosome.

? Review questions

14.8 Transcription and translation are two phases in protein synthesis. To what do these two terms refer?

14.9 Describe the roles played by each of the following molecules in protein synthesis.

(a) DNA
(b) gene
(c) mRNA
(d) tRNA
(e) amino acids
(f) endoplasmic reticulum
(g) polypeptide chain
(h) Golgi apparatus.

14.10 Which of the following is the correct pathway for the production, transport and secretion of a cellular glycoprotein?

A. mitochondria—ribosomes—endoplasmic reticulum—DNA
B. DNA—ribosomes—endoplasmic reticulum—Golgi apparatus —cell membrane
C. lysosomes—vacuoles—ribosomes—endoplasmic reticulum
D. nucleolus—nuclear membrane—ribosomes—Golgi apparatus

14.3 Cell division

Each species has a specific number of chromosomes, and different chromosomes carry different sorts of genetic information. The dividing cells must ensure that the new cells have both the same number and the same types of chromosomes as the original.

Usually the cells of the adult organism contain pairs of chromosomes. There are two of each type of chromosome which carry the same kinds of genetic information. These cells are said to be in the **diploid** condition and are represented as $2n$, where n is the number of types of chromosomes. If the cell contains only one of each type of chromosome, it is said to be in the **haploid** condition and is represented as n.

Cell division is initiated by the division of the nucleus. Two types of nuclear division occur: mitosis and meiosis.

Mitosis takes place during the growth of an organism and is the basis of the reproductive processes of binary and multiple fission in unicellular organisms, gamete formation in plants and budding and vegetative propagation in multicellular organisms. It yields daughter cells that have the same number and types of chromosomes as the parent cell.

Meiosis generally takes place in the formation of gametes, although in plants it occurs in the formation of spores. During sexual reproduction, a gamete from each of two different parents fuses to form the zygote, the start of a new individual. In order to maintain species continuity the zygote must have the same number and types of chromosomes as the adults. Thus gametes must have half the number but the same types of chromosomes as an adult cell. During meiosis, therefore, haploid cells are formed from a diploid cell.

14.3.1 The cell cycle

The cells of multicellular organisms grow and multiply through a cycle of four phases. The first three stages of this cycle involve growth and high metabolic activity within the cell and the fourth phase involves division. The length of the **cell cycle** is different in different cells in the body or at different stages of overall growth of the body. Thus the cycle of some cells may only take a matter of hours, whereas for others (like human brain cells) the cycle may take many years to complete.

Three of the phases can be grouped together as **interphase** and the fourth phase (involving nuclear division, or mitosis, and separation of the daughter cells, or **cytokinesis**) is called **cell division**.

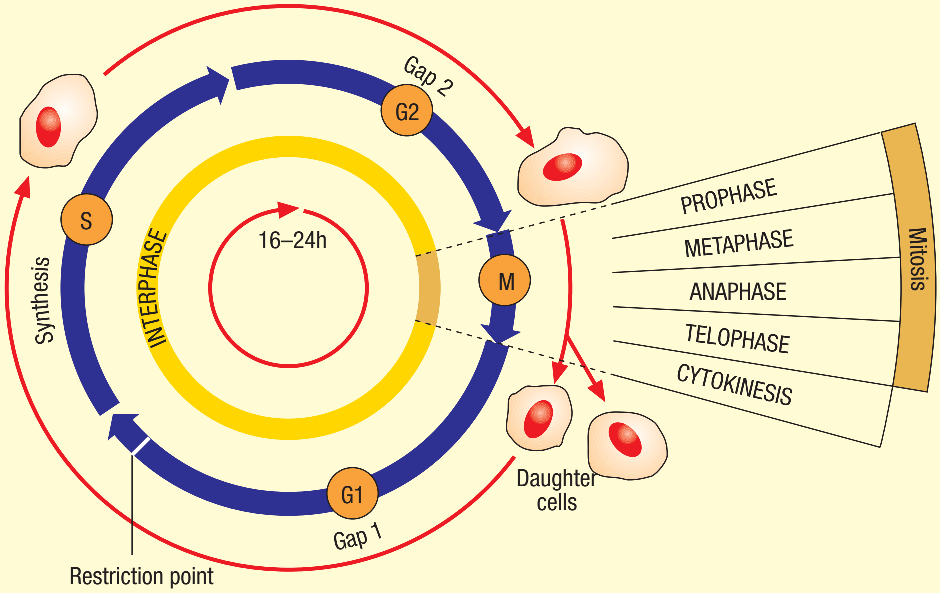


Figure 14.6 The cell cycle

The first phase of interphase is known as the G1 phase, where G represents growth. It is a time of very rapid growth which involves a high degree of metabolic activity resulting in the synthesis of a RNA and a large number of proteins. This allows the increase in size and number of cell organelles such as mitochondria, chloroplasts (in plants), the endoplasmic reticulum and the Golgi apparatus.

The second, S, phase involves the synthesis of nucleotides in the nucleolus and replication of DNA. During interphase the chromosomes are not visible as distinct bodies but are strung out in long chromatin threads which are swollen at intervals. As the cell grows and matures, the genetic material (DNA) of each chromatin thread replicates (is copied), using the existing DNA molecules as the patterns and nucleotides in the nucleus for material. The original and replicated strands of DNA remain connected at a point called the **centromere.** Protein molecules, called histones, are produced and cover each DNA strand. Each chromosome has become two **chromatids**.

The third, G2, stage involves cellular synthesis in preparation for cell division—a process that is energy-intensive and requires many proteins. In animal cells the centrioles replicate. Strands of protein that will form the spindle fibres start to assemble.

The cell has now accumulated the chemical resources and energy necessary to undertake nuclear division. This involves the separation of chromatids and the segregation of the chromosomes at opposite sides of the cell. At the completion of mitosis the entire cell divides so that each new daughter cell has a complete set of chromosomes as well as cytoplasm and organelles. Each of these cells then enters interphase and the cycle repeats itself.

Mitosis and cytokinesis

There are four stages in nuclear division or mitosis: prophase, metaphase, anaphase and telophase. These phases are followed by division of the cytoplasm to form two cells (by cytokinesis).

Prophase

Prophase mobilises mitotic division. The DNA threads condense to form distinct, thickened chromosomes. Each of these chromosomes consists of two strands, chromatids, which lie parallel to each other along their length and are joined at a point called the centromere. Each chromatid contains one side of the original DNA and a complementary, replicated side. While the chromosomes are condensing, a series of protein threads are formed in the cytoplasm to form a spindle which spans the length of the cell. The two ends of the spindle are called the poles and the middle region the equator. In animal cells the centrioles separate and migrate to opposite poles of the spindle. The nucleolus of the nucleus breaks down and the nuclear membrane begins to separate.

Metaphase

With the disappearance of the nuclear membrane, the chromosomes migrate to the equator of the spindle, each chromosome attaching to an individual spindle fibre at its centromere. The arrangement of the chromosomes on the spindle fibres is apparently random and may change from division to division.

Anaphase

During anaphase the chromatids separate to opposite poles of the spindle. The exact mechanism is not known but congregation of mitochondria around the spindle suggests that large amounts of energy are required. It has been suggested that the spindle fibres, with the input of energy, contract and separate at the equator and as they pull towards opposite poles the centromere, and thus the chromatids part company.

Telophase

On reaching the polar ends of the spindle, the chromatids, which will become the chromosomes of the daughter cells, congregate tightly together. The spindle breaks down and a new nuclear membrane is formed around each bundle of chromosomes. The nucleolus reappears and the chromosomes uncoil to revert to chromatin threads.

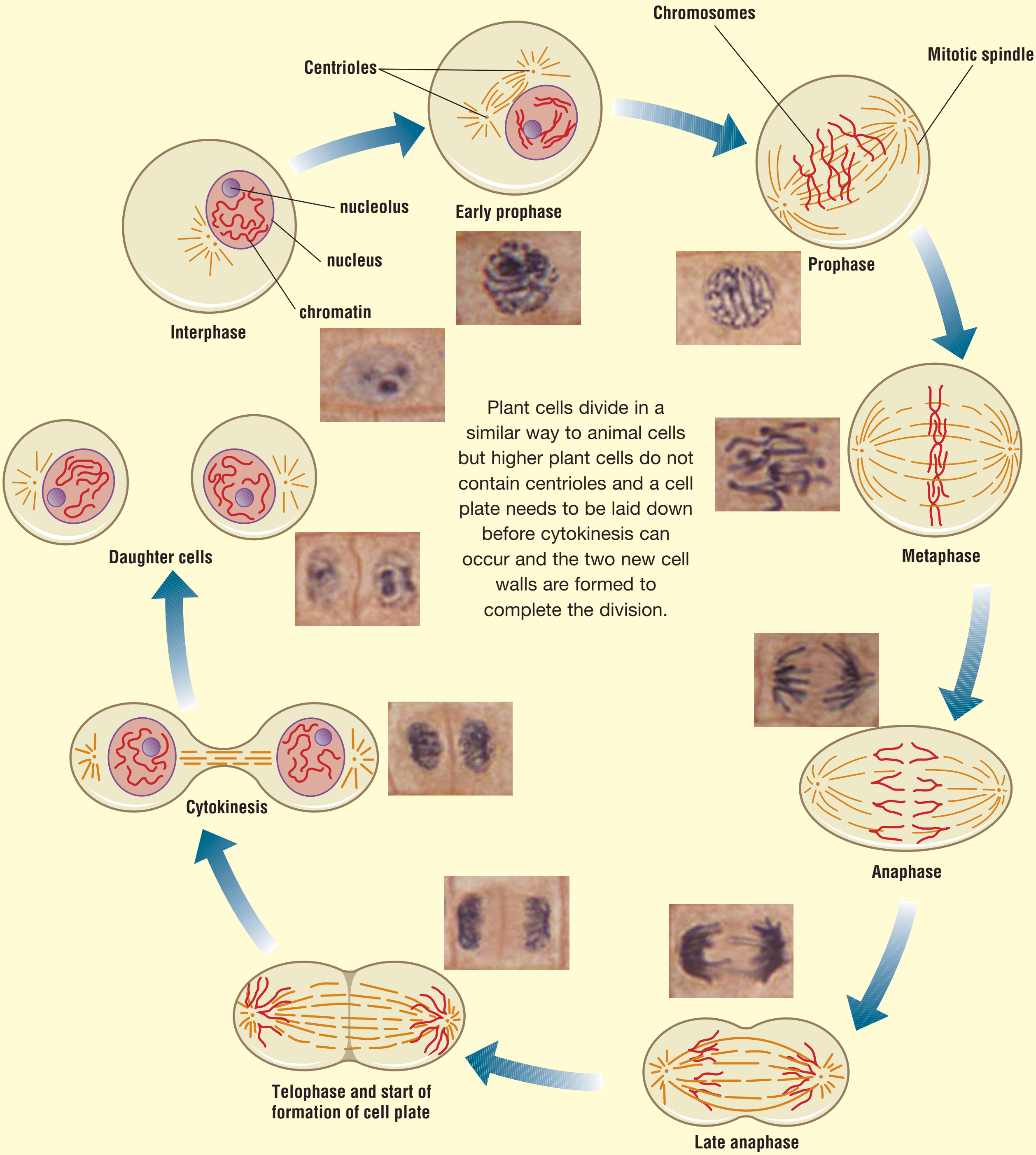


Figure 14.7 Stages in mitosis and cytokinesis in a diploid animal cell with four chromosomes (drawings) and a plant cell (photographs).

Cytokinesis

While the events of telophase are occurring, division of the cytoplasm between the two poles commences. In animal cells the cell membrane constricts across the equator of the spindle to form two new cells. In plants a cell plate, derived from vesicles of the Golgi apparatus, grows across the middle of the cell to unite with the existing cell membrane. New cell walls are produced between the membranes of the plate prior to separation.

Significant features in the cell cycle are:

- Just prior to division there is replication of DNA. Each chromosome now consists of two identical chromatids.
- Each chromosome attaches to a separate spindle fibre.
- Separation of the chromatids of each chromosome to opposite poles of the spindle ensures that each pole contains the same number and types of new chromosomes.
- The daughter cells will therefore have exactly the same number and type of chromosomes as the original cell. Thus diploid cells will divide to form diploid daughter cells, and haploid cells will form haploid daughter cells.
- At each division two daughter cells are produced.
- A period of time between divisions (interphase) is required for the cell to grow, store energy and replicate DNA and organelles.

Although cytokinesis normally follows mitosis, there are exceptions. The plasmodial phase in the life cycle of some slime moulds and the formation of skeletal muscle fibres in vertebrate animals result from mitosis without cytokinesis.

Some cell types go through the cell cycle—growth, mitosis and cytokinesis—continuously throughout the life of the organism. Examples of this include single-celled organisms and certain plant and animal cells. Since red blood cells of vertebrates do not have a nucleus and live only for about 120 days, cells in the bone marrow constantly divide to maintain the correct number of red blood cells in the body. Other cell types (e.g. brain cells) do not undergo further division once the organism is mature.

A third category of cells divide only at a sufficient rate to produce the number of cells that are required for growth and replacement. Human liver cells, for example, do not normally divide after the liver has reached a certain size. If some of the liver is surgically removed, the existing cells are triggered into division mode until the liver has regained its original size. Cell division then stops.

The nature of the control system or systems that regulate the cell cycle are still unclear. Certain hormones (e.g. growth hormone) and other chemicals have been shown to stimulate cell division. Other chemicals or cell overcrowding can inhibit it. The control of cell division is of particular interest to researchers since cancers result from uncontrolled cell division in multicellular organisms.

Case study 14.1: Cancer—uncontrolled cell division

Within each cell of multicellular organisms is a gene which programs for cell death, or apostasis (*apo* = away; *ptosis* = fall), and causes the cell to shrink and fragment. The fragments are then destroyed. Another gene suppresses this gene. It appears that the balance of activity between these two genes determines whether a cell lives or dies. In many cases studied, any damage to the cell's DNA triggers the activity of the death gene and suppresses that of the survival gene.

Selective pressures favour whole organisms which can reproduce at a greater rate than others of their kind which may have slightly different genetic compositions. In a similar way selection pressures act on individual cells within the organism. Any mutant cell in the organism which can grow more rapidly than surrounding cells has an advantage. The advantage to the particular cell type, however, creates a disadvantage to the whole organism.

Eventually these cells become independent of their surrounding cells, forming a bulk of tissue or tumour. If they become encapsulated, the tumour does not spread from the area: it is benign. Other tumours are not contained in a capsule and can spread throughout the whole body. These are termed cancers. Because they are not restricted to one area, they do not develop the characteristics of any particular tissue type. Cancer cells remain very generalised in their structure. They kill the surrounding cells, either by strangling them or by being more competitive in gaining limited resources. Vital functions of the body are therefore disrupted. The DNA mutations in the cancer cells have somehow deleted or suppressed the death gene. At the same time they have become independent of the normal body controls on cell division.

The causes of cancer are numerous. All cancer cells result from changes in the DNA of body cells. They often have abnormal numbers of chromosomes or chromosomal abnormalities. Some cancers result from constant injury or aggravation of tissue (thus benign moles can become cancerous), mutagens (radiation and chemicals which cause DNA changes or mutations) and viruses.

14.3.2 Meiosis

During meiosis, the chromosome number is halved so that each daughter cell has only one of each type of chromosome. The diploid condition of the original cell is reduced to the haploid condition. Each daughter cell has exactly the same types of chromosomes, but only one of each pair. When haploid cells fuse during fertilisation, therefore, the diploid condition is restored and species continuity assured.

In meiosis there are two successive divisions. The first involves the separation of the pairs of chromosomes into separate cells and the second involves separation of the chromatids. Interphase involves growth of the cell, storage of energy and replication of the DNA and organelles.

Prophase 1

During prophase 1 the nucleolus disappears, spindles form and the nuclear membrane breaks down as in mitosis. In animal cells the centrioles migrate to opposite poles of the cell. The chromosomes, each consisting of two chromatids joined at the centromere, condense. As they do so, they align themselves in pairs of **homologous** (same type of) **chromosomes**. Thus there is an arrangement of four chromatids, or a **tetrad**, of the same type lying side by side.

These chromatids may become very entwined and joined at points called **chiasmata** along their length, where later exchanges of genetic material between chromatids may occur. The significance of this will be discussed in Unit 7 and is not included in this description.

Metaphase 1

The homologous chromosomes arrange themselves as a tetrad at the equator of the spindle fibres, in such a way that each member of the pair aligns itself towards opposite poles. Each set of chromatids orients itself to the same pole.

Anaphase 1

Contraction of the spindle fibres separates the homologous chromosomes to opposite poles of the cell. At each end of the cell there is one of each type of chromosome, each consisting of two chromatids.

Telophase 1 and Cytokinesis 1

The cell divides across the equator of the spindle. The spindle fibres break down. Some cells may then go into a short interphase or they may proceed directly to the second meiotic division. A nuclear membrane is not formed around the chromosomes at this stage.

Prophase 2

A new spindle is formed perpendicular to that of the original cell.

Metaphase 2

Individual chromosomes, each consisting of two chromatids, migrate to the equator of the spindle and attach at the centromeres.

Anaphase 2

Contraction of the spindle fibres separates the chromatids at the centromere and each is pulled to the opposite poles of the cell.

Telophase 2 and Cytokinesis 2

The spindle fibres disappear, the cell divides across its equator and a new nuclear membrane is formed around the chromosomes. The four daughter cells so formed then go into interphase.

Significant features of meiosis are:

- There are two successive divisions.
- The first division separates homologous chromosomes into separate cells.
- The second division, like mitosis, separates the chromatids into separate cells.
- Four haploid daughter cells are produced, each having half the number but exactly the same types of chromosomes as the parent cell.

SUMMARY

Multiplication of cells is part of the cell cycle. At interphase, cells grow, store energy and replicate chromosomes and cytoplasmic inclusions. During mitosis the nuclear membrane breaks down, spindle fibres attach to chromosomes and the replicated chromosomes are drawn to opposite poles of the cell along spindle fibres in a precise manner so that each pole has the same number and types of chromosomes as the original. New nuclear membranes form around each set of chromosomes. The cell cycle is completed at cytokinesis or division of the cytoplasm. Two 'daughter' cells thus result which are identical to the 'mother' cell.

During gamete formation in animals and spore formation in plants special cells undergo meiosis to form daughter cells with half the number but the same types of chromosomes as the original 'mother' cell. Thus one diploid cell produces four haploid cells. This involves two successive divisions. The first division separates tetrads of homologous chromosomes and the second separates the chromatids of each type of chromosome. The diploid number, and thus correct species information, is restored during sexual reproductive processes.

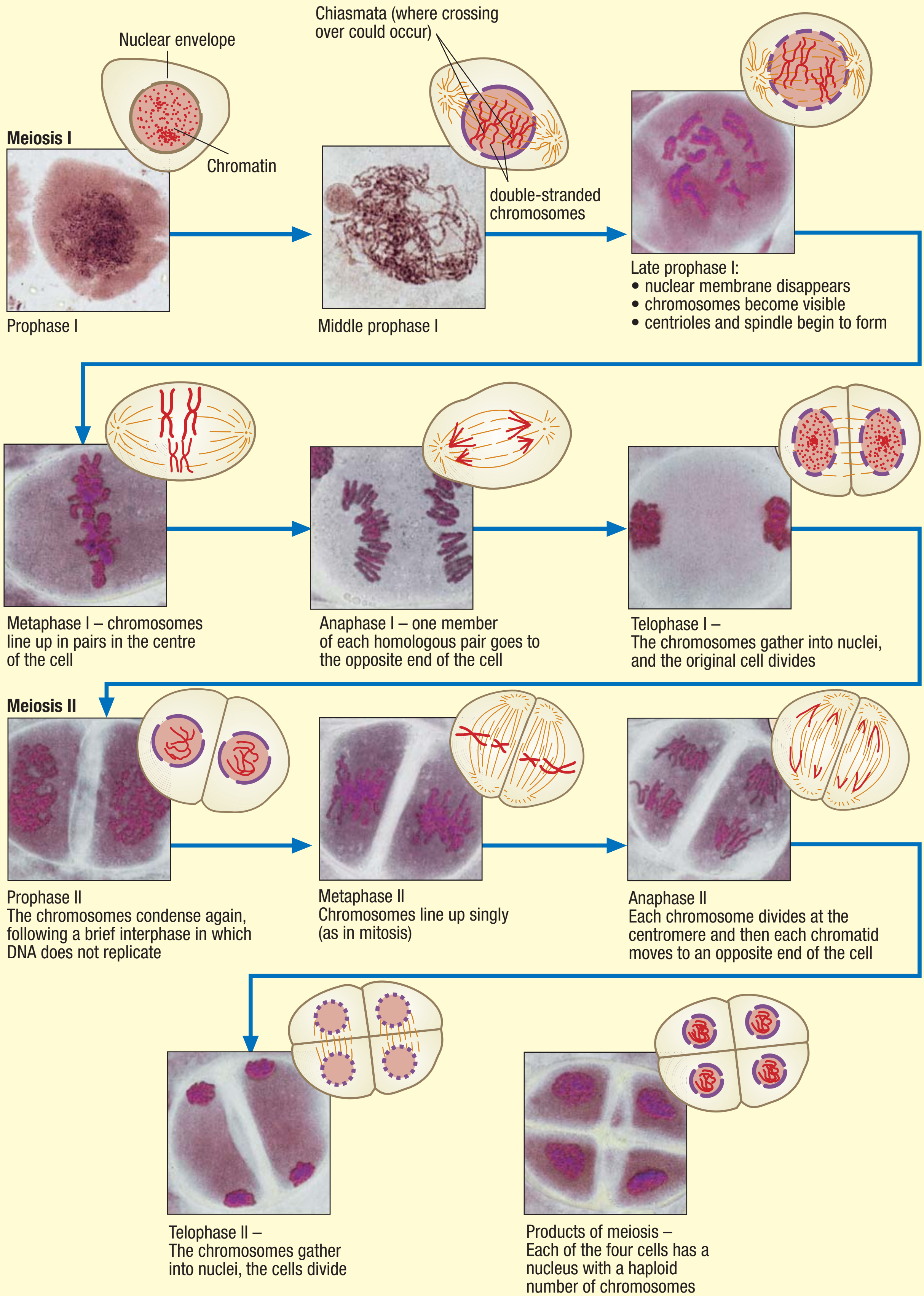


Figure 14.8 Stages in meiosis

Review questions

14.11 Place the following events of the cell cycle in the correct sequence:

- DNA replicates
- chromosomes line up at the equator of the spindle
- spindle forms
- nuclear membranes form
- chromatids separate
- nuclear membrane disintegrates
- chromosomes move to the ends of the spindle

14.12 What structures take part in the cell cycle of animal cells but not that of plant cells?

14.13 What structure is unique to plant cell division?

14.14 Why is it necessary for DNA to replicate before mitosis takes place?

14.15 There are two types of nuclear division—mitosis and meiosis. For each type of division describe:

(a) the chromosomal condition before and after cell division

(b) the possible functions of the division.

14.16 What would happen during sexual reproduction in animals if meiosis had not occurred before fertilisation?

14.17 What happens to homologous pairs of chromosomes during meiosis?

14.18 The 'nucleus' divides only once during mitosis but twice during meiosis. Explain this difference.

14.19 State whether each of the following is the result of mitosis or meiosis:

(a) two diploid cells

(b) four haploid cells

(c) repair of damaged skin cells

(d) gamete formation in dogs.

14.20 Compare and contrast the processes of mitosis and meiosis.

14.4 Energy, light and life

The ultimate energy source for the great majority of living systems on earth is the sun. The amount of solar energy striking the earth every day is equivalent to 1 million Hiroshoma-sized bombs. Most radiant energy impinging on the earth is either reflected as light or absorbed as heat by the earth or the atmosphere. Some of this absorbed heat energy serves to evaporate the water of the oceans, producing clouds which, in turn, produce rainfall on land. Solar energy, in combination with other factors, is responsible for the movement of air and water that contributes to patterns of climate.

Less than 1 per cent of this energy is converted to chemical energy in a form that can be utilised by living systems. This fraction of the sun's energy is responsible for the great majority of life forms on this planet.

14.4.1 Energy and electrons

The electrons of atoms move in 'clouds' at certain fixed distances from the central nucleus, corresponding with different energy levels. Energy conversions in chemical systems involve the movements of electrons from one energy level to another. An input of energy to the atom can raise electrons to a higher energy level. So long as they remain at this energy level, the atom possesses potential energy. When a lower level is restored, its potential energy is released. The fall of electrons from higher to lower energy levels is the source of energy for biological work. In photosynthesis light energy pushes electrons of certain molecules to a higher energy level, and this potential energy is used in the formation of chemical bond energy.

Oxidation and reduction

Changing the energy level of an electron often involves passing the electron from one atom or molecule to another atom or molecule. This passing of an electron from one molecule to another is called an **oxidation–reduction reaction**.

The loss of an electron is known as **oxidation**, and the compound that loses the electron is said to be oxidised. Many substances, such as carbohydrates, will lose electrons only when oxygen is available to accept them; hence the term oxidation. **Reduction** is the gaining of an electron. Oxidation and reduction take place simultaneously because the electron that is lost by one atom is gained by another.

Often an electron travels in company with a proton—that is, as part of a hydrogen atom. In this case, oxidation involves the removal of the hydrogen ion ($H+$ = proton) and its electron from one substance, and reduction involves the transfer of both a hydrogen ion and an electron to another substance. The reduction of oxygen (by the addition of hydrogen atoms) therefore results in the formation of water. The reduction of carbon dioxide (which occurs in photosynthesis) can result in the formation of carbohydrate $[(CH_2O)_n]$. The oxidation of a carbohydrate results in carbon dioxide and water.

If a reaction results in a net increase in chemical bond energy, it is referred to as a reduction reaction. Conversely, if there is a net decrease in chemical bond energy (with a release of energy as heat or light), the reaction is referred to as an oxidation process.

A simple way to remember these reactions is with the mnemonic OIL RIG:

Oxidation (gain oxygen or lose hydrogen)
Is
Loss of electrons;
Reduction (lose oxygen or gain hydrogen)
Is
Gain of electrons.

14.4.2 Energy composition of solar radiation

Solar energy (sunlight) contains the entire electromagnetic spectrum of different wavelengths. Light energy travels in waves as small 'particles' called photons. Each wavelength has a different energy level. The wavelengths (the distance from the peak of one wave to the peak of the next) range from the very short gamma rays which are measured in nanometres (1 nm = 10^{-9} m) to long radio waves which are measured in kilometres.

The shorter the wavelength, the greater is its frequency (number of waves which pass a point in a unit of time) and thus energy level. Light forms a small part of this spectrum. White or visible light is composed of seven colours—red, orange, yellow, green, blue, indigo and violet. Photons of violet light have almost twice the energy of photons of red light.

When light passes between materials of different density, its path is bent. The greater the frequency of the wavelength, the more the wave is bent. Rainbows are formed in the sky as light passes through small water droplets in the atmosphere, which separate the white light into its constituent colours.

Case study 14.2: Detection of the electromagnetic spectrum

Organisms respond only to aspects of their environment that have an effect on their ability to survive and reproduce. Most of the radiation energy that impinges on the earth has little known effect on organisms. Light detection is, however, of major significance to living things. Organisms either seek or avoid light. Vision is a purely animal adaptation and very much related to heterotrophic nutrition. Animals have to seek out food, and the evolution of sight has been a significant factor in evolutionary patterns of many animals.

Most animals utilise only the visible spectrum. Many animals cannot distinguish colours, only hues of grey between black and white. A few animals, however, are known to be able to detect other energy levels in the electromagnetic spectrum. For example, infrared radiation is emitted from warm bodies, and snakes can detect this radiation and use it in hunting prey.

Insects and a few birds can detect ultraviolet (UV) radiation. Some insects use this ability to guide them from areas of dark vegetation to open spaces. Detection of UV radiation (e.g.

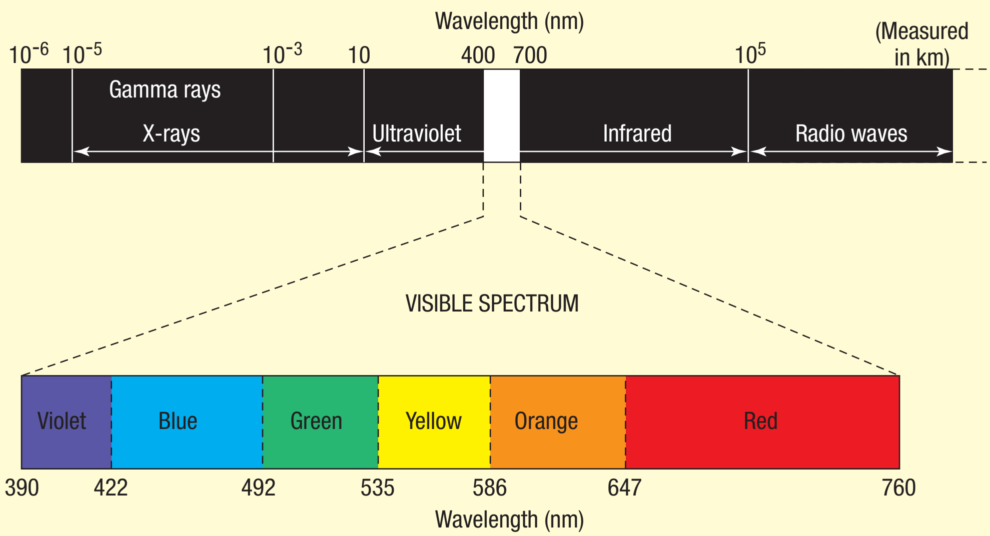


Figure 14.9 The electromagnetic spectrum

reflecting from flower petals, fungi and liquid surfaces) leads other insects to a food source.

Those species of *Eromophila* (emu bush) which are insect pollinated have UV-reflective patterns surrounding the dark, central area of the flower in which the reproductive and honey-producing structures are found. Bird-pollinated species of emu bush do not have this pattern. The interaction between the insects and flower is of mutual benefit: the insect gains food and the flower is efficiently pollinated.

All spiders produce silk. Many spin this silk into webs to capture insects. Some species produce a UV-reflecting silk. This may be used to confuse insects into thinking that they are moving into an open space. The insects then become trapped in the web. Other species of spiders (e.g. the St Andrew's cross spider, *Argiope aetherea*) decorate their webs with patterns which are thought to simulate the patterns in flower petals. The body of *Argiope* also reflects UV radiation. The combined effect of the positioning of the spider on the 'cross' and UV reflection entices the insects into the hub of the web, where they are killed and devoured.

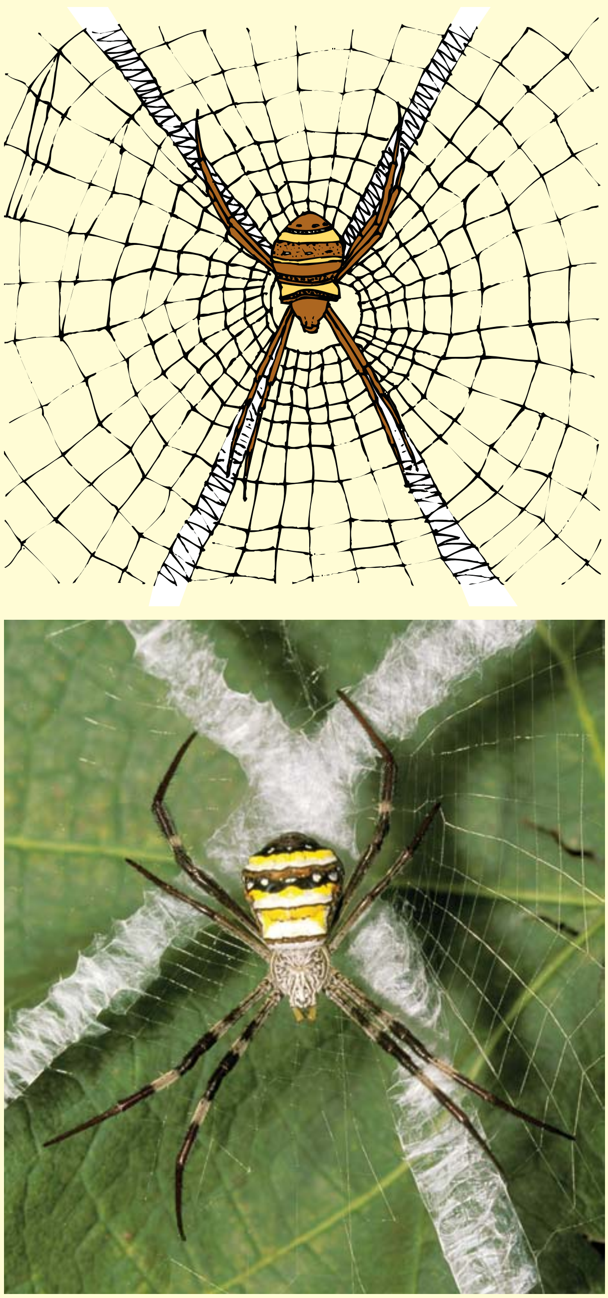


Figure 14.10 St Andrew's cross spider

14.4.3 The action of solar energy on organic molecules

Living things are composed of large complex molecules held in special configurations and relationships to one another by hydrogen bonds and other weak bonds. Radiation of even slightly higher energies than the energy of violet light breaks these bonds. This disrupts the structure and function of the molecules. Radiations with wavelengths smaller than those of visible light are called ionising radiations, because they drive electrons out of atoms.

Infrared and longer wavelengths are absorbed by water, which makes up the bulk of all living things. When they reach the large organic molecules, their lower energies cause the molecules to increase their motion (adding heat), but do not trigger changes in their structure.

Only those radiations within the range of visible light have the ability to excite molecules (raising electrons from one energy level to another) to produce useful biological changes. Most of the radiation reaching the earth from the sun is within this range. Higher-energy wavelengths are screened out by the oxygen and ozone high in the atmosphere. Much infrared radiation is screened out by water vapour and carbon dioxide before it reaches the earth's surface.

14.4.4 The role of pigments

In order for light energy to be used by living systems it must first be absorbed. Pigments are substances that absorb light energy. They are easily recognised because to the human eye they appear coloured. A black pigment is black because it absorbs light of all wavelengths. Red pigment is red because it absorbs all wavelengths except red; that is, it reflects or transmits red. A red pigment viewed under blue light will appear black because it has nothing to reflect or transmit. Chlorophyll, the pigment involved in photosynthesis, absorbs violet, blue and red light and sends back green.

An **absorption spectrum** can be used to analyse the wavelengths of light absorbed by any particular pigment. White light is passed through a container of pigment and the transmitted colours are noted. Those wavelengths not transmitted are absorbed by the pigment. An absorption spectrum is a graph that shows the relative absorption of the different wavelengths of light by a pigment. In contrast, an **action spectrum** is a graph showing how effective the different wavelengths of light are in stimulating the process that is under investigation: for example, photosynthesis.

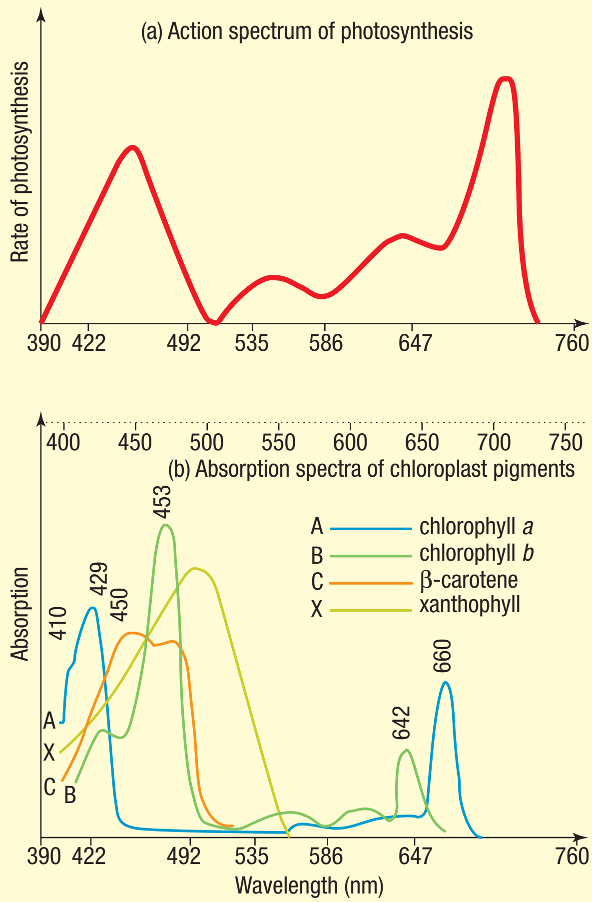


Figure 14.11 Absorption and action spectra

SUMMARY

Solar radiation consists of different energy levels. Each level has a specific wavelength. The composition of these energy levels is called the electromagnetic spectrum. The energy levels of visible light are seen as different colours.

Pigments are chemicals which can absorb specific wavelengths of energy. The colour of an object represents those wavelengths which are reflected or transmitted by the pigment. When pigments absorb energy the energy level of their electrons is increased. This may result in the loss of an electron(s) from the molecule.

When an electron is lost from a molecule (which may also involve gaining an oxygen atom or losing a hydrogen atom), oxidation is said to occur. When the reverse occurs, the process is called reduction.

Wavelengths of light which are absorbed by a pigment can be plotted as an absorption spectrum. An action spectrum represents the ability of a wavelength to perform a particular function.

? Review questions

14.21 What is the electromagnetic spectrum?

14.22 What is the relationship between wavelength and energy content of any particular portion of the electromagnetic spectrum?

14.23 Most of the electromagnetic spectrum does not impinge on earth. Why is this so?

14.24 Why is only a small proportion of the electromagnetic spectrum responsible for life on earth?

14.25 What is the difference between an action spectrum and an absorption spectrum?

14.5 PHOTOSYNTHESIS

During photosynthesis, light energy is converted to chemical energy. This chemical energy is bound in the glucose molecule formed during the photosynthetic process by producer organisms. Other metabolic processes convert, with the addition of other elements, these simple carbohydrates to all other organic compounds required by living organisms. These are then passed on to consumers and decomposers through the food web. The raw materials for photosynthesis are carbon dioxide and water. The chlorophyll molecule is necessary for the energy transformations, although it is not ‘used up’ in the process.

Organisms possessing chlorophyll include green plants, algae, cyanobacteria and some bacteria. Algae and green plants are eukaryotic, so chlorophyll is contained within chloroplasts.

The chloroplast is a cell organelle with two membranes. The **stroma** which is enclosed by these

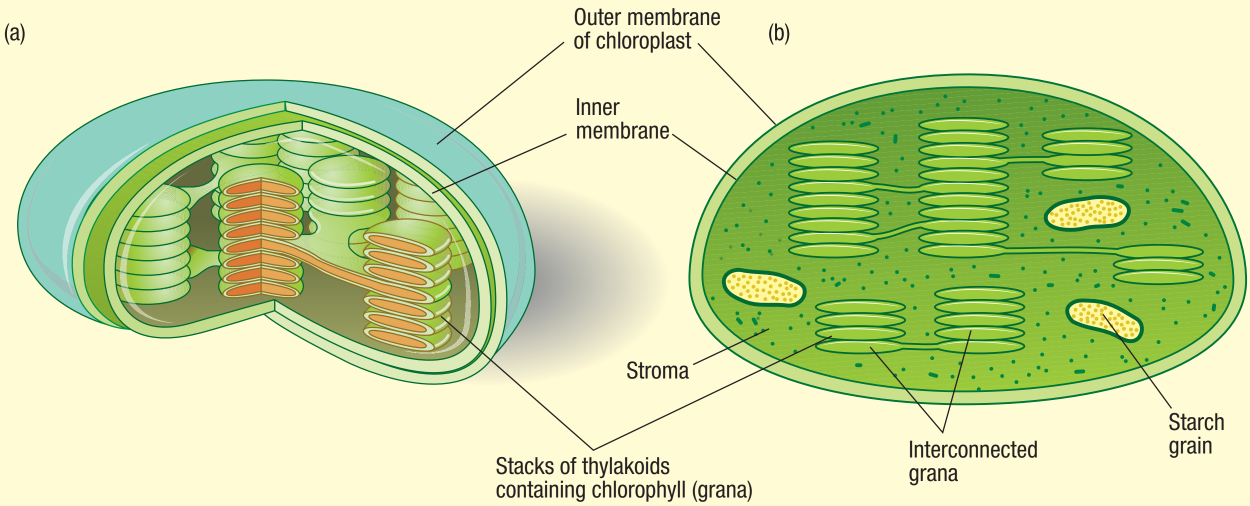


Figure 14.12 Structure of the chloroplast: (a) cutaway view; (b) transverse section

membranes is a watery material of different composition from the cytoplasm. Membranes within the stroma form flattened disc-shaped sacs (thylakoids). These lie one on top of the other like a stack of coins to form a **granum** (plural *grana*). Adjacent grana are interconnected.

Within the grana are found the pigment system (chlorophyll *a*, chlorophyll *b* and carotene), electron carriers, enzymes, and other molecules associated with the capture of light energy. A suitable temperature is required for photosynthesis to occur, since enzymes are temperature-sensitive. Carbon dioxide is readily available in all environments. Probably the single most important factor controlling the rate of photosynthesis is the availability and intensity of light.

14.5.1 The process of photosynthesis

Photosynthesis involves processes whereby light energy from the sun is converted into chemical bond energy. Carbon from carbon dioxide is 'fixed' into organic compounds. The generalised equation for this reaction is:

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2$$

In plants, light energy is trapped by pigments. The main pigments involved in photosynthesis in eukaryotic cells are chlorophylls and carotenoids which are found in the plant cell chloroplasts.

Photosynthesis occurs in two distinct steps. The first step involves **light-dependent reactions.** These take place in the pigment systems within the grana of the chloroplast. In this process:

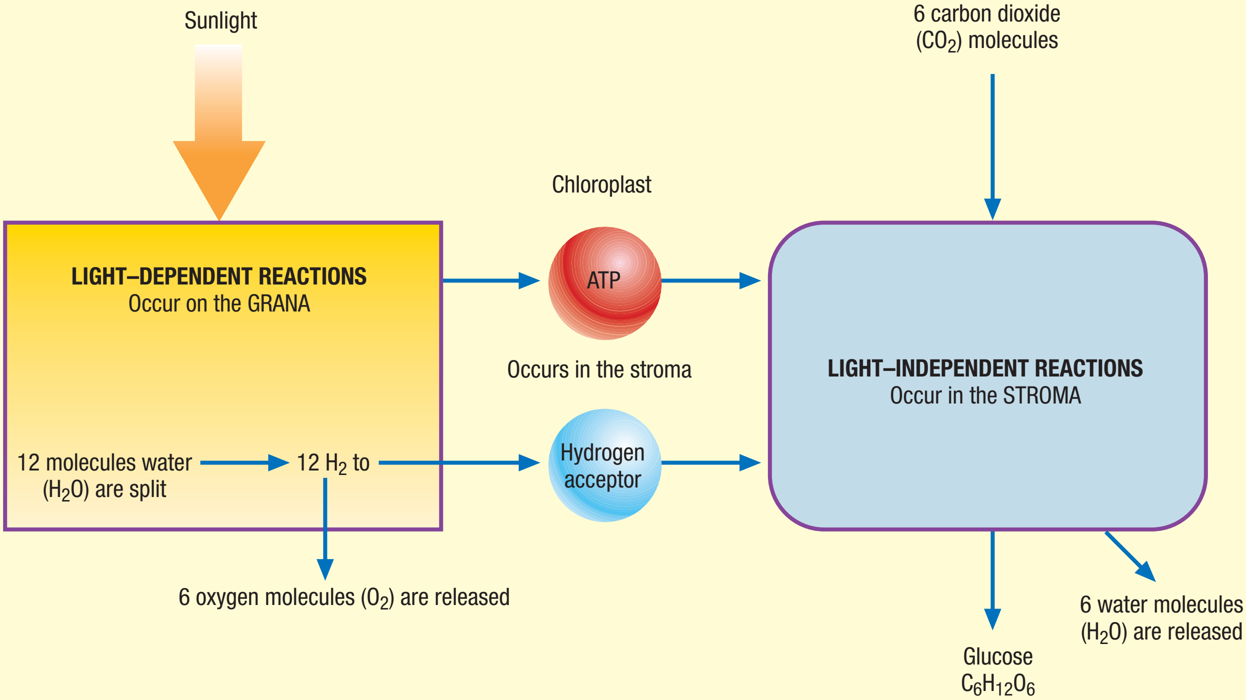
- Light energy, predominantly from the blue and red bands of the visible spectrum, is absorbed by the chlorophyll pigments.
- This extra energy 'excites' electrons in the chlorophyll *a* molecules, resulting in their release from the molecule.
- The energy of the excited electrons is used:
  i. in the formation of ATP
  ii. to decompose water into hydrogen ions and oxygen—the hydrogen ions are taken up by a hydrogen acceptor and the oxygen is released into the environment as a metabolic waste product.
- The electrons, having released their extra energy, are returned to the chlorophyll molecules.

The second step, consisting of **light-independent reactions**, takes place in the stroma. These reactions do not have to proceed in the dark, but they do not require light. They do, however, require the products of the light-dependent reactions. The hydrogen (released from the water) combines with carbon dioxide, using the energy from ATP, in a complex series of reactions to form glucose.

14.5.2 Biochemical pathways in photosynthesis

Light-dependent reactions

The pigments embedded in the thylakoid membranes of the grana can be divided into two groups which are referred to as **photosystem I** (P700) and



Overall reaction:

$$12H_2O + 6CO_2 \xrightarrow[\text{chlorophyll}]{\text{sunlight}} C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Figure 14.13 Summary of the main stages of the photosynthesis reaction

photosystem II (P680). Each photosystem contains a cluster of chlorophyll pigments and accessory pigments; for example, carotenoid molecules. Chlorophyll *a* is the only pigment which can transform light energy to chemical energy (ignoring two other chlorophylls found only in bacteria). Chlorophyll *b* and other accessory pigments, e.g. carotene, absorb light of slightly different wavelengths and pass bundles of energy on to chlorophyll *a*.

The light energy absorbed by chlorophyll *a* boosts its electrons to a higher energy level. These unstable, energy-rich molecules are said to be in an 'excited' state; the electrons are called 'excited electrons'.

The currently accepted model of light-trapping reactions is as follows:

- Light energy striking the pigments of photosystem II boosts electrons from chlorophyll *a* into an 'excitable' high-energy state and these are passed to an electron acceptor in the electron transport system.
- These electrons are replaced by electrons obtained from the splitting of water.
- During the splitting of water (photolysis):
  — Free electrons are released to photosystem II in a ground or low-energy state
  — Hydrogen ions (H^+) accumulate on the inside of the thylakoid membrane;
  — Oxygen (O_2) forms and diffuses out of the chloroplast and the cell as a waste product.
- Hydrogen ions continue to accumulate inside the thylakoid, as photosystem II releases 'excited, engergised' electrons to the electron transport system.
- A component of this electron transport system (a hydrogen and electron carrier) collects H^+ ions in the stroma of the chloroplast and the electrons from photosystem II and carries them as hydrogen atoms across the membrane. Once there, they are released into the interior of the thylakoid as hydrogen ions and so the concentration of H^+ ions increases.

- The electrons are now low in energy and are passed to photosystem I.
- Light strikes photosystem I, causing the electrons to again be excited and energised to a higher energy level where they again enter a second transport system.
- Hydrogen (H^+) ions in the stoma combined with electrons released at the end of this second electron system are taken up by the hydrogen acceptor NADP (nicotinamide adenine dinucleotide phosphate) to form $NADPH_2$.
- $NADPH_2$ carries the hydrogen to the light-independent reactions.
- Concentration of hydrogen ions is greater on the inside of the thylakoid than the outside. This causes a concentration and ionic gradient and this propels the hydrogen ions through ATP synthesases. These proteins/enzymes are embedded in and span the membrane of the thylakoid. Therefore the hydrogen ions flow out into the stroma of the chloroplast and this flow provides the energy to bond ADP and P to form ATP.
- ATP carries this energy to the light-independent reactions.

Phosphorylation occurs when a phosphate is added to ADP to form ATP. Energy is now stored in the high-energy bonds of ATP. Since the electrons do not cycle between the same photosystems, this process is termed **non-cyclic phosphorylation**. This is the normal set of light reactions. If NADP is not available to accept electrons and hydrogen ions or if there is a cellular demand for more ATP, however, the electrons from photosystem I are shunted to the first electron transport system where further ATP is formed. The electrons therefore cycle between photosystem I and the electron transport system. In **cyclic phosphorylation** water is not broken down, photosystem II shuts down and the light-independent reactions do not occur because no NADPH2 is formed. If NADP is available, the light-independent reactions proceed.

Light-independent reactions

- Glucose is formed in light-independent reactions in the **stroma** of the chloroplast.
- The $NADPH_2$ and ATP produced in the light-dependent reactions are used to reduce carbon dioxide to organic carbon molecules.
- **The Calvin cycle** is a series of reactions in which:
  - One molecule of carbon dioxide is combined with the starting 5-carbon sugar molecule, RuBP (ribulose biphosphate), to form a very unstable 6 carbon sugar.
  - This immediately splits to give two molecules of the 3-carbon compound PGA (phosphoglyceric acid).
  - The energy from the light-dependent reactions (in the form of ATP) and hydrogen (bonded to $NADPH_2$) is used in the production of two molecules of the 3-carbon compound PGAL (phosphoglyceraldehyde).
  - If the cycle is to proceed, some of this PGAL is converted, in a series of complex reactions, to re-form the carbon dioxide acceptor RuBP. It takes three turns of the cycle to produce one free molecule of PGAL.
  - Two molecules of PGAL (= six turns of the cycle) are needed to form one molecule of glucose.
  - PGAL can be used instead of glucose as a starting material for the production of other organic compounds.

SUMMARY

Photosynthesis in plants and algae takes place in the chloroplasts of the cell. Each chloroplast has a double membrane. Stacks of pigment-containing membranes (grana) are found within the watery matrix (stroma) of the chloroplast. In complex plants, photosynthesis mainly takes place in the leaf, which has many adaptations for this function.

Photosynthesis is a two-stage process, the first requiring light (and taking place on the grana) and the second capable of occurring without light (and taking place in the stroma).

The function of the light-dependent stage is to produce ATP, and to split water. The oxygen released from the splitting of water is a waste product of the process.

In the light-independent stage the carbon dioxide is reduced and carbohydrate synthesised, using the hydrogen atoms and ATP that were formed in the light-dependent reactions.

Review questions

14.26 What is the purpose of photosynthesis?

14.27 Photosynthesis takes place in two distinct steps: light-dependent and light-independent reactions.
(a) Where in the chloroplast does each step occur?
(b) Summarise the major processes in each of these steps.

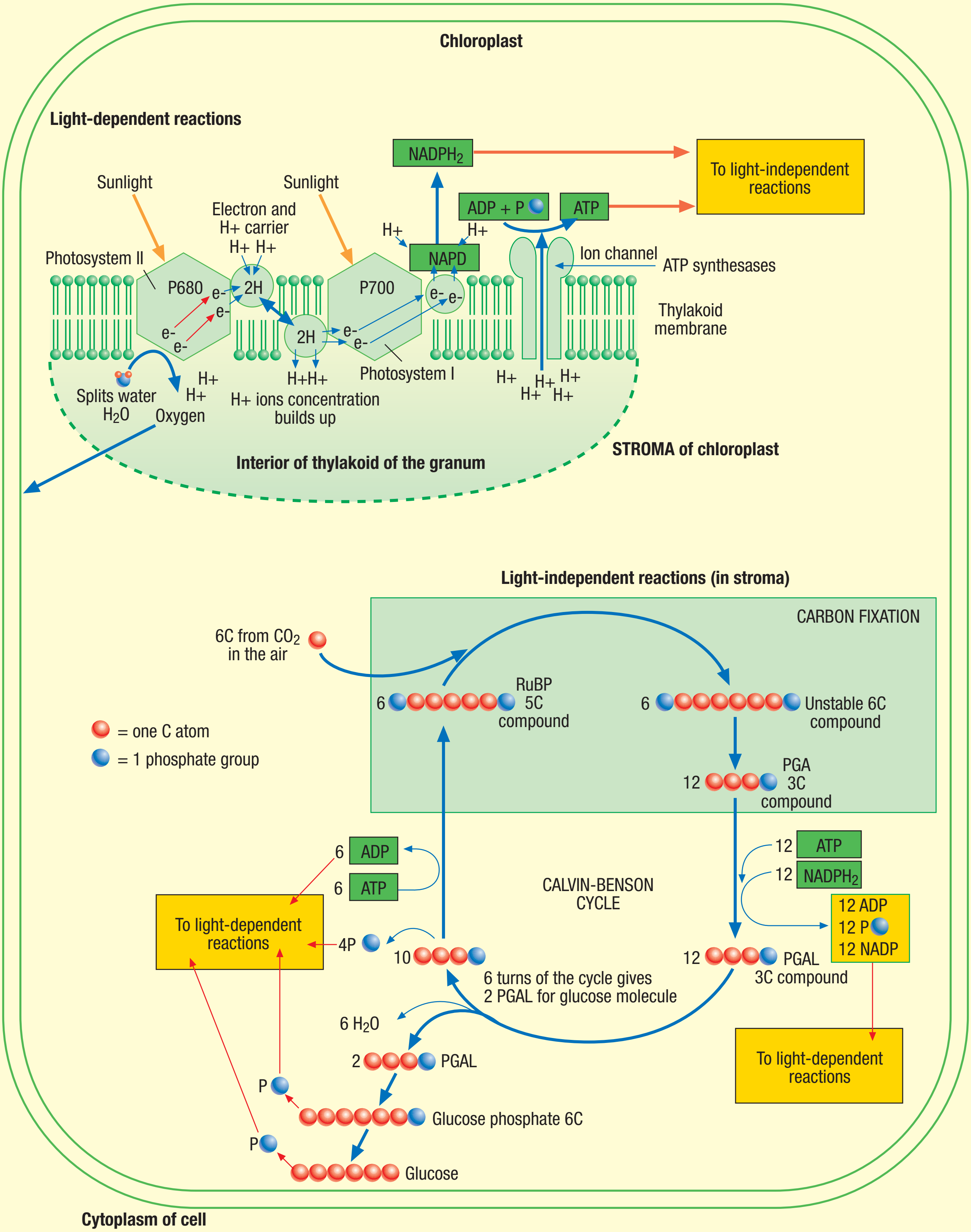


Figure 14.14 The reactions of photosynthesis

EXTENDING YOUR IDEAS

1. Explain the advantages to the cell of having a cyclical metabolic system such as the Calvin cycle or citric acid cycle. UB

2. Several jars of strawberry jam were made and stored in a cupboard. When opened several months later, they were found to be frothy and smelling of alcohol. UB
   (a) What do you think has happened and why?
   (b) How could this have been prevented?

3. Mammalian sperm cells expend a large amount of energy in moving through the female reproductive tract. On the basis of this information you would predict that these cells would contain a large number of: UB
   A. vacuoles.
   B. mitochondria.
   C. ribosomes.
   D. chloroplasts.

   Explain your answer.

4. Figure 14.15 (a) and (b) below show two stages of meiosis in a diploid plant. UB

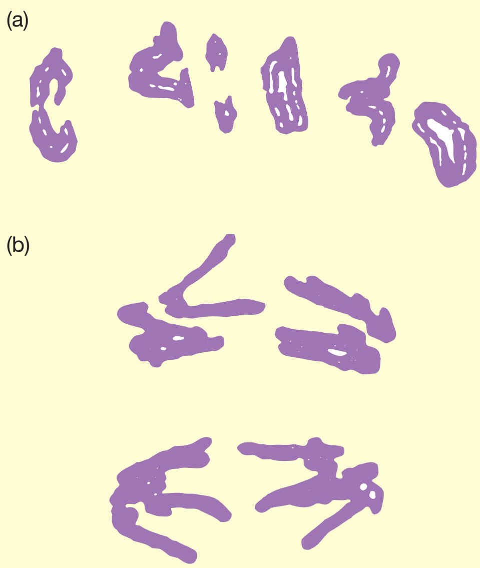


Figure 14.15

   (a) Give one piece of evidence from Figure 14.15 (a) to support the fact that this cell is undergoing meiosis.
   (b) Giving one reason for your answer in each case, identify the stage of division shown in:
      (i) figure 14.15 (a).
      (ii) figure 14.15 (b).

5. The graph in Figure 14.16 shows the movement of chromosomes during mitosis. Curve A shows the mean distance between the centromeres of the chromosomes and the corresponding pole of the spindle. UB

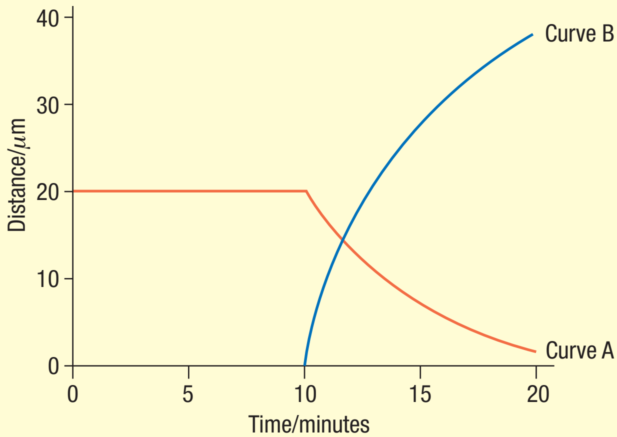


Figure 14.16

   (a) What is represented by curve B? Justify your answer.
   (b) Giving one piece of evidence from the graph, state when anaphase begins.

6. Diagram I of Figure 14.17 below shows a three-dimensional view of one of the stages of mitosis in a typical animal cell. The chromosomes are shown lying in the same plane. UB

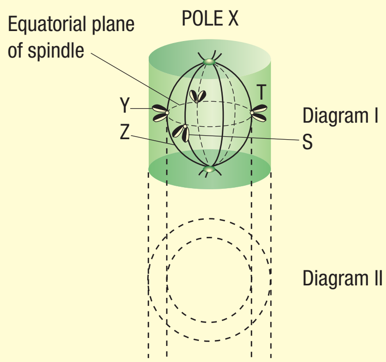


Figure 14.17

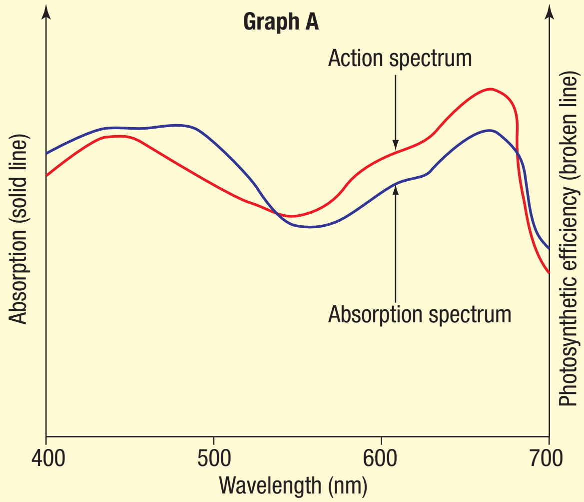
   Diagram II shows the outline of the equator of the cell. Draw all of the chromosomes in diagram I as they would appear looking down from pole X in diagram II.

7. An isotope of oxygen, ^{18}O (normal oxygen is ^{16}O) was used by scientists to find out whether the oxygen released in photosynthesis comes from water or carbon dioxide. UB

   Which of the following, if true, would support the hypothesis that the oxygen comes from the water?
   A. When normal water and carbon dioxide with ^{18}O were used in photosynthesis, all the oxygen released was the ^{18}O isotope.
   B. When normal water and carbon dioxide with ^{18}O were used in photosynthesis, some of the oxygen released was the ^{18}O isotope and some was ^{16}O.
   C. When normal carbon dioxide and water with ^{18}O were used in photosynthesis, all the oxygen released was the ^{18}O isotope.

D. When normal carbon dioxide and water with ^{18}O were used in photosynthesis, some of the oxygen released was the ^{18}O isotope and some was ^{16}O.

8. UB In graph A in Figure 14.18, the solid line shows the absorption spectrum of a solution of pigments extracted from bean leaves. The broken line shows the action spectrum of a bean plant, determined by measurement of the rate of photosynthesis when the plant was illuminated by different wavelengths of light. Graph B shows the absorption spectra of three pigments which have been extracted from bean leaves and examined individually.



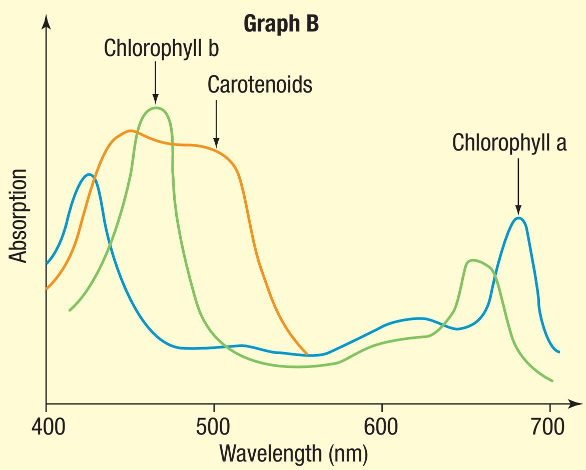


Figure 14.18

(a) With reference to graph A:

(i) Comment on the biological significance of the relationship between the action spectrum and the absorption spectrum.

(ii) State the approximate wavelengths at which photosynthesis is most efficient.

(b) With reference to graphs A and B, account for the differences between photosynthetic rate and light absorption rate at a wavelength of 490 nm.

9. UB Movement of an electron from one pigment molecule to another must involve some loss of energy in the form of heat, since energy cannot be transferred with 100 per cent efficiency. Chlorophyll *b* passes energy to chlorophyll *a*. Predict whether chlorophyll *a* or chlorophyll *b* has the lower energy of excitation. Explain.

10. IB A large glass-stoppered flask containing nasturtium leaves and air was exposed to bright sunlight for 3 hours. Figure 14.19 shows the apparatus used.

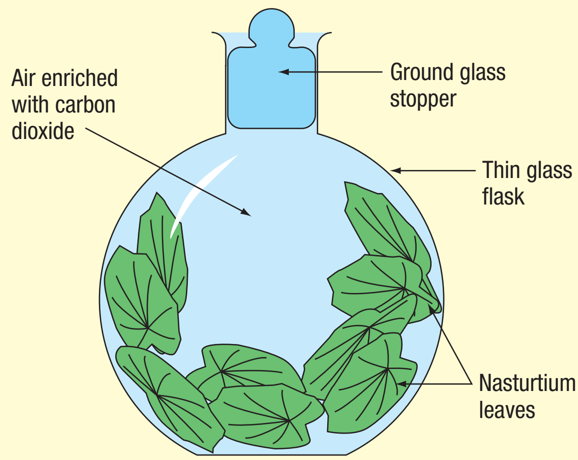


Figure 14.19

Two samples of gas were withdrawn from the apparatus. The first (sample A) was withdrawn at the beginning of the experiment and the second (sample B) was withdrawn at the end of the 3 hours. The volume of each sample was measured after exposure, first, to potassium hydroxide and, second, to alkaline pyrogallol solutions. (Potassium hydroxide absorbs carbon dioxide and alkaline pyrogallol solution absorbs oxygen.) The results are tabulated below.

	Sample A	Sample B
Original volume:	100 cm^3	100 cm^3
Volume after exposure to potassium hydroxide solution	94 cm^3	98 cm^3
Volume after exposure to alkaline pyrogallol solution	73 cm^3	73 cm^3

(a) Calculate the percentage of carbon dioxide present in each of the samples A and B.

(b) Explain the difference in carbon dioxide volume between the two samples.

11. The graphs below (Figure 14.20) show the effects of temperature, light and carbon dioxide levels on the rate of photosynthesis. **IB**

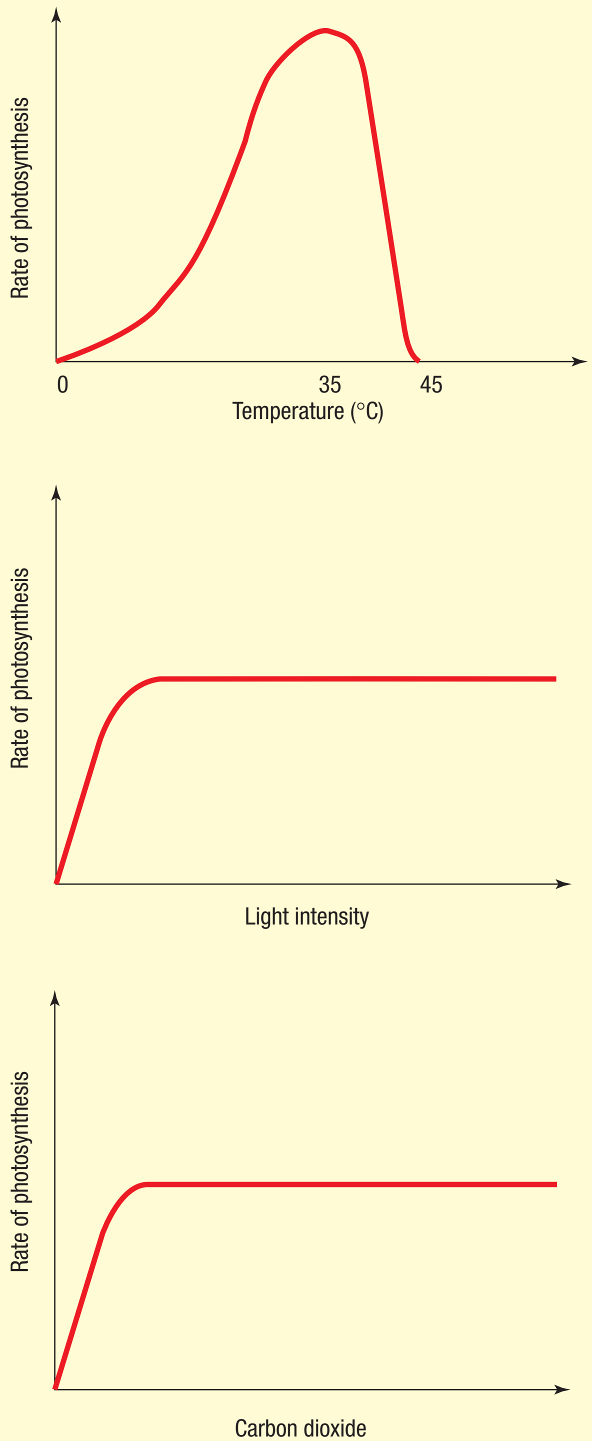


Figure 14.20

(a) Explain why, in spite of either increased light intensity or carbon dioxide concentration, the rate of photosynthesis does not increase beyond a certain level.

(b) What feature(s) of biological systems would explain the decrease in photosynthetic rate at temperatures higher than about 35°C?

(c) What factors would limit photosynthetic rate? (Not all factors are necessarily shown on the graphs.)

12. The relationship between the rate of photosynthesis and light intensity was determined for two types of plants; the results are given below.

	Light intensity (arbitrary units)					
	0.5	1.0	2.0	3.0	5.0	10.0
Plant	**Rate of photosynthesis (arbitrary units)**					
Oxalis	0.5	1.0	2.1	2.2	2.3	2.2
Pteridium	0.5	0.9	2.1	3.2	4.2	5.0

IB (a) Plot graphs for the results, and comment on the results.

UB (b) In which type of habitat would you expect to find each plant type?

UB (c) Give a reason for your choice of each habitat.

13. Most ectotherms (i.e. animals which cannot physiologically control body temperature) cannot survive extremely cold environmental conditions. As the extracellular fluids in the animal's body begin to freeze, the fluids become more concentrated than the cytoplasm. This causes water to be drawn from the cell, resulting in dehydration and death of the animal. Canadian biochemists have discovered that this does not occur in the wood frog, *Rana sylvanica*. As environmental temperatures decrease, the frog accumulates massive amounts of glucose in the cells. Properties of the cell membrane ensure that the glucose remains within the cells. Even when water in the extracellular fluid has frozen and the heart and breathing have stopped, the frog will revive unharmed when temperatures increase.

UB (a) This ability is related to the fact that the presence of glucose in the cells ensures:

A. the cells can continue aerobic respiration at all times.

B. the cell cytoplasm remains less concentrated than the extracellular fluid and thus dehydration will not occur when extracellular fluid freezes.

C. the cell cytoplasm remains more concentrated than the extracellular fluid and will not dehydrate, while providing an energy source for anaerobic respiration.

D. the cell cytoplasm remains more concentrated than the extracellular fluid and will not dehydrate, while providing an energy source for aerobic respiration.

EBI (b) Discuss the significance of this discovery in relation to storing organs for transplants.

UNIT 6

The functioning organism

Plants play a vital role as primary producers of chemical energy within the earth's ecosystems. In order to sustain life, plants have evolved morphological, anatomical and physiological adaptations to obtain, process, transport and store raw materials and energy under varying environmental conditions. The capture and subsequent conversion of radiant energy to chemical energy takes place in chloroplasts which are localised in specialised tissues. Photosynthetic products are utilised in respiration, growth, repair, maintenance and storage. Since only specialised tissues exposed to light are involved in photosynthesis, the products of this process must be transported to other parts of the plant. These substances are converted to forms required by the plant. This involves energy-consuming reactions. Energy is supplied to plant cells through respiration. Movement of materials within vascular and non-vascular plants occurs by processes such as diffusion, osmosis and active transport. Large molecules must be digested prior to transport. Throughout all these activities water and mineral ions must be supplied and conserved within the plant body.

Animals obtain, transform and store supplies of energy and raw materials from the environment. These processes are common to all animal groups, but different ways of achieving the same ends have evolved in response to specific environmental demands. Since animals are heterotrophs they must seek out their food, and this usually involves moving around their environment. Locomotion is an energy-demanding process.

The food that animals obtain is rarely in a form which can be taken directly into the body. The processing of food involves ingestion, digestion, absorption, assimilation and egestion. Specialised organs are involved in these processes in the majority of animals.

It is critical for the majority of heterotrophs to obtain an adequate supply of oxygen for aerobic respiration and thus high-energy production. Most animals have specialised respiratory surfaces for gas exchange. Gas exchange surfaces (skin, trachea, gills and lungs) have characteristics which facilitate this exchange.

Materials are transported and distributed within the bodies of animals. This usually occurs in circulatory systems, because the size of most animals makes diffusion from cell to cell far too inefficient for survival. Transported materials may be utilised in processes such as cell respiration and protein synthesis; stored as glycogen in the liver, or as fat in adipose tissue; and excreted. Elimination of wastes involves the removal of undigested residues such as faeces, and the excretion of metabolic products; for example, carbon dioxide, water and urea.

The integration of the physiological systems of the human body exemplifies the coordinated activity of the many processes necessary to sustain the life of a complex, multicellular animal.

The unique processes of biological growth and reproduction are characteristics of life. They are crucial in ensuring the continuity of the species. Some living things reproduce asexually, producing similar offspring, while others reproduce sexually with resulting diversity in the offspring. Sexually reproducing organisms produce gametes, usually by the process of meiosis, at some stage in their life cycle. The processes associated with asexual and sexual reproduction have different consequences for the species. There are major developmental stages, with observable patterns, in the growth of multicellular organisms. The potential for growth and development depends on the availability of balanced nutritional requirements.

Key concepts

- Multicellular organisms are functioning sets of interrelated systems.
- A variety of mechanisms result in continual change at all levels of the natural world.
- There are processes which maintain dynamic equilibrium at all organisational levels.
- There are mechanisms by which characteristics of individuals in one generation are passed on to the next generation.

Key ideas

- Energy required by all living things is obtained in different ways.
- The sets of systems comprising an organism enable it to function in its environment.
- All systems are interrelated and interdependent.
- Systems of the body work together to maintain a constant internal environment.
- Malfunctioning in one system or one part of a system may affect the whole organism.
- The external features and the internal functioning of organisms together enable an organism to obtain its needs.
- Living things employ a variety of reproductive strategies.
- During reproduction DNA is passed from parent(s) to offspring.

15 PLANT PHYSIOLOGY

The cellular structure of plants has been instrumental in dictating their overall structure and the way they perform their life functions. Due to the presence of a cell wall around each cell, plant cells (and thus the organism as a whole) lack mobility. Plants therefore either drift on the surface of water or are attached to the substratum. As a result, they must be able to utilise resources effectively from very limited surroundings. Since they are non-motile, however, the energy demands of plants are relatively low. If conditions become adverse, plants without adaptations to cope will die. Their only means of dispersal is through their reproductive structures.

Although the cell wall has imposed limitations on movement, it also brings about turgor pressure within the cells, which provides a 'skeletal' structure to individual cells and thus to the whole plant. This support is further enhanced in some plants by the deposition of lignin in the cell walls of particular tissues. Rings and spirals of lignin within the cell wall produce strong mechanical properties.

As the major producers of chemical bond energy and oxygen, plants play a vital role in all ecosystems.

15.1 PLANTS AS ENERGY CONVERTERS

15.1.1 PHOTOSYNTHESIS

The ultimate energy source for the majority of living systems is the sun. Most radiant energy impinging on earth is either reflected as light or absorbed by the earth or the atmosphere as heat. Less than 1 per cent is utilised in the process of photosynthesis.

Photosynthesis is the process whereby radiant energy from the sun is converted to the chemical bond energy of glucose. In plants it occurs in chloroplasts within specialised cells. Chlorophyll molecules are instrumental in the first step, which is the conversion of light energy to the chemical bond energy of ATP. Energy to transform carbon dioxide and hydrogen (from water) to glucose is then provided by the ATP. Oxygen is released as a waste product of the process. The overall reaction can be given as:

$$\text{carbon dioxide + water} \xrightarrow[\text{chlorophyll}]{\text{sunlight}} \text{glucose + oxygen}$$

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

Thus inorganic compounds with low chemical bond energy are converted to an organic compound with high chemical bond energy. The chemistry of photosynthesis was considered in more detail in Chapter 14. Plants exhibit a wide variety of adaptations for obtaining adequate illumination.

Adaptations of the plant for photosynthesis

In complex plants most photosynthesis occurs in one specialised 'organ', the leaf. The typical leaf consists of a broad, flat part called the **lamina**, which is joined to the rest of the plant by a stalk or **petiole**. Running through the petiole are vascular bundles containing the **xylem** (transporting water and mineral ions from the roots) and **phloem** (transporting sugars and other small organic molecules between different parts of the plant).

The leaf consists of several layers of tissues. The top and bottom of the leaf are covered by a layer of closely fitting, flat cells: the **epidermis**. It functions to protect the inner layers of cells. The epidermal cells often secrete a waxy **cuticle** which reduces evaporation of water from the cells. On the lower epidermis, there are usually small holes called **stomata** (singular stoma). Each stoma is surrounded by a pair of sausage-shaped **guard cells** which can open or close the space between them. Unlike epidermal cells, the guard cells contain chloroplasts.

Water loss from the leaf is reduced, as most stomata are on the undersurface of the leaf. In most leaves the majority of photosynthesis is carried out in the upper cell layers. The upper leaf surface therefore receives most of the light energy. As a consequence it is also subjected to higher temperatures and greater air movement. Both of these factors increase the rate of evaporation.

Much of the carbon dioxide needed for photosynthesis passes through the stomata along a diffusion gradient from the air to the cells. Carbon dioxide is continually being used in the leaf. The concentration of carbon dioxide within the inner **mesophyll** cells will therefore be lower than that in the atmosphere. Similarly, the oxygen released in photosynthesis passes out of the stomata along a diffusion gradient.

Mesophyll cells (*meso* = middle; *phyll* = leaf) all contain chloroplasts. The cells near the top of the leaf are columnar in shape and closely joined, forming the **palisade** layer. The cells beneath them are rounder and arranged quite loosely, with large air spaces between them. They form the **spongy** layer. Running through the mesophyll are **veins** carrying the vascular tissue.

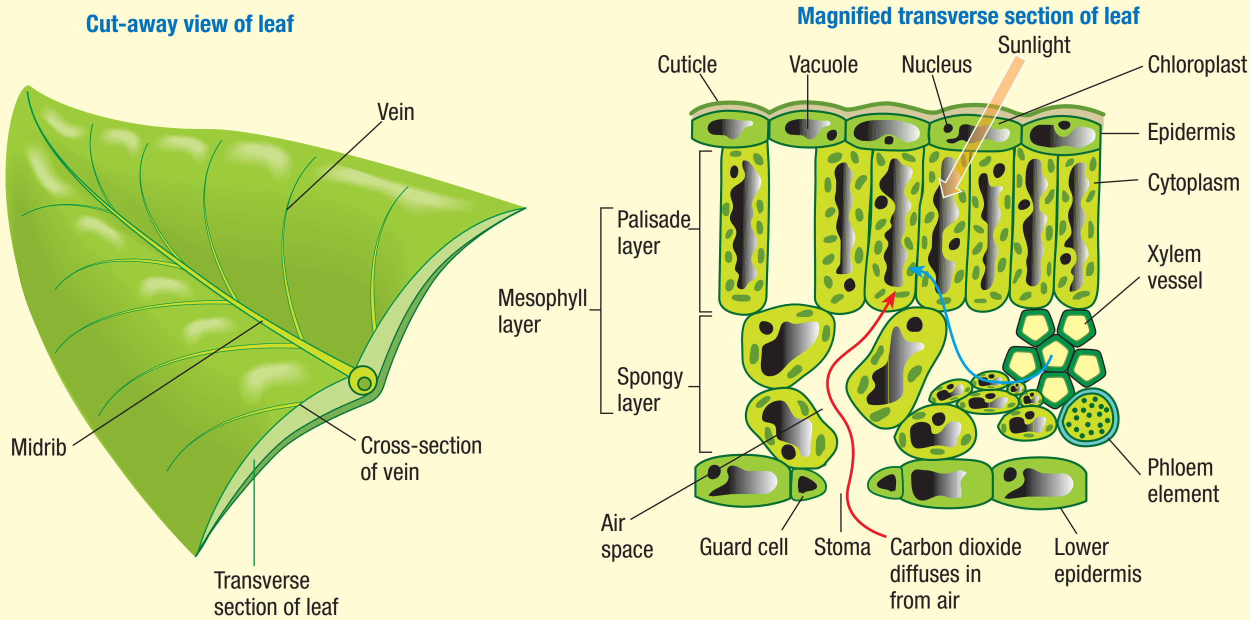


Figure 15.1 Structure of the leaf, showing movement of raw materials for photosynthesis into the palisade cells

Table 15.1 Adaptations of leaves for photosynthesis.

Adaptation	Function
Supported by stem and petiole	Exposes as much of leaf as possible to sunlight and air.
Arrangement on stem	Maximises light absorption.
Large surface area	Exposes as much of leaf as possible to sunlight and air.
Thin	Allows sunlight to penetrate to all cells; allows CO_2 to diffuse in and O_2 to diffuse out as quickly as possible.
Stomata on lower epidermis	Allows CO_2 and O_2 to diffuse in and out; to reduce evaporative water loss.
Air spaces in spongy mesophyll	Allows H_2O, CO_2 and O_2 to diffuse to and from all cells.
No chloroplasts in epidermis	Allows sunlight to penetrate to mesophyll layers.
Mesophyll layers packed with chloroplasts	Allows sunlight, providing energy to combine CO_2 and H_2O.
Palisade cells arranged end on	Keeps as few cell walls as possible between sunlight and chloroplasts.
Chloroplasts in palisade cells oriented horizontally to the light rays	Exposes as much chlorophyll as possible to sunlight.
Xylem vessels within a short distance of every mesophyll cell	Supplies water to chloroplasts for photosynthesis.
Phloem tubes within short distance of every mesophyll cell	Takes away organic products of photosynthesis.
Cytoplasmic streaming	Maintains chloroplasts in position to receive maximum light.

SUMMARY

Photosynthesis in plants takes place in the chloroplasts of the cell. In complex plants, photosynthesis mainly takes place in the leaf, which has many adaptations for this function.

Review questions

15.1 Describe features of the plant leaf that are adaptations for photosynthesis.

15.2 In which part of the plant does photosynthesis occur? Describe the specific locations of the plant cells in which this process takes place.

15.1.2 Respiration

The chemistry of cellular respiration was described in Chapter 14. In this process the release of chemical bond energy generally involves the oxidation of sugar in a series of small steps, each controlled by an enzyme. This energy is stored in the ATP molecule for further use by the cell, or transported to other cells within the plant.

The first stages of respiration are carried out in the cell cytoplasm. If oxygen is not present in the cell, the final products of these reactions are ethyl alcohol and carbon dioxide, with a net gain of two ATP molecules. This is termed anaerobic respiration.

If oxygen is present, aerobic respiration proceeds in the mitochondria, producing a further thirty-four ATP molecules, carbon dioxide and water.

The energy produced during these reactions is utilised by the plant to convert the carbohydrates formed during photosynthesis into other organic compounds such as proteins and lipids, and for the chemical reactions required for 'just living'.

All living cells need a continuous supply of energy for life functions. Thus all living plant cells, like animal cells, are always respiring. Some plant cells also photosynthesise. In the leaf cells the chloroplasts take in carbon dioxide and release oxygen during the daytime. At the same time respiration is occurring in the mitochondria, using some of the oxygen and glucose provided by photosynthesis.

In the daytime photosynthesis proceeds at a faster rate than respiration and all of the carbon dioxide released in respiration is used up in the chloroplasts, in addition to extra carbon dioxide taken in through the stomata.

At night photosynthesis ceases, but respiration must continue. Oxygen, which diffuses from the atmosphere through the stomata, is used up and carbon dioxide is released. Oxygen diffuses to non-photosynthetic cells in the stems through special 'pores'. Roots get their oxygen from the air spaces in the soil by diffusion through the root hair cells.

Carbohydrates used during respiration at night are normally replaced when photosynthesis resumes at dawn. The rate of photosynthesis increases with increasing light intensity. Sooner or later the rate of

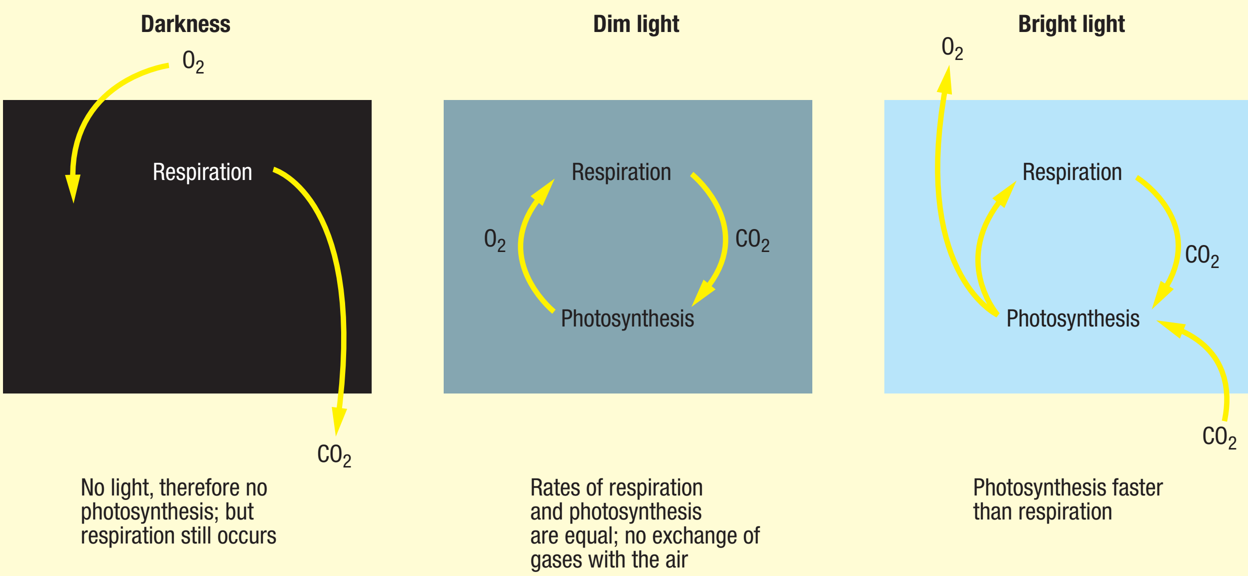


Figure 15.2 The balance between photosynthesis and respiration in a green plant

photosynthesis equals the rate of respiration and there is no net gain or loss of carbohydrates.

The light intensity at which photosynthesis and respiration proceed at the same rate is known as the **compensation point**. The time taken for a plant to reach its compensation point is known as the **compensation period**. With further increase in light intensity, the rate of photosynthesis is greater than respiration and there is a net gain in carbohydrate.

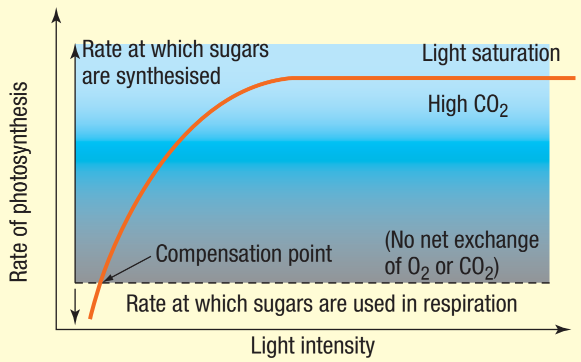


Figure 15.3 Compensation point

SUMMARY

Plants require energy from respiration to perform their life functions. Respiration occurs in plant cells at all times. During daylight photosynthesis occurs at a greater rate than respiration, whereas at night only respiration occurs. The compensation point is the light intensity at which the rates of respiration and photosynthesis are the same.

Review questions

15.3 Explain why plants respire at all times.

15.4 Write a general equation describing respiration.

15.5 Define compensation point.

15.6 Plot a graph to show how the rates of photosynthesis and respiration in a green plant vary during one day.

15.1.3 Gas exchange

Both photosynthesis and respiration require exchange of gases between the cells and the external environment. Plants are considerably less 'active' than animals and also produce oxygen as a by-product of photosynthesis. As a result, they generally require much less oxygen than animals do. Even the largest plants, therefore, do not require special organs for gas exchange. They rely on diffusion alone to supply their gaseous exchange needs.

Primitive plants such as mosses and liverworts are imperfectly adapted to life on land. These plants use the entire body surface for gas exchange and thus are small in size and limited to moist environments.

Higher plants have evolved adaptations in response to these problems. Gas exchange in higher plants occurs in leaves, stems and roots. The leaf is well adapted for gas exchange:

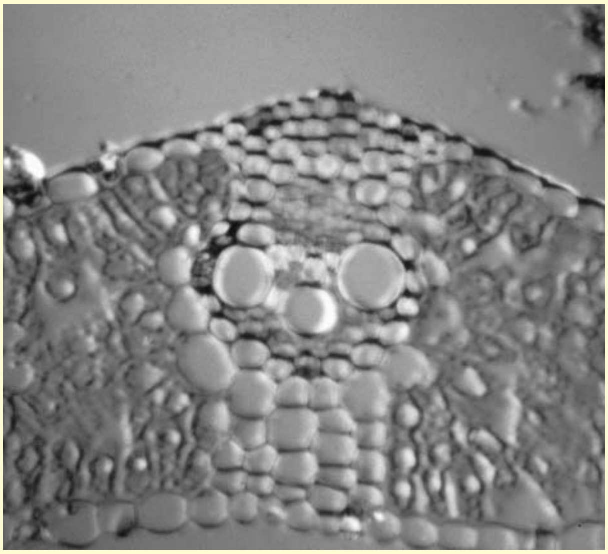
- The surface area for gas exchange is very large.
- A waterproof cuticle reduces water loss from the surface except at the stomata.
- Gas exchange between the environment and the leaf tissues is through the stomata.
- Internal transport within the leaf does not require special adaptations, because gases can reach each cell directly through the intercellular air spaces.
- The leaf epidermis protects the internal exchange surfaces.
- Gas exchange surfaces and all cells within the leaf are always moist, because they are exposed only to the air in the intercellular spaces. This air remains humid because the spongy mesophyll cells maintain a transpiration stream, and the stomata close if moisture loss becomes excessive.

Gas exchange also occurs in the stems. Herbaceous stems and young growing shoots of woody plants have stomata. Woody stems become covered with a layer of impervious cork, but this contains small areas of loosely arranged cells, each with many intercellular spaces, through which air may diffuse. These areas are called **lenticels**.

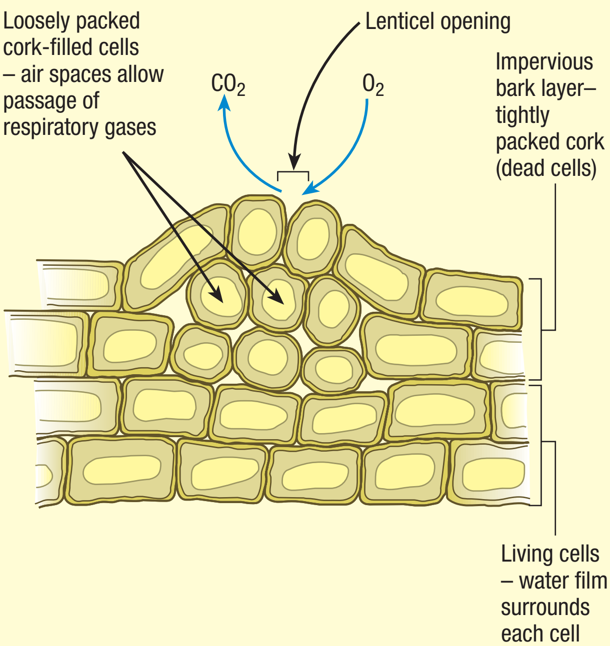
In the roots gas exchange occurs by diffusion across root hairs and other epidermal cells. This exchange requires good aeration of the soil and thus will vary in differing soil types. The stems and roots, like the leaf, have adequate internal air spaces to allow effective diffusion of gases to individual cells, and no special internal gas transport system is required.

SUMMARY

Exchange of gases between the external environment and the cells of the plant is necessary for photosynthesis and respiration. In plants this is achieved by diffusion. Higher plants have special adaptations which maximise gas exchange while reducing water



(a) Micrograph: TS through a lenticel



(b) Diagram showing structure and function

Figure 15.4 Structure of a lenticel

loss. Diffusion occurs in leaves and green stems through stomata, in woody stems through lenticels, and in roots through root hairs and other epidermal cells.

Review questions

15.7 Explain why diffusion is adequate to supply the gas exchange need of plants.

15.8 With the aid of a labelled diagram, describe features of the leaf which show adaptations for gas exchange.

15.9 Describe a lenticel and discuss the significance of its structure for gas exchange.

15.10 Some of the roots of certain mangrove plants have lenticels. From your knowledge of the mangrove environment, comment on the significance of this adaptation (See Case study 9.5 on page 221).

15.1.4 Digestion

Digestion is the breakdown of large, complex, insoluble molecules into small, simple, soluble ones that can pass through cell membranes. In plants digestion is chemical and usually **intracellular.** Enzymes bring about the hydrolysis of specific bonds in macromolecules. Small amounts of enzymes in the cytoplasm break down specific macromolecules. After digestion has occurred the enzyme may be:

- used in the reverse reaction
- inhibited by other chemicals
- broken down.

This mechanism prevents the general cytoplasm from being digested.

The simple sugars produced in the leaves by photosynthesis are usually immediately converted to osmotically inactive starch, and stored in the photosynthetic cells. However, from time to time some organic molecules need to be transported to the non-photosynthetic cells for energy-requiring processes. Since complex molecules cannot pass through the cell membranes, they must be broken down into simple sugars before they can be transported to the other cells. Digestion, therefore, is intracellular.

Some plants living in nitrogen-deficient soils have evolved a secondary mode of heterotrophic nutrition: they are insectivorous. These plants trap their food in various specialised structures. Special cells lining the 'trap' secrete digestive enzymes onto the captured insects. **Extracellular digestion** of the insect's protein results, and the amino acids are then absorbed through the epidermis.

A few plants are parasitic. Dodder (*Cuscuta australis*), for example, has special structures which penetrate the tissues of other plant species. Some of these tap into the xylem and take up water and dissolved minerals from the host. Others tap into the phloem to obtain the simple organic molecules transported in them. No specialised digestive structures are therefore required.

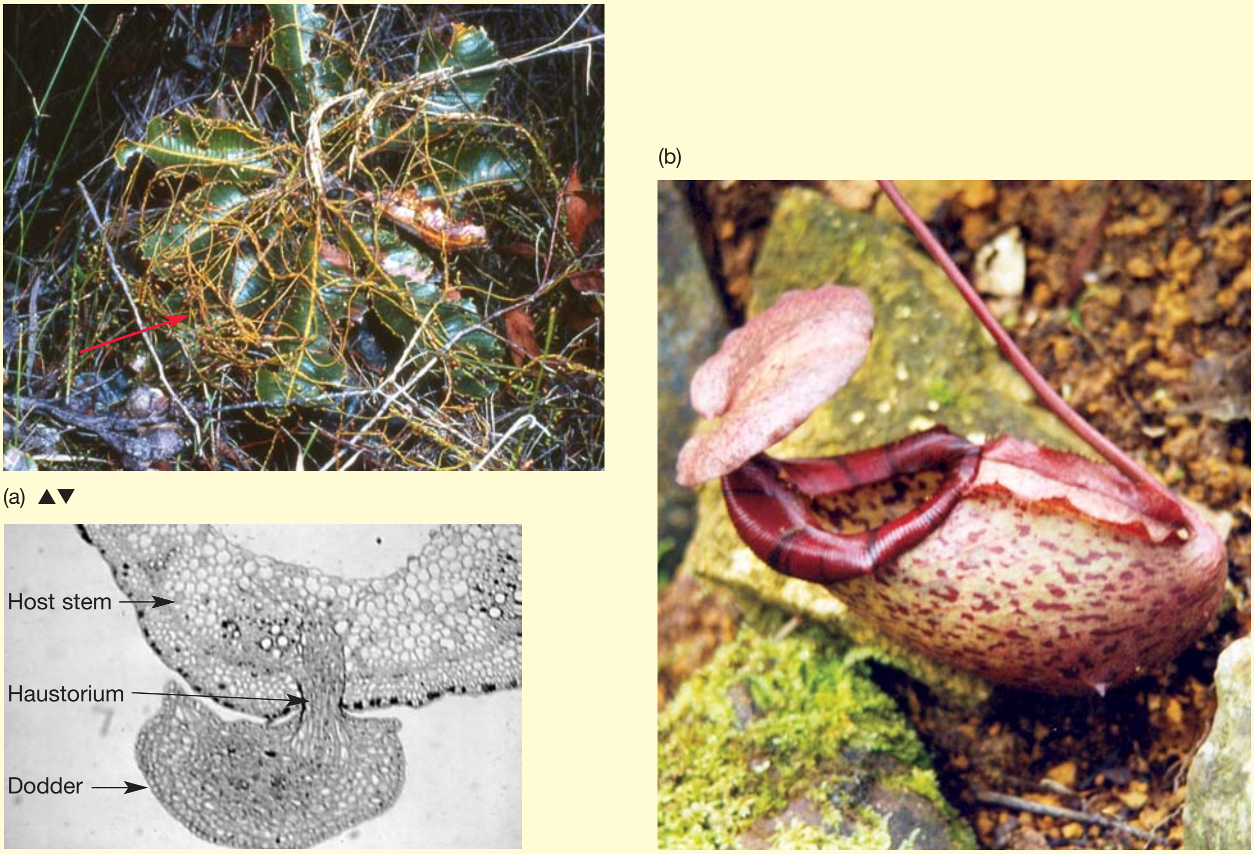


Figure 15.5 Examples of heterotrophic plants: (a) dodder (yellow threads) and (b) pitcher plant

SUMMARY

Digestion is an enzymatic reaction which breaks down a large molecule into molecules small enough to be dissolved and to pass through cell membranes. Different macromolecules need different enzymes to bring about their hydrolysis. Plants need to digest macromolecules to transport 'food' from one part of the body to another. In most plants this involves only intracellular digestion. However, some plants living in nitrogen-deficient soils capture insects and, through extracellular digestion and absorption of the digested molecules, gain the amino acids they need. Parasitic plants usually tap directly into the host's transport systems and do not need to digest the acquired molecules.

Review questions

15.11 Define digestion.

15.12 Why do plants need to digest food?

15.13 Compare the means by which insectivorous and parasitic plants derive extra nutrients.

15.14 Distinguish between intracellular and extracellular digestion.

15.15 Under what circumstances might a plant evolve a heterotrophic means of obtaining nutrients?

15.16 What happens to the digestive enzymes after they have performed their functions? Explain why this is necessary.

15.2 Regulation of fluids

During metabolic reactions certain substances are used and others produced. Some products are wastes which may be toxic if allowed to accumulate in living cells. At all times the concentrations of chemicals within the cell must be maintained within certain set ranges if the cell is to remain functional. This involves three main mechanisms: osmoregulation, excretion and transport.

15.2.1 General features

Evidence suggests that life originated in the sea. Of all the environmental media of living organisms, only sea water has any degree of stability, particularly over long spans of time. Because of the vast bulk of the constantly moving oceans, changes in temperature, acidity and salt concentrations take place very slowly and gradually. Since there is constant interaction between organisms and their environment, it is not surprising that life processes evolved with a close dependence on the stable conditions that exist in sea water. Nor is it surprising to find that complex multicellular organisms have developed body fluids exhibiting many of the features of the marine environment.

Movement onto land involved evolution of adaptations to a diverse range of environments. This resulted in different ways, both physically and chemically, of carrying out life functions. The capacity to maintain a constant internal fluid environment, regardless of changes in the external environment, has been a critical factor for survival.

Regulation of body fluids involves:

- **osmoregulation—**the maintenance of a constant solute and water balance
- **excretion—**removal of metabolic waste material.

In many organisms the two processes occur simultaneously. In all organisms, osmoregulation is closely connected with the environment in which the organism lives.

In general, water can be considered as being distributed in three main areas within the body of multicellular organisms:

- the transport medium (e.g. blood plasma in animals; fluids in the vascular system of plants)
- extracellular fluid in interstitial spaces between cells
- intracellular fluid of the cytoplasm.

The transport medium accounts for the smallest proportion of water; the intracellular fluid the largest. The substances dissolved or suspended in the water differ among the three areas, both in kind and in amount.

The exchange of materials between body fluids is complex. It depends upon moment-to-moment changes in the selectively permeable nature of the cell membrane, and changes in types and quantities of various solutes inside and outside the cells. The metabolic activity of the cells is responsible for both of these changes.

15.2.2 Osmoregulation in plants

Plant cells can tolerate a much wider range of osmotic concentrations bathing their cells than animals can. This is associated with their cell structure. Plant cells are surrounded by a cell wall which exerts a pressure on the cell contained within it.

When plant cells are placed in a hypotonic medium, the uptake of water is limited by the wall pressure. Plant cells cannot continue to take up water until they burst, as animal cells would. In a hypertonic medium, however, water loss causes cell shrinkage similar to that in animals. The resulting high concentration of cytoplasmic solutes often has profound effects on the well-being of the plant. Since they are surrounded by water, marine and freshwater plants do not have osmoregulatory problems. Terrestrial plants, however, can be subject to conditions that may cause severe water loss.

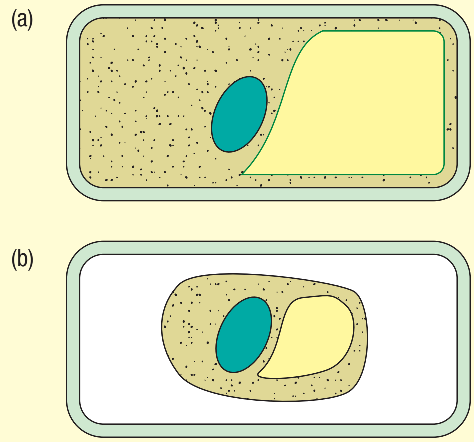


Figure 15.6 The effects of (a) hypotonic and (b) hypertonic extracellular fluid on a plant cell

The epidermis of the leaf is thin and transparent. It is nearly waterproof and airproof because of its waxy outer surface of cutin which covers both surfaces of the leaf. Between the upper and lower epidermis are the two layers of mesophyll tissue. In a typical dicotyledonous leaf, palisade mesophyll cells are found directly under the upper epidermis. Below these cells is a loose spongy layer of parenchyma (spongy mesophyll) containing extensive air spaces. The veins (bundles of xylem and phloem) pass through this spongy layer. (See Figure 15.1, page 374.)

Within the epidermis are the stomata, which close when water levels in the plant are low. The stomata may be found on both leaf surfaces or only on the lower surface, depending on the species of plant and/or its habitat. They are also found in the epidermis of young stems, in floral organs and in fruit.

Transpiration

The carbon dioxide needed for photosynthesis enters the leaf through the stomata along a diffusion gradient, and diffuses into the cells from the air spaces in the mesophyll layer. Because the stomata are open during the process, moisture is lost by evaporation from the wet cell walls surrounding the intercellular spaces. The sun's rays provide the heat energy for evaporation.

Water loss from the plant by evaporation from its surfaces is called **transpiration**. Unless this water is continually replaced, the stomatal guard cells will collapse and the stomata will close, preventing further diffusion of carbon dioxide into the leaf. If this happens, the supply of carbon dioxide for photosynthesis is restricted to what is produced by the respiration of the leaf cells. In this case there will be no increase in organic matter produced by the plant. For a net increase in photosynthetic products, plants must continually take in water through their root systems to compensate for water lost through transpiration.

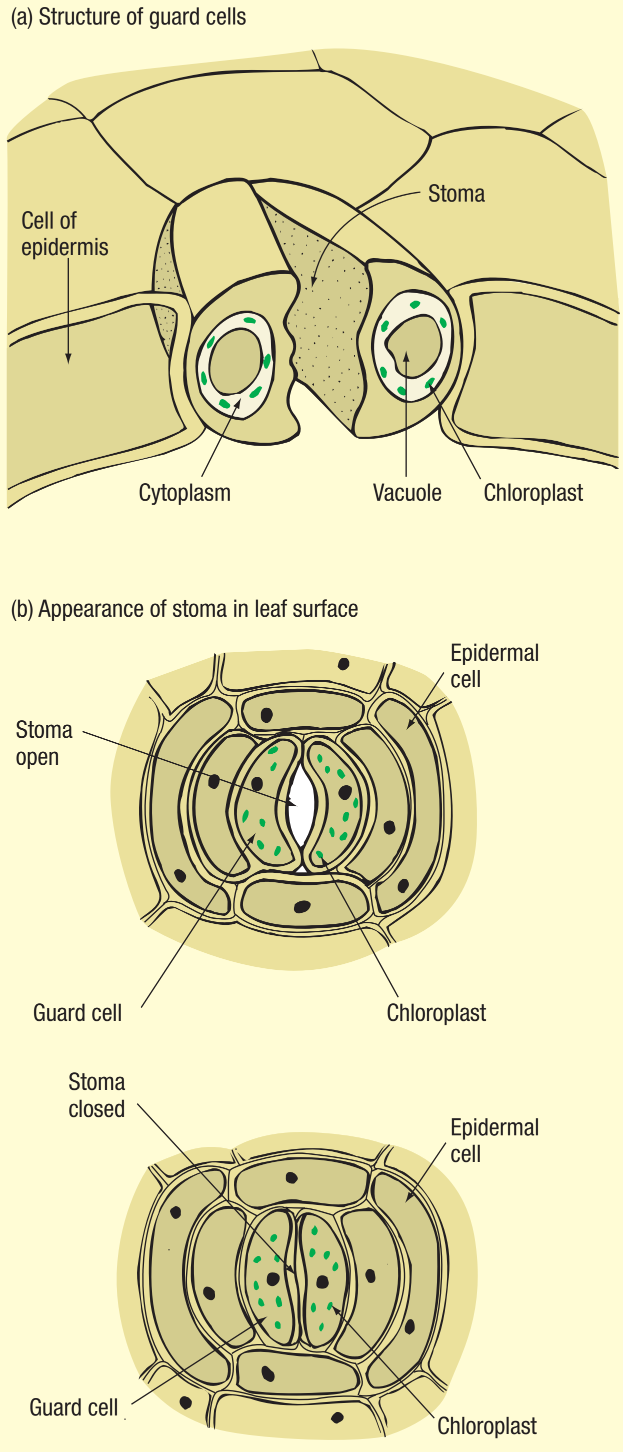


Figure 15.7 The structure of stomata

The function of guard cells

Each stoma is surrounded by two modified epidermal cells called guard cells which are supported by the surrounding epidermal cells. They occupy a very small proportion of the leaf's surface, but diffusion through the stomata is extremely efficient.

The opening and closing of stomata involves variations in the water content of the guard cells. Their cell walls are thicker next to the pore than next to the surrounding epidermal cells. When they are full of water (turgid), their thin walls stretch more than the thick ones, causing the two cells to curve away from each other and the pore to open. As the guard cells lose water and their turgor pressure decreases, the guard cells become straighter and the pore closes.

Hypotheses on the operation of guard cells

The way in which guard cells work has not, as yet, been fully explained. There are various hypotheses, however.

Unlike other epidermal cells, guard cells contain chloroplasts and photosynthesise. Glucose therefore accumulates in them during the day. It has been proposed that carbon dioxide from cell respiration accumulates in the saturated intercellular spaces of the leaf during darkness. Carbon dioxide dissolves in water to form carbonic acid, and this lowers the pH inside the leaf. Acidic conditions trigger the conversion of glucose in the guard cells to starch, which is osmotically inactive. This causes the guard cells to lose water by osmosis, collapse and close the stomata.

In the light, the carbon dioxide is rapidly used in photosynthesis. This raises the pH and favours the conversion of starch to glucose, an osmotically active substance. Water is therefore drawn into the guard cells, creating turgor pressure and opening the pore.

Since the movement of the guard cells can be quite rapid, it is proposed that a second mechanism also may act in altering the turgidity. Experimental evidence suggests that an ATP-driven potassium ion pump operates in the guard cell membrane. Potassium ions are pumped into the cell in response to appropriate stimuli (associated with a decrease in levels of the hormone abscissic acid). This increases the osmotic pressure in the cell, causing an osmotic influx of water and making the guard cell turgid.

These are only possible hypotheses to explain the opening and closing of guard cells; as yet there is no definitive explanation of this process.

Factors affecting transpiration rate

Transpiration rate has been shown to be affected by a range of external factors.

Light

Stomata usually open in the light and close in the dark.

Temperature

An increase in temperature increases the rate of transpiration.

Humidity

An increase in humidity causes a decrease in transpiration. This is due to a decreased diffusion gradient between the intercellular spaces and the atmosphere, which reduces evaporation.

Wind

Wind increases transpiration by the removal of water vapour around the stomatal pore.

Soil water

If the supply of soil water is reduced, uptake decreases and the transpiration rate falls as a result.

15.2.3 Plant adaptations for osmoregulation

If the plant is growing in a well-watered soil, evaporative loss of water does not present a problem because it can be rapidly replaced by uptake from the soil. These plants, called **mesophytes,** therefore have no special means for conserving water.

For plants living in dry conditions, however, transpirational loss can lead to drastic dehydration. Two strategies are available for such plants. They have evolved either to avoid adverse conditions or have adaptations which enable them to resist drought conditions. Some plants have tissues which are capable of withstanding extremes of desiccation. Their protoplasm can be almost totally dried out and yet resume normal functioning when water again becomes available (e.g. some desert plants and many mosses and ferns: resurrection plants). Ephemeral desert plants complete their life cycle in an extremely short time immediately after a wet season. They pass the drought periods as hard fruits or seeds that lie dormant in the soil. Some of these ephemerals may take only ten days between germination and seed production. Other plants survive the dry months as storage organs (bulbs, corms, tubers or fleshy roots).

Xerophytes are plants that have evolved special adaptations which enable them to resist drought conditions. Some of these adaptations are listed below.

- The possession of a very extensive, shallow root system (e.g. mulga) and/or deep 'water-seeking' roots to increase water uptake.
- The presence of special water-storage tissues. Where these fleshy areas make up a large part of the plant, they are described as succulents (e.g. pigface).
- The presence of one or more **transpirational checks**. These include:
  - — leaves with low surface area to volume ratio (e.g. small and/or succulent leaves)
  - — reduction in the number of stomata (e.g. prickly pear)
  - — sunken stomata which increase humidity around the pore (e.g. *Hakea*)
  - — hairs on the leaf surface which increase humidity close to the leaf by reducing air currents across the stomatal openings
  - — rolling and/or folding of leaves, thus increasing humidity in the central core (e.g. spinifex and marram grass)
  - — reduction in the length of time that stomata remain open.

Many plants suffer **physiological drought** because, although water is present in the habitat, it is not readily available. Plants living in saltmarshes may suffer water loss due to the osmotic effects resulting from the hypertonic medium. These plants, called **halophytes**, have root cells which exert a higher than normal osmotic pressure, allowing them to take in water by osmosis. Some store water in their tissues.

Many plants of temperate regions effectively suffer drought conditions when the soil water freezes and becomes unavailable to them. Herbaceous plants may survive winter conditions as seeds or storage organs. Deciduous trees and shrubs shed their leaves. Conifers reduce transpiration because they have a reduced leaf surface area and a thick cuticle.

Plants in more humid habitats have a different problem: they must get rid of excess water. Some species (e.g. many rainforest plants) are able to

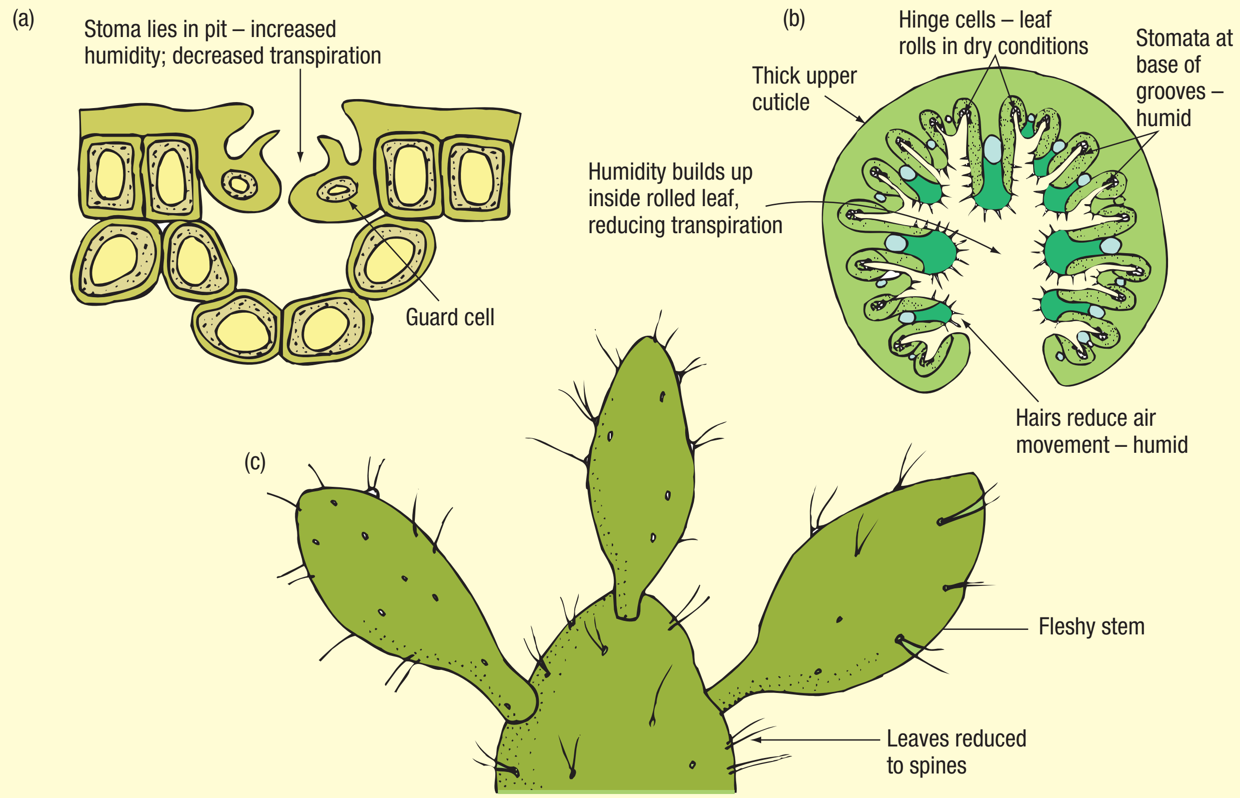


Figure 15.8 Some adaptations of xerophytes

actively secrete water from special structures called hydathodes, situated at the terminal ends of the veins around the edges of the leaves. This action is known as **guttation**. The removal of the excess water is aided in these species by the presence of a pointed, drooping tip on the leaves called a **drip tip**.

15.2.4 Plant excretion

Excretion is the removal of metabolic waste products. Compared with animals, plants produce very little excretory material. Carbon dioxide, produced as a by-product of respiration, is either released by diffusion through root hairs, lenticels or stomata, or utilised by photosynthetic cells in photosynthesis. Plants can regulate the synthesis of proteins according to their needs, so they do not usually excrete nitrogenous wastes. Wastes from other processes are generally converted into relatively insoluble, non-toxic forms. These are stored either inside cells (in the large vacuole) or in intercellular spaces. This storage is either for life or in parts which are periodically lost and replaced, such as leaves or bark. Tannins are soluble wastes which can be found in roots, wood, bark, leaves and fruit. Some plants, such as tea, have very high levels of tannins.

SUMMARY

Regulation of body fluids involves both osmoregulation and excretion.

Osmoregulation is the maintenance of a constant solute and water balance in the cells and body fluids. It is intimately connected with the environment of the organism. Due to lack of water in terrestrial environments, plants have evolved adaptations to prevent water loss or to maximise water uptake. Open stomata, necessary for gas exchange, result in the escape of water vapour from the plant (transpiration). Heat energy is required for the evaporation of water. This is supplied by solar energy. The plant itself does not expend any biological energy in transpiration. The transpiration rate is affected by light, temperature, humidity, wind and the availability of soil water.

Adaptations to reduce transpirational water loss include:

- leaves with low surface area to volume ratio
- reduced number of stomata
- sunken stomata
- hairs on leaf surface
- folding of leaf
- reduction in time the stomata are open.

Excretion is the removal of metabolic waste material. Osmoregulation and excretion may occur simultaneously. Plants produce very little excretory material. Wastes either diffuse out of the plant or are stored within the plant.

? **Review questions**

15.17 Photosynthetic rate and transpiration are intimately linked. Explain the factors that connect these two processes.

15.18 With the aid of diagrams, describe the structure of a stoma of a dicotyledon. Explain the series of events which are believed to lead to the opening of the stoma.

15.19 Explain the high water loss from stomata in relation to the pore size.

15.20 List factors affecting transpiration rate.

15.21 Describe adaptations by plants to reduce water loss in hot, dry conditions.

15.22 What is meant by the term 'physiological drought'? Give examples of how plants cope with physiological drought.

15.23 Distinguish between osmoregulation and excretion.

15.24 Explain why plants produce very little excretory material compared with animals.

15.3 Transport

All organisms take in gases and nutrients from the external environment, utilise them within their 'body' for immediate or future use, and dispose of unwanted materials. In all cases these materials must be moved around the organism, even if it is only within the cytoplasm of a single-celled organism.

Simple organisms rely upon the physical process of diffusion (including osmosis) and active processes which expend cellular energy (e.g. carrier molecule systems, cytoplasmic streaming, phagocytosis and pinocytosis) for movement of materials between the environment and cell(s). These same processes operate in the individual cells of multicellular organisms.

As organisms become larger, and specific parts of the body become differentiated for particular functions, these processes become very inefficient except at the cellular level. With increase in size and specialisation, organisms have evolved a separate system, the circulatory or **transport system**, to perform this function.

Table 15.2 Materials transported in organisms

Intracellular transport	Intercellular transport
Small amounts of small ions or molecules and water over small distances	Large amounts of large molecules, particles and water over long distances
High surface area:cell volume ratio	Low surface area:body volume ratio
Vacuoles fluid filled, and contain particles in animals	Vessels fluid filled (blood in animals)
Diffusion in vacuoles or cytoplasm of ions and small molecules	Diffusion in intercellular spaces
Endoplasmic reticulum tubules transport large protein and lipid molecules. Plasmodesmata are narrow tubes connecting adjacent plant cells.	Vessels transport large molecules in phloem of plants and vessels of animals; small molecules in plant xylem. Pits connect adjacent vessels in vascular plants.
Cytoplasmic streaming	Circulatory system (heart and blood vessels in most animals) Transpiration stream and translocation in land plants
Microtubules associated with cell motion and microfilaments in amoeboid movements	In animals—ciliated epithelium transports mucus and small particles, e.g. dust. Peristalsis occurs in tubular organs in gut, uterus and ureter.

Transport refers to the movement, circulation or flow of different substances within living organisms, either with or without a continuous tubular vascular system.

Transported substances include:

- aqueous solutions of ions and small molecules
- solids composed of large molecules, insoluble suspensions and food particles
- gases or vapours: oxygen, carbon dioxide and water vapour; or mixtures of gases in air.

SUMMARY

Transport is the movement of materials within the organism. It may be intracellular or intercellular. Intercellular transport may involve a system of vessels.

Review questions

15.25 Distinguish between intracellular and intercellular transport.

15.26 Describe ways in which intracellular transport is achieved.

15.27 Simple organisms do not have special transport systems. Explain:

(a) how they operate without such a system

(b) limitations that lack of a transport system places on them.

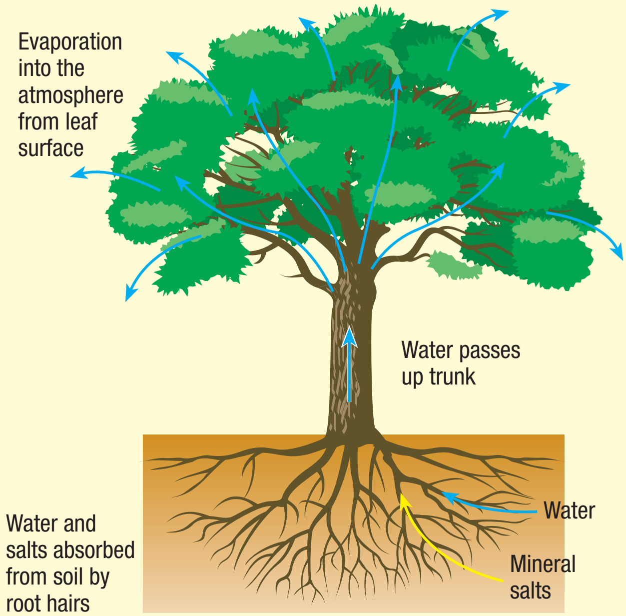


Figure 15.9 The transpiration stream.

15.4 Transport systems of flowering plants

15.4.1 Movement of water and ions into the root

Water (containing dissolved mineral ions) enters through the root hairs of land plants. It passes up through the stem and is lost through the leaves and stem by transpiration.

The direction of water movement is in one direction only, from roots to leaves, and is referred to as the **transpiration stream**.

Most water absorption occurs in the root hairs. These are fine outgrowths from the outer cells of the growing tip of the root. Collectively they provide a very large surface area in close contact with the soil particles. Water passes from the soil into the root hairs by osmosis as a result of the higher concentration of solutes in their cell sap. This process continues so long as the cell sap is more concentrated than the surrounding soil water.

Water passes from the root hair, across the cortex to the xylem by one of the three different pathways:

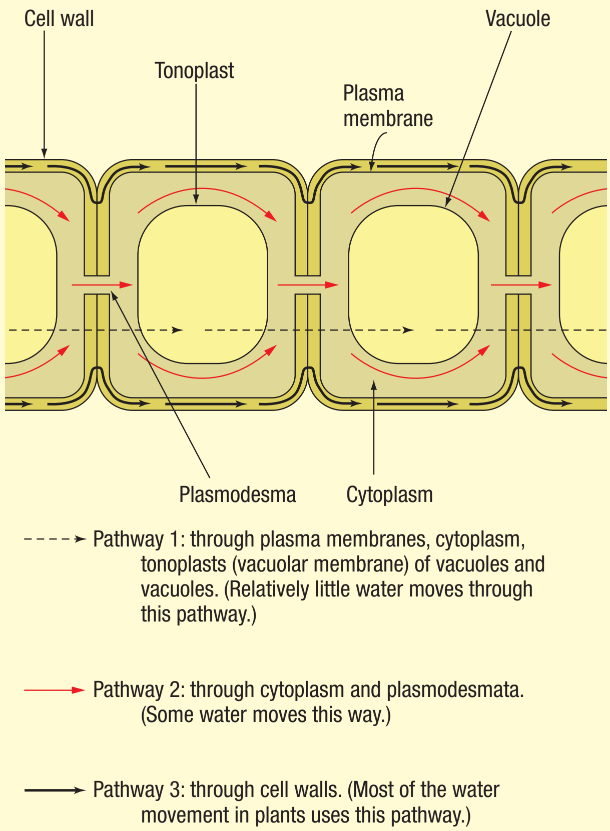


Figure 15.10 The possible pathways for movement of water through plant cells

Pathway 1: passing from one cell vacuole to the next by osmosis, through cell wall and all cell contents

Pathway 2: moving through the plasmodesmata (fine protoplasmic connections) from one cell to the next by osmosis

Pathway 3: moving along and through the intercellular spaces and cellulose cell walls from one cell to the next (i.e. bypassing cell membrane and contents).

These pathways also occur between cells in the leaf.

The general structure of roots and stems, and the tissue arrangements in monocotyledonous and dicotyledonous plants is shown in Figure 15.12 on pages 386–7.

Any pathway taken by water that involves the cell walls is interrupted in the root by a ring of specialised cells surrounding the vascular tissue. These cells are termed the endodermal cells, and are illustrated in Figure 15.11. In most species these cells have a thickening of a waxy, waterproof substance called suberin, the **Casparian strip**, around one diameter of the wall.

It is thought that the Casparian strip may force water to pass through the cell cytoplasm rather than along its walls. This regulates the movement of water into the xylem. Such control is necessary to regulate salt movement. It may also be a protective measure against the entry of toxic substances, fungal pathogens and so on.

Water probably enters the xylem by active secretion from the surrounding living cells, creating a **root pressure** which forces the water a short distance up the stem. The extent to which water can move up the stem as a result of root pressure is limited, and it is counteracted by a downward gravitational pull, which increases with the height of the stem.

Nutrient ions enter the plant dissolved in water and pass with the water to the xylem. It is thought that positive ions are actively transported into the root hairs. This is an energy-consuming process. Negative ions passively diffuse into the cell to counteract the electrical imbalance created in the cell sap.

15.4.2 Movement of water in the xylem

Xylem is a mixture of living and dead cells:

- dead cells—tracheids, vessels and supporting fibres
- living cells—parenchyma (starch storage).

The vessels and tracheids offer little resistance to water movement. They have lignified (waterproof) walls and no cell contents when mature.

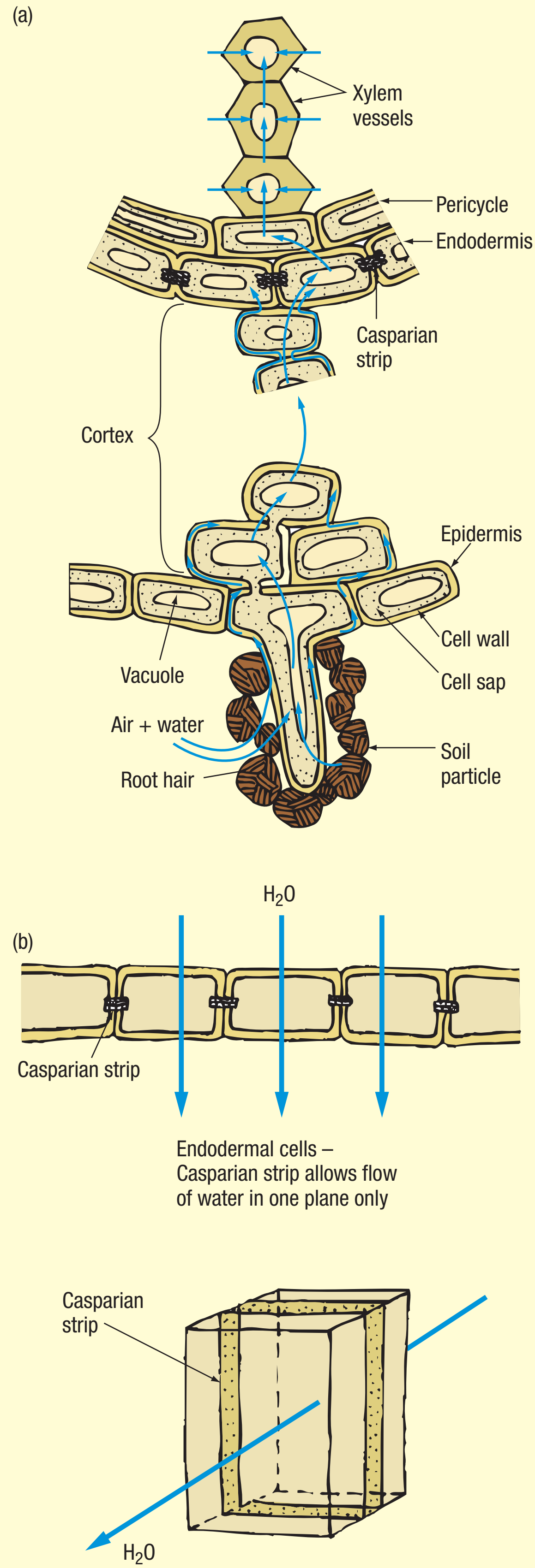


Figure 15.11 Movement of water into the root

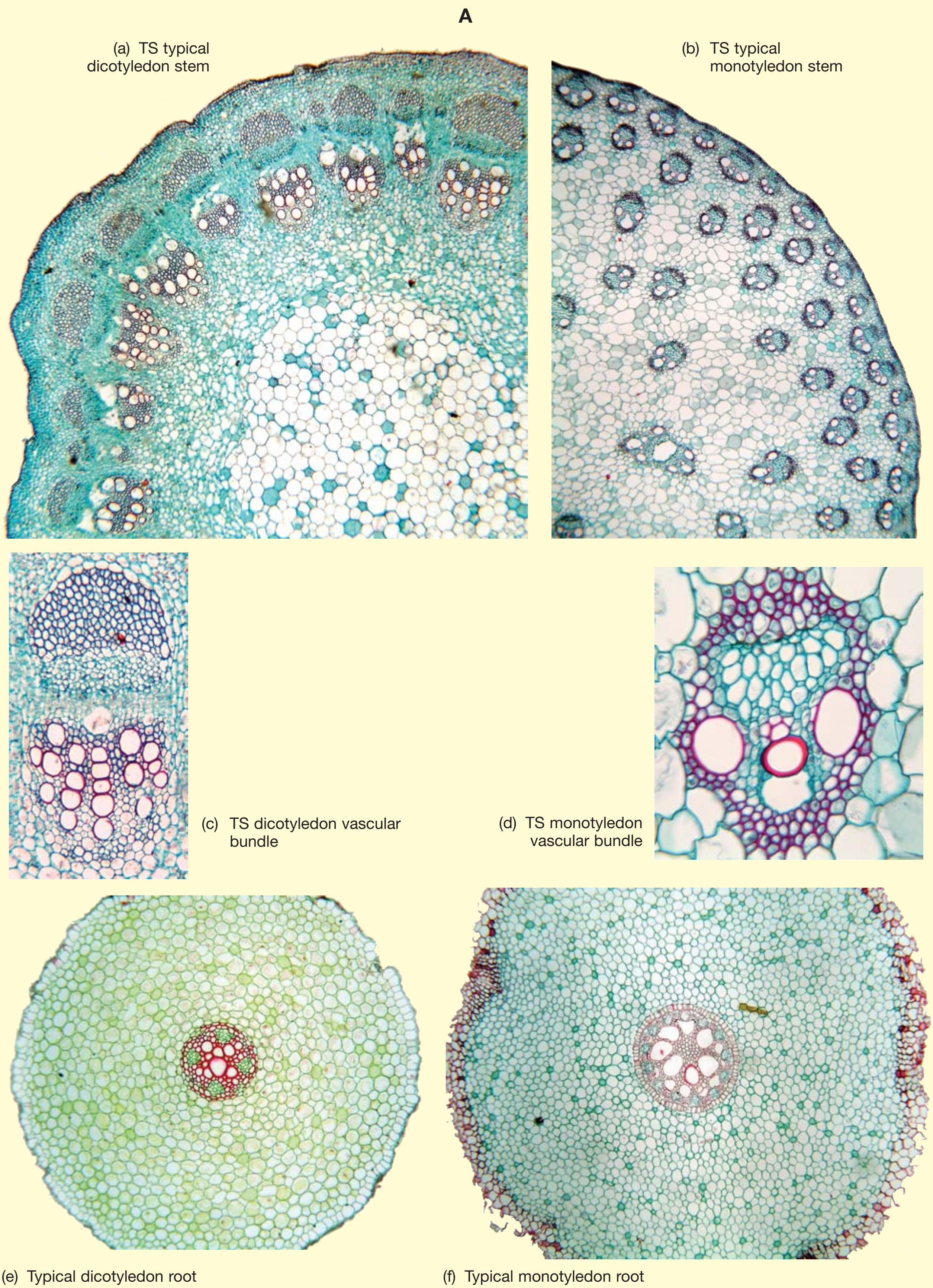
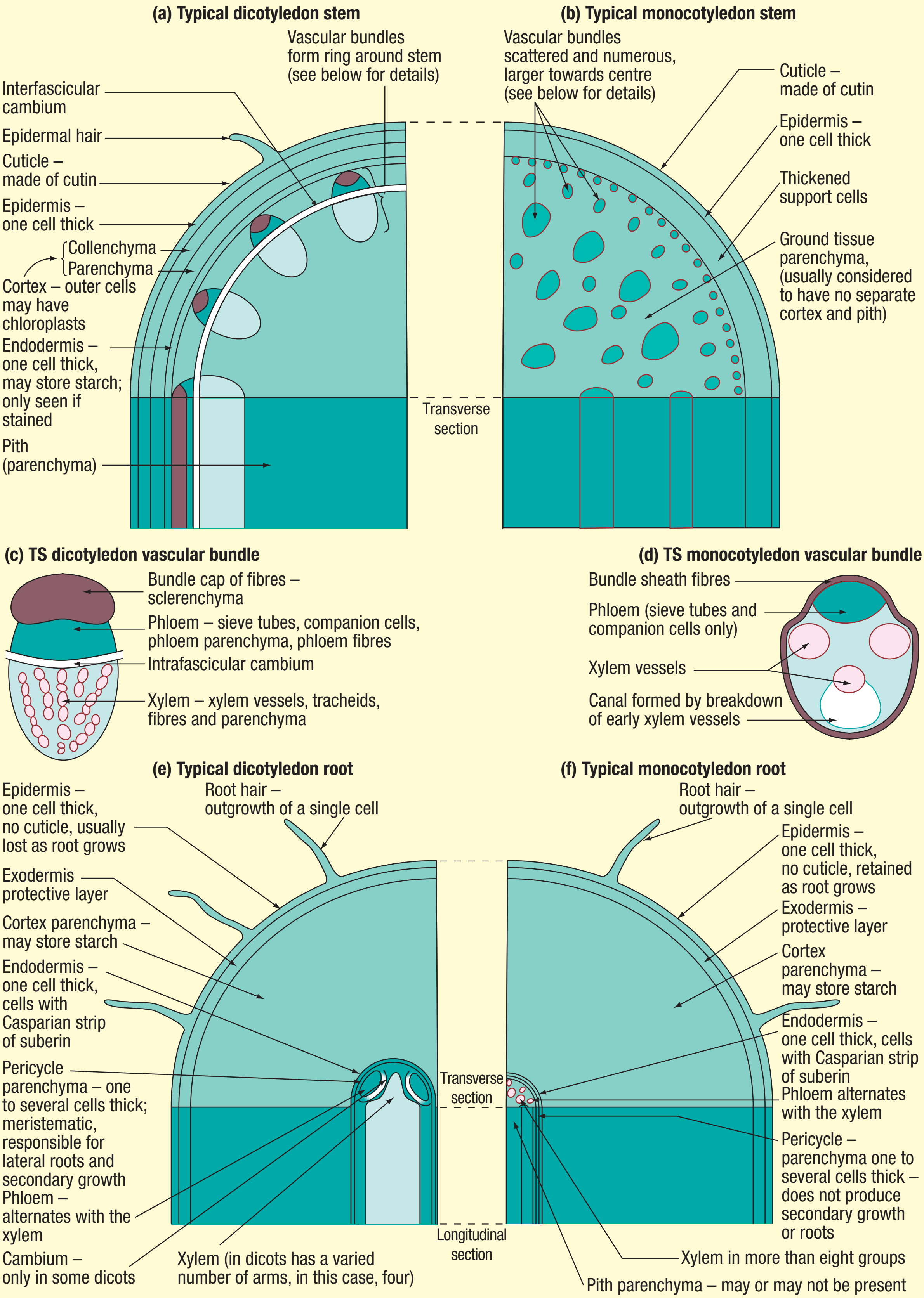


Figure 15.12 Microscope photographs (A) and zone diagrams (B) of stem and root of dicots and (TS = transverse section; LS = longitudinal section) monocots

B



(a) Typical dicotyledon stem
Vascular bundles
form ring around stem
(see below for details)
Interfascicular
cambium
Epidermal hair
Cuticle –
made of cutin
Epidermis –
one cell thick
Collenchyma
Parenchyma
Cortex – outer cells
may have
chloroplasts
Endodermis –
one cell thick,
may store starch;
only seen if
stained
Pith
(parenchyma)
(b) Typical monocotyledon stem
Vascular bundles
scattered and numerous,
larger towards centre
(see below for details)
Cuticle –
made of cutin
Epidermis –
one cell thick
Thickened
support cells
Ground tissue
parenchyma,
(usually considered
to have no separate
cortex and pith)
Transverse
section
(c) TS dicotyledon vascular bundle
Bundle cap of fibres –
sclerenchyma
Phloem – sieve tubes, companion cells,
phloem parenchyma, phloem fibres
Intrafascicular cambium
Xylem – xylem vessels, tracheids,
fibres and parenchyma
(d) TS monocotyledon vascular bundle
Bundle sheath fibres
Phloem (sieve tubes and
companion cells only)
Xylem vessels
Canal formed by breakdown
of early xylem vessels
(e) Typical dicotyledon root
Epidermis –
one cell thick,
no cuticle, usually
lost as root grows
Root hair –
outgrowth of a single cell
Exodermis
protective layer
Cortex parenchyma –
may store starch
Endodermis –
one cell thick,
cells with
Casparian strip
of suberin
Pericycle
parenchyma – one
to several cells thick;
meristematic,
responsible for
lateral roots and
secondary growth
Phloem –
alternates with the
xylem
Cambium –
only in some dicots
Xylem (in dicots has a varied
number of arms, in this case, four)
(f) Typical monocotyledon root
Root hair –
outgrowth of a single cell
Epidermis –
one cell thick,
no cuticle, retained
as root grows
Exodermis –
protective layer
Cortex
parenchyma –
may store starch
Endodermis –
one cell thick, cells
with Casparian strip
of suberin
Phloem alternates
with the xylem
Pericycle –
parenchyma one to
several cells thick –
does not produce
secondary growth
or roots
Transverse
section
Longitudinal
section
Xylem in more than eight groups
Pith parenchyma – may or may not be present

Vessels are composed of a series of cells called vessel elements arranged end to end. The end walls of these elements break down during maturation, leaving a continuous tube. At numerous points in their walls are thinner, unlignified regions called pits. They are composed only of the cellulose wall. Water can easily pass laterally from cell to cell through these pits. Pits may have a border or projecting rim of lignin surrounding them. Some of these pits have a central plug of lignin, a torus, which may regulate lateral water movement.

Tracheids offer much more resistance to water flow because they retain their end walls which taper and overlap each other. They (like the lateral walls) are pitted. Angiosperms contain both vessels and tracheids, but gymnosperms have only tracheids.

Two strong forces act on water molecules in the xylem: cohesion and adhesion. Cohesion acts between the water molecules, holding them together. Adhesion acts between the water molecules and the cellulose of the cell walls. Since the vessels and tracheids are very narrow in relation to their length, there is a large surface area in contact with the water which enhances the force of adhesion.

As water transpires through the stomata, the spongy mesophyll cells of the leaf draw water from the xylem in the veins. This effect is similar to water being soaked up by blotting paper. This exerts a pull on the water column in the leaf xylem. Due to the strong force of cohesion between the water molecules, this force is transmitted back down the stem to the roots, dragging more water upwards.

During rapid transpiration, the pull exerted on the network of water columns in the xylem can be so strong that a negative pressure is generated. Since adhesion is strong, the xylem walls can be pulled inwards, causing the whole diameter of the stem to shrink.

Damage to individual xylem cells or groups of them does not interrupt water flow. Airlocks associated with damage may stop at the perforated end walls of vessels, and water can pass to adjacent cells via the lateral wall pits. This remedies any potential loss of cohesion due to air bubbles in the stream.

To summarise, water transport through the plant involves:

- *osmosis* along a diffusion gradient from the leaves down to the roots and the soil
- *root pressure* causing water to move a limited distance up the stem until counteracted by the force of gravity
- *adhesion* of water molecules to the walls of the vessels and tracheids and the spongy mesophyll cells

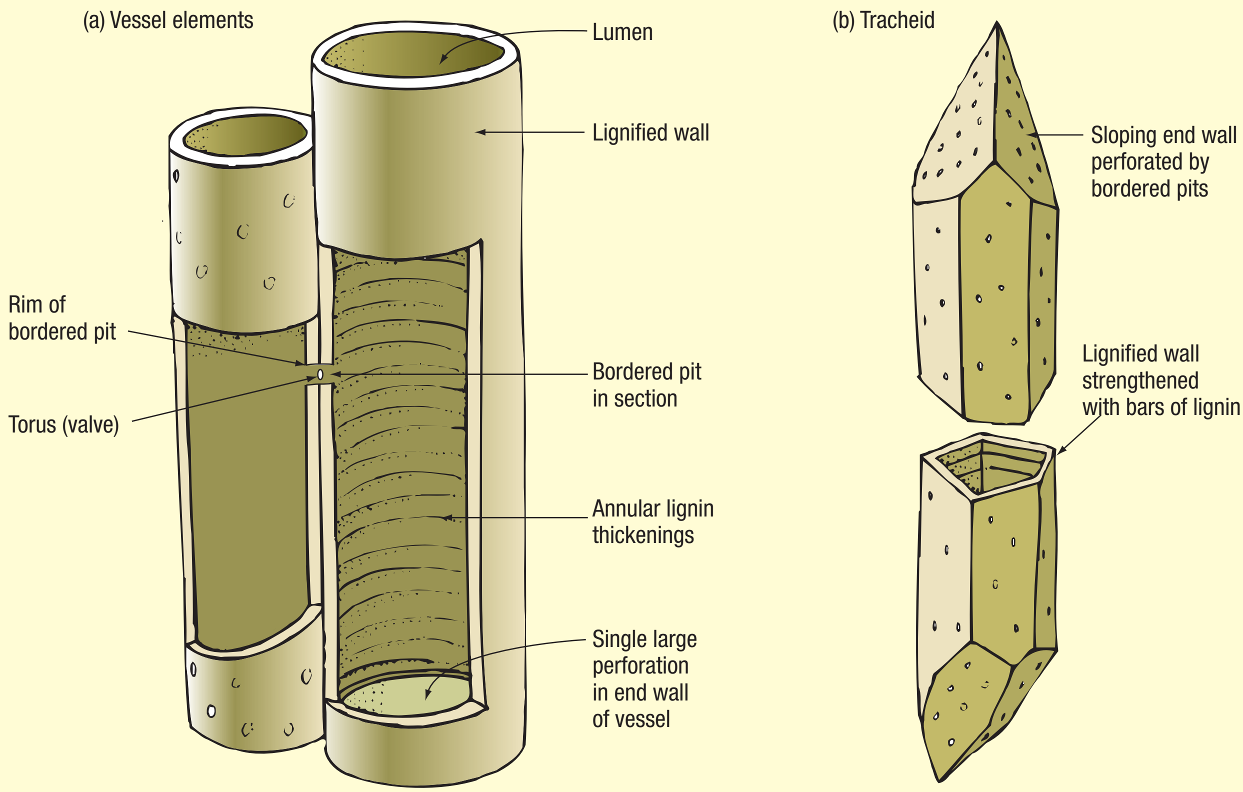


Figure 15.13 Water-carrying components of xylem

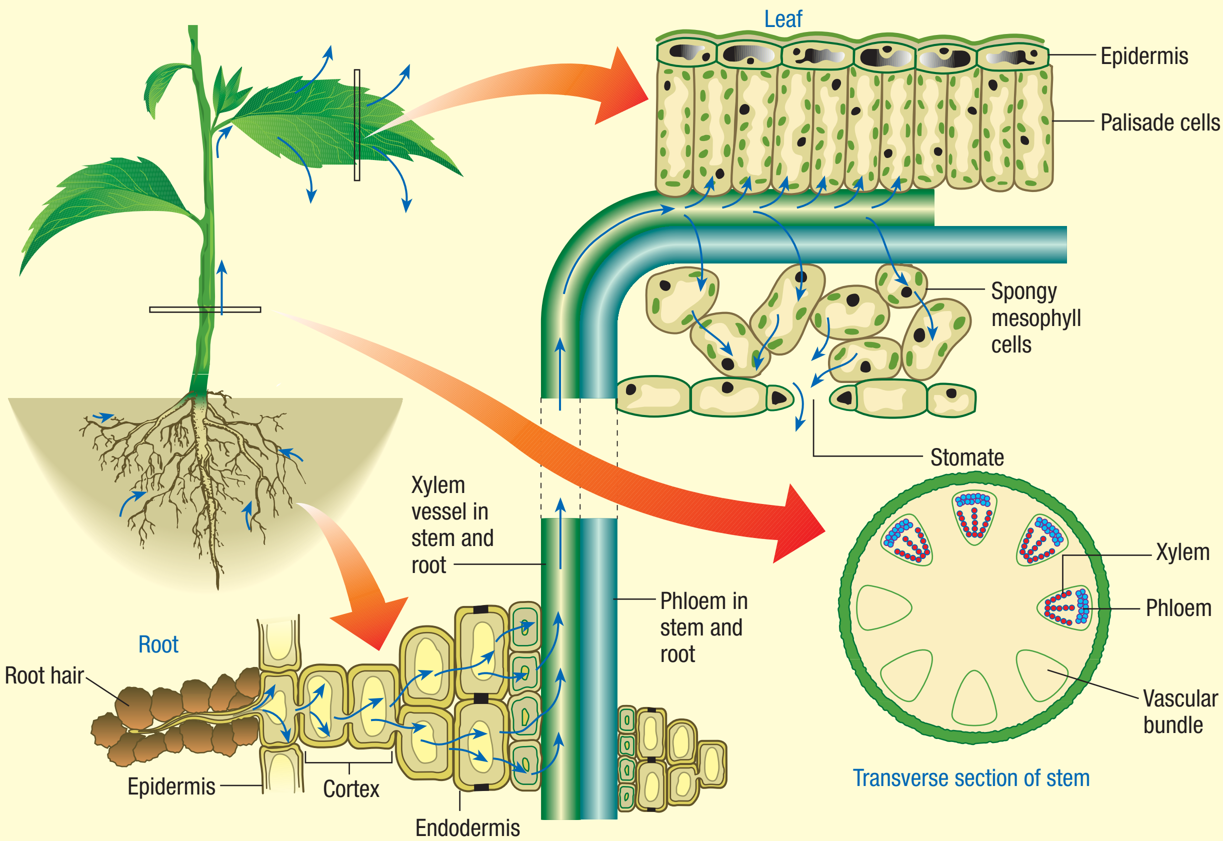


Figure 15.14 A summary of the passage of water through the plant

- *cohesion* between the water molecules forming the thin water columns in the xylem
- *transpiration*, causing loss of water from the stomata of the leaves.

At no stage does the plant expend any energy in water transport. A large amount of energy is, however, required for its operation, but this energy is provided by the sun. Heat is absorbed by the water, bringing about its evaporation at the leaf's surface.

15.4.3 Movement of organic molecules

Translocation, the movement of organic molecules throughout the plant, occurs in the sieve tubes of the phloem. This movement can occur in all directions, from leaves to roots, leaves to apex and conversely. Molecules (sugars, amino acids etc.) produced in the photosynthetic cells of the leaf must be transported to the non-photosynthetic cells of the plant, particularly to actively growing points such as the apex, branches and root tips. Excess food materials can be stored in specific parts of the plant (in modified roots, stems and leaves) for future needs. The stored material can be transported to active cells at a later time.

Phloem is a complex tissue composed of supporting fibres and sclereids (both dead) and the living sieve tubes, companion cells and parenchyma. The sieve tubes run parallel to the long axis of the plant and are made up of elongated sieve tube elements placed end on end. Each sieve tube element has a specialised end wall (sieve plate) which is perforated by numerous pores. Although the cell nucleus and most organelles disintegrate once the element is mature, some organelles persist close to the cellulose wall and structurally simple cytoplasm filaments exist. These filaments are continuous with those of adjacent elements through the pores of the sieve plate, and so create a cytoplasmic stream throughout the length of the tube.

Specialised, elongated companion cells are found closely associated with each sieve tube element in most flowering plants. The walls of these two cell types are thin where they are in contact and connected by plasmodesmata. It has been hypothesised that the nucleus of the companion cell controls the cytoplasm of both cells. Gymnosperms do not have companion cells but do have closely associated parenchyma cells which may also serve this function. The functional unit of the phloem, therefore, consists of a sieve tube element and its companion cell.

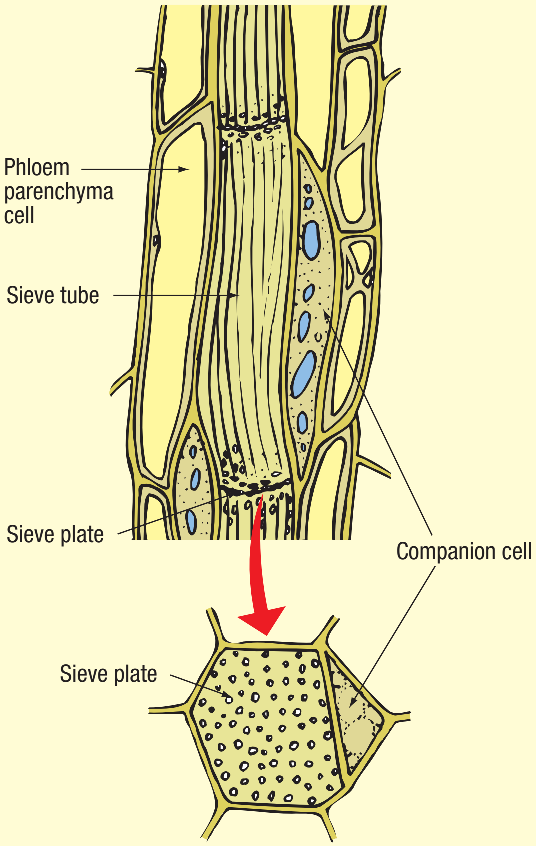


Figure 15.15 Components of phloem

The way in which phloem functions is not fully understood. The following observations have been made on the movement of solutes in the phloem:

- The movement is often more rapid than can be accounted for by simple diffusion.
- The speed of movement differs for different elements.
- The direction of movement within a given sieve tube may be reversed.
- The direction of movement in adjacent sieve tubes may be opposite.
- The direction of movement of solutes carried on separate cytoplasmic filaments within one sieve tube may be opposite.
- Metabolic poisons such as hydrogen cyanide inhibit carbohydrate translocation.
- Up to 35°C, a rise in temperature increases the rate of translocation.

Although it is generally agreed that solutes enter and leave the sieve tubes by active transport, it is not certain how they travel through the tubes. Several hypotheses (none totally satisfactory) have been proposed in an attempt to explain these phenomena.

Cytoplasmic streaming

This hypothesis proposes that materials diffusing into one end of a sieve cell are picked up by the streaming cytoplasm and carried to the other end of the cell, where they diffuse across the sieve plates (this may involve active transport) and are picked up by the streaming cytoplasm of the next element.

This hypothesis explains opposite movements of solutes within the one tube, but there is no direct evidence that cytoplasmic streaming does occur in the mature elements. In addition, measurements of the velocity of streaming in other cells indicate that it is too low to account for the speed of movement of solutes in the tubes.

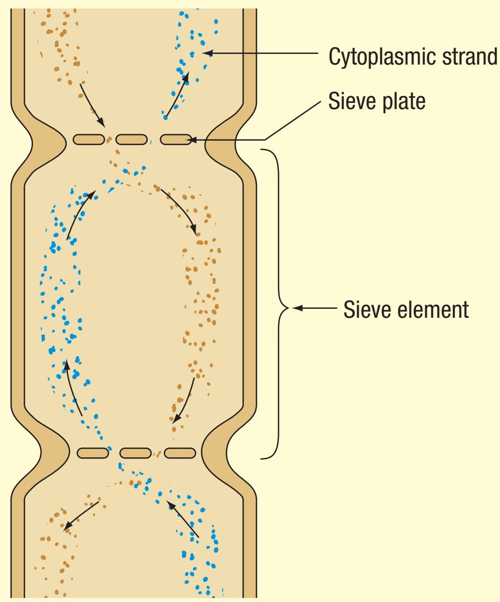


Figure 15.16 Cytoplasmic streaming hypothesis of translocation

Activated diffusion

According to this hypothesis, solutes diffuse through the sieve tubes along a concentration gradient. The rate of flow is increased by the input of energy from the companion cells. Not all movement of solutes, however, is along a concentration gradient.

Mass flow

Cells in the leaf, for example, contain high concentrations of osmotically active substances such as sugar. Much water therefore tends to diffuse into them, thus raising their turgor pressure. The mass flow hypothesis states that this pressure acts on adjacent cells and tends to force substances from cell to cell. Substances are forced, under pressure, to enter the sieve tube elements in the upper parts of the plant, exerting a further pressure at this point. In storage organs or actively growing tissues, sugars are used up or converted to starch which is osmotically inactive. This results in loss of water from these areas by osmosis and a reduced turgor pressure. In the sieve tube system, therefore, some portions of the plant are under considerable turgor pressure, whereas others are under lower pressure. This causes water, carrying dissolved solutes, to flow from high to low turgor pressure through the sieve tubes.

The mass flow hypothesis does not explain why living cells are needed for translocation, or why factors affecting metabolic rate also affect translocation speeds. Neither does it explain the bidirectional flow of solutes in a tube. It assumes relative freedom of flow across the sieve plate and ignores the fact that the pores are very small, and would offer high resistance to mass flow as proposed. A major criticism of this hypothesis is that, even when leaves are wilted (i.e. where turgor pressure is low), translocation away from them still occurs. In this case some sort of active transport is required to move the organic solutes.

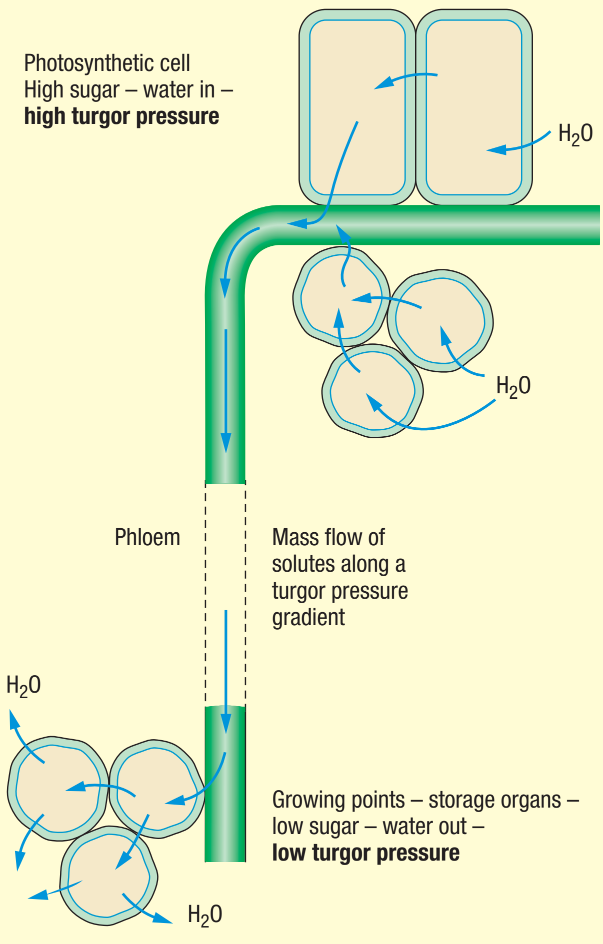


Figure 15.17 Mass flow hypothesis of translocation

Electro-osmotic mass flow

It has been proposed that two different factors may work together to produce movement of material in the phloem. Mass flow occurs down the sieve elements and is assisted across the sieve plates by an electro-osmotic effect. According to this hypothesis, the sieve plates become polarised because potassium ions are taken up below the plate and secreted back into the tube above it by the companion cells. This is an energy-consuming process. An electrical gradient is produced across the pores. Passive diffusion of solutes occurs as they are carried across the sieve plate with accelerated potassium ions. (See Figure 15.18.)

This theory explains the need for living cells and the fact that potassium ions are found in sieve tubes in the appropriate concentrations. It does not explain bidirectional flow.

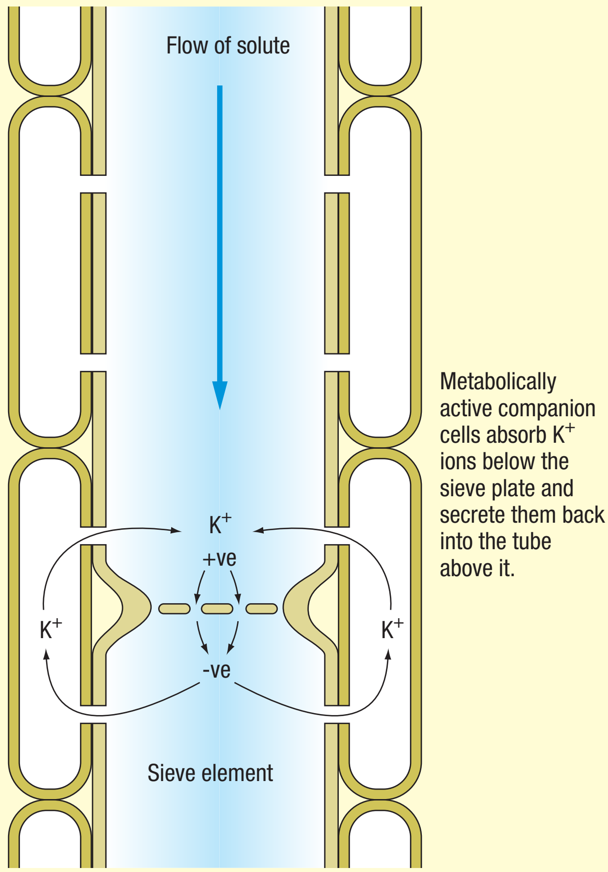


Figure 15.18 Electro-osmosis across the sieve plate

No one hypothesis fits all the known facts of phloem translocation, but combinations of active transport, electro-osmotic mass flow and cyto-plasmic streaming comply with most of them. Energy is required for active transport and for development of an electro-osmotic gradient across sieve plates. This energy must be expended by the plant and released by respiration processes which most likely occur in the companion cells and phloem parenchyma.

SUMMARY

To replace the water lost by transpiration, water taken up by the roots flows through the plant in the transpiration stream. There is a one-way flow from roots to leaf surface in xylem.

Movement of water from the soil to the vascular tissues (and between all plant cells) occurs in three ways:

- from one cell to the next by osmosis through cell wall and all cell contents
- by osmosis through plasmodesmata
- along and through the intercellular spaces and cellulose walls from one cell to the next.

Dissolved mineral ions are taken up by root hairs by active transport, and move with the water into the xylem.

The transpirational stream is achieved by:

- osmosis along a diffusion gradient between the leaves and the roots and soil
- root pressure, causing water to move up the stem a limited distance until counteracted by the force of gravity
- adhesion of water molecules to the walls of the xylem elements and the spongy mesophyll cells
- cohesion between the water molecules, forming thin water columns in the xylem
- transpiration, causing a water loss from the stomata of the leaves.

Organic compounds are translocated throughout the plant in sieve tubes in the phloem of the vascular bundles. Companion cells associated with each sieve tube cell are rich in mitochondria and are thought to provide energy for the movement of solutes in the sieve tubes.

Simple chemical solutes only are translocated. The mechanism for translocation is not fully understood, but may take place by means of mass flow and/or active transport (e.g. electro-osmosis). Several observations have been made on the movement of solutes in the phloem. No single translocation hypothesis fully accounts for all observations.

? Review questions

15.28 Define the following terms:

(a) adhesion
(b) capillarity
(c) cohesion
(d) Casparian strip
(e) cytoplasmic streaming
(f) diffusion
(g) drip tip
(h) guttation
(i) humidity
(j) mass flow
(k) plasmodesmata
(l) phloem
(m) root pressure
(n) translocation
(o) transpiration
(p) xylem

15.29 How do each of the following contribute towards the maintenance of the transpiration stream?

(a) osmosis
(b) root pressure
(c) cohesion
(d) adhesion
(e) transpiration

15.30 How could you demonstrate that movement of water occurs in the xylem?

15.31 Describe the three possible pathways of water through root and leaf tissues.

15.32 How does the Casparian strip of root endodermal cells influence the passage of water through root tissues?

15.33 In what form are chemicals translocated throughout the plant?

15.34 In what part of the plant does translocation occur?

15.35 Give evidence for and against the following theories of translocation:

(a) cytoplasmic streaming
(b) activated diffusion
(c) mass flow
(d) electro-osmotic mass flow.

EXTENDING YOUR IDEAS

1. UB After severe or prolonged saturation of the soil by water during floods, many plants die. Suggest reasons for this.
2. UB Animals generally have a specialised digestive system in which food is digested. Suggest reasons why plants do not have such a system.
3. UB An experiment was conducted on gas exchange in plants. The rates of oxygen uptake and release by a shoot of water-weed were measured over a 10-hour period. For 5 hours of the experiment the shoots were in darkness and for 5 hours they were placed in daylight. All other factors were kept constant. The results are plotted in Figure 15.19.

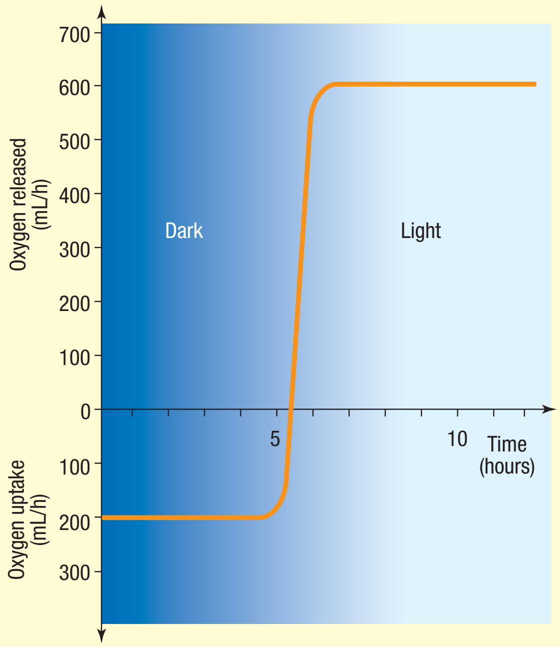


Figure 15.19

(a) Suggest why the shoot used was from a water plant and not a land plant.

(b) If it is assumed that the changes in light intensity have no effect on the rate of respiration, calculate the total volume of oxygen used by the shoot for respiration during the 10 hours of the experiment. Explain your answer.

(c) At what time after the experiment began was the compensation point reached? Explain your answer.

4. **UB** Both maintenance of the transpiration stream and translocation require a large amount of energy. For which process does the plant expend more energy? Explain your answer.

5. **UB** Suggest a reason for each of the following:

(a) In summer it is better to water plants in the evening than earlier in the day.

(b) After transplanting plants it is a good idea to remove some of the leaves.

(c) Water moves up a stem more quickly on a hot dry day than on a cool wet day.

6. **UB** Stomatal guard cells have been described as 'turgor-regulated valves'. Explain why they are so described.

7. **IB** Water loss from the leaves of two different species of plants, species A and species B, was compared. One leafy shoot was taken from each plant. The leaves were weighed, hung in air and reweighed at 15-minute intervals. The results are shown in the table (a dash indicates that a result was not available).

Time after start of experiment (minutes)	Mass of leafy shoot (g)	
	Species A	Species B
0	210.0	240.0
15	195.3	–
30	184.4	–
45	176.4	–
60	170.1	–
75	166.3	213.1

(a) Plot a graph of mass against time for species A. Account for the shape of this curve.

(b) Calculate the percentage of change in mass for each species after 75 minutes.

(c) Explain which of these two species you would expect to be more successful in an arid region.

8. **UB** Three hypotheses have been put forward to explain the increase in cell sap volume that causes stomata to open. Each has inherent problems.

Hypothesis 1: In the light the acidic gas carbon dioxide is removed and starch is converted to glucose-1-phosphate.

(a) As water potential depends upon the total number of molecules ions in solution, explain why this reaction is unlikely to cause stomata to open.

Hypothesis 2: Guard cells have chloroplasts and may produce sugars in the light. However, it is also suggested that these cells do not contain all the enzymes required for the dark stages of photosynthesis.

(b) What would be the implication of guard cells being able to carry out the light reactions but not the dark reactions?

Hypothesis 3: Potassium ions accumulate in the guard cells in the light and this causes the stomata to open.

(c) Explain how potassium ions enter the cell.

(d) If the movement of potassium ions causes stomata to open and close, explain why it may be advantageous for guard cells to possess chloroplasts even if the dark stage of photosynthesis is not completed.

9. **UB** Phloem sap can be collected from aphids. These are sucking insects that use their mouthparts (stylets) to penetrate phloem sieve tubes for sugar. The stylet is a hollow, syringe-like structure. If the stylets of feeding aphids are cut, samples of phloem sap exude through them and can be collected for analysis. What does this method of collecting phloem sap indicate about:

(a) pressure of fluid in the phloem

(b) the amount of energy expended by the aphid in obtaining its food?

16 Plant reproduction, growth and development

16.1 The process of reproduction

Reproduction is the production of offspring by organisms. This process is achieved in two different ways:

- **asexually** — only a single organism is involved, and the offspring are genetically identical to the parent
- **sexually** — involves the fusion of specialised sex cells, **gametes**, usually derived from two different individuals of the same species.

The offspring after sexual reproduction contain genetic material from both parents. Mixing of genetic information may produce new characteristics in the offspring. This may be significant for survival, not only of the individual but also of the species, in unfavourable conditions.

Regardless of whether reproduction occurs sexually or asexually, cell division occurs. Two types of cell division — mitosis or meiosis — may be involved. The stages involved in these divisions were described in Chapter 14.

16.1.1 Life cycles

Plants have a life cycle where an asexually reproducing generation is followed by a sexually reproducing one. This is termed **alternation of generations**. The cells of the two alternating generations differ in the number of chromosomes they contain. The asexual phase is termed diploid or $2n$ because its cells contain two of each type of chromosome (n represents the number of types of chromosomes). The sexual phase is termed haploid or n because its cells contain only one of each type of chromosome.

The diploid ($2n$) plant is called the **sporophyte**, because it reproduces asexually by producing spores. The haploid (n) spores are formed by a type of cell division called meiosis, or reduction division. Each pair of chromosomes separates, so that each of the daughter cells contains half as many chromosomes as the mother cell — one from each pair.

Each spore that is released from the sporophyte can grow to form a plant in which all of the cells are haploid. The haploid (n) plant, which differs in appearance from the sporophyte, is termed the **gametophyte** because it produces male and female gametes. This time the type of cell division is mitosis, whereby each daughter cell has the same number of chromosomes (n) as its mother cell. The female gametes, or eggs, are retained in the protective structures in which they are formed. The male gametes, or sperm, are transported to the egg in a fluid medium. Fertilisation is the union of a sperm and egg to form a **zygote**. Thus reproduction in the gametophyte generation is sexual.

The zygote has two of each type of chromosome (one from the sperm and one from the ovum), so it is diploid ($2n$). The zygote grows and develops into the next sporophyte generation. The growth of the gametophyte from the spore and the sporophyte from the zygote involves the change from a single-celled form to a multicellular organism. To achieve this, the cells divide by mitosis, ensuring that the daughter cells have exactly the same numbers and types of chromosomes as the original 'mother' cell.

Figure 4.41 on page 86 shows this alternation of generations diagrammatically in a generalised plant life cycle.

In sexual reproduction variations in characteristics of individuals can occur. In changing environmental conditions sexual reproduction may be important for the survival of the species since some of the offspring are likely to have characteristics which suit them to the changed conditions. Individuals with characteristics that best suit them to the environment will grow and compete for resources more effectively than other individuals without these specific characteristics. Therefore in the asexual phase they will produce the most spores. The asexually reproducing stage ensures that a large number of individuals with desirable features will be retained within the population, since no variations of features will occur.

Plants have multicellular reproductive organs with a non-dividing (sterile) outer layer of cells which protects the enclosed structures from desiccation. **Gametangia** (singular *gametangium*) are the gamete-forming organs. The male gametangium is known as the **antheridium** and the female gametangium is the **archegonium**. The eggs are fertilised while they are still contained within the archegonium, which then protects the developing embryo. The spore-producing structures are termed **sporangia** (singular *sporangium*).

Some multicellular algae also display alternation of generations, but their cycle differs from that of plants in that:

- The gametophyte and sporophyte generations usually look alike and both may be haploid. (See Section 4.7.4 on page 87.)
- The female gametangium does not produce a protective layer of cells.
- The egg is released from the female gametangium and fertilisation takes place externally, in the surrounding water. Meiosis may occur in the zygote.

The various groups of plants differ greatly with respect to the relative importance of the diploid and haploid phases in their life cycle. This is related to the availability of water. The mosses and liverworts do not have a vascular system and so their survival depends on living in damp places where water is readily available for life processes. In these plants the gametophyte generation is the dominant phase of the life cycle. Environmental water is used by the sperm to swim from the antheridium of male plants to the archegonium of female plants. The life cycle of a moss is shown in Figure 4.45 on page 89.

Those plants which have developed a vascular system, and are fully terrestrial, have a much reduced gametophyte generation. Ferns display a life cycle where the sporophyte is the dominant generation and the gametophyte is reduced to a small, heart-shaped prothallus. Fertilisation, however, is still dependent upon an external source of water for the sperm to swim to the ovum. This type of life cycle is shown in Figure 4.46 on page 90.

This is even further reduced in the seed plants, making them independent of free external environmental water for fertilisation.

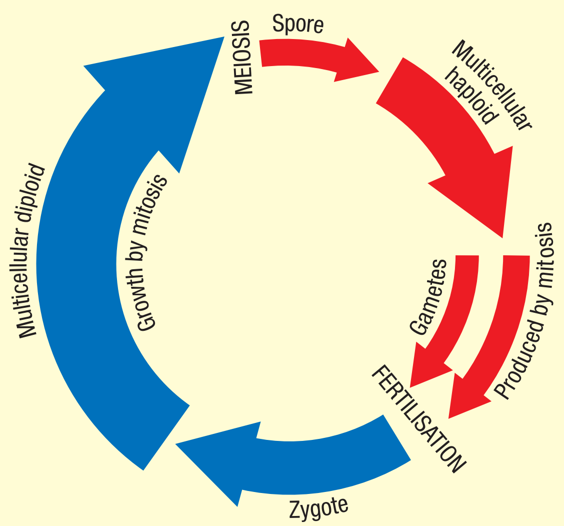


Figure 16.1 Alternation of generations in higher plants

SUMMARY

Reproduction is the production of offspring by organisms. It may be asexual or sexual.

Nuclear and cell division is responsible for reproduction and growth. In both asexual and sexual reproduction, the chromosomes must be correctly distributed between the daughter cells to ensure that offspring have the same types and number of chromosomes as the parent.

Two main types of nuclear division are recognised: mitosis and meiosis.

Mitosis is significant in growth and production of gametes in plants and in growth in sexually reproducing animals. Meiosis is involved in the production of gametes in animals and spores in plants.

Mitosis in diploid generations (sporophyte of plants) preserves the diploid condition. Meiosis results in daughter cells containing only one of each type of chromosome, the haploid state.

Meiosis involves two successive divisions. Four haploid cells are formed from a diploid cell.

Plants display alternation of generations between a diploid sporophyte generation and a haploid gametophyte generation. The availability of environmental water is a major determinant in which phase is dominant.

Review questions

16.1 There are two types of nuclear division — mitosis and meiosis. For each type of division describe:

(a) the chromosomal condition before and after cell division

(b) the possible functions of the division.

16.2 State whether each of the following is the result of mitosis or meiosis:

(a) two diploid cells

(b) four haploid cells

(c) spore formation in a moss

(d) gamete formation in ferns

(e) growth of the gametophyte generation

(f) growth of the sporophyte generation

(g) repair of damaged skin cells

16.3 Compare and contrast the processes of mitosis and meiosis.

16.4 Describe the life cycle of a typical plant.

16.2 Reproduction in flowering plants

16.2.1 Sexual reproduction

The reproductive organ of the angiosperms is the flower, which consists of modified leaves.

The outer parts of the flower (sepals and petals) are modified leaves. Flowers may be single (e.g. the tea-tree), grouped as an inflorescence (e.g. the bottlebrush) or compound (e.g. the daisy). Compound flowers consist of dense aggregates of flowers into a head on a single **receptacle** or base. Like leaves, flowers may be either sessile, arising directly from the end of a shoot, or borne on a stalk or petiole.

Flower parts are typically arranged in four whorls from the swollen receptacle:

- the outer **calyx**, composed of small, green, separate **sepals** which protect the flower bud;
- the **corolla** of **petals**, the base of which may have a nectary producing nectar;
- the male parts or **stamens**, each composed of a narrow stalk (**filament**) and a swollen end, the **anther**. The anther produces **pollen grains** which give rise to the male gametes.
- the female parts or **carpels**, each of which is flask-shaped and composed of the basal **ovary**, from which arises a **style** bearing the **stigma**. The ovary contains the **ovules** which produce the eggs. After fertilisation the ovules form the seed, while the walls of the ovary expand to form the **fruit**.

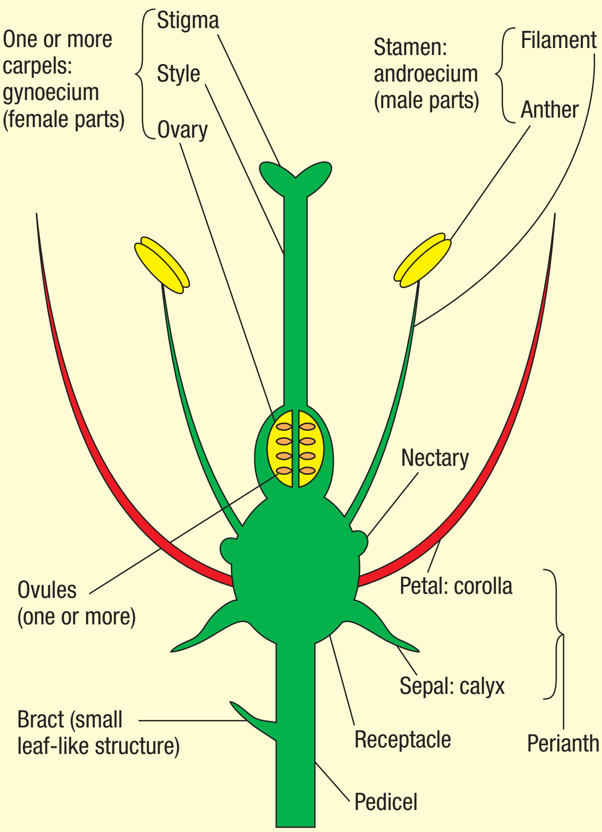


Figure 16.2 Vertical section through a typical flower, showing the four whorls

There is wide variation in flowers. In some species—for example, gum trees and grasses—there are no petals or sepals. Heath petals are fused to form a tube.

Most species have flowers containing both male and female parts—they are **hermaphrodite** and **monoecious**. Others, such as the pawpaw, bear male flowers on one tree and female ones on another (**dioecious**), and plants such as the pumpkin have separate male and female flowers on the same plant and are therefore monoecious.

Gametophyte formation

The flowers of the sporophyte produce two types of spore. Specialised diploid cells in the anther undergo meiosis, each cell producing four haploid spores. Each spore can grow into a male gametophyte. During growth, the spore nucleus divides by mitosis to form two nuclei, one of which is called the **generative nucleus** and the other the **tube nucleus**. A hard outer wall develops around the whole structure to form the pollen grain or male gametophyte.

The female spores are produced inside the ovule within the ovary. Each ovule starts as a small protuberance, connected to the wall of the ovary by a stalk and projecting into the cavity of the ovary. Initially the ovule consists of a uniform mass of cells but as development proceeds the wall of the ovule differentiates into inner and outer integuments. These enclose and protect the central tissue. There is a small opening, the **micropyle**, at one end.

The centre of the ovule is a structure called the **embryo sac** which develops from a specialised diploid cell. This 'mother cell' undergoes meiosis to form a row of four haploid spore cells. Three of these cells degenerate; the remaining one becomes vacuolated and enlarges rapidly. The nucleus of this cell undergoes three successive mitotic divisions, resulting in eight haploid nuclei, four at each end of the developing embryo sac. One nucleus from each end migrates to the centre to form the polar nuclei. The remaining six nuclei become separated by cell walls.

Thus the mature embryo sac or female gametophyte contains three cells at each end and two free polar nuclei in the centre, all of which are haploid.

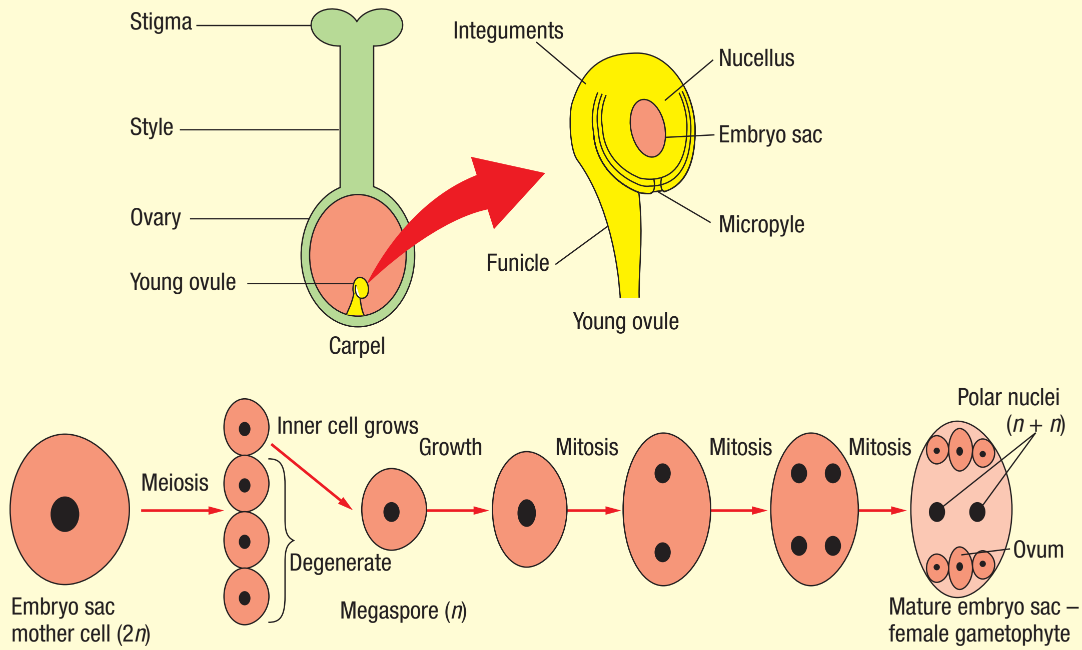


Figure 16.3 Formation of the female gametophyte

One of the cells at the micropylar end becomes the functional egg cell. The remaining five end cells of the embryo sac eventually disintegrate.

Pollination

Transfer of pollen from anthers to stigma is called **pollination**. When the anthers mature, their walls dry out and this causes shrinkage of the cells. The resulting tension causes the sides of the anther to rupture and release the pollen grains. Pollen may fall from the anther directly onto the stigma of the same flower (**self-pollination**). More often, however, pollen is transferred to another flower by some agent (**cross-pollination**). Pollen is usually transferred from the anther to the stigma by wind, by a pollinating agent such as bees, flies, moths, birds and mammals or by water. Pollinators are generally attracted to the flower as a food source.

Flowers display many adaptations that reflect the way they are pollinated.

Wind-pollinated plants

Wind-pollinated plants include she-oaks (*Casuarina*) and grasses. They show the following adaptations:

- small, inconspicuous flowers grouped together
- sepals and petals reduced and green in colour, or absent
- light, dry pollen grains, often winged
- anthers hanging on long filaments
- long, branched and feathery stigmas for catching pollen carried by wind.

Animal-pollinated plants

- Animal-pollinated flowers are very conspicuous:
  - — brightly coloured petals and sepals if pollinated in daylight: for example, yellow, blue or purple flowers attract bees, and red, pink and orange flowers attract butterflies and birds
  - — cream or white petals if pollinated at night by nocturnal insects such as moths or by nocturnal mammals such as bats and possums.
- Flowers may be grouped together.
- There is abundant pollen and sugary nectar (food for the animals).
- Pollen grains are sticky, rough and/or spiny to cling to the hairs of an animal.
- Insect-pollinated flowers may produce a scent, the type depending on the insect: fly-pollinated flowers invariably produce a pungent odour, whereas bee-pollinated flowers produce a sweet scent. Flowers pollinated at night usually have an odour or perfume.
- Flowers may possess 'landing platforms' — specialised petals on which an insect may land, arranged in such a way that the insect must touch the anthers and stigmas.
- The colour pattern of the petals may act as a 'honey guide', leading an insect to the nectary so that it also brushes the anthers and stigmas.

Figure 16.4 Types of pollination: (a) and (b) insect-pollinated; (c) wind-pollinated; (d) self-pollinated flower

- Certain orchid flowers mimic the shape, colour and odour of a female digger wasp. They attract the male wasp which attempts to copulate with it, thereby bringing about cross-pollination.

Adaptations to prevent self-pollination

Although the flowers of most angiosperms are bisexual, cross-pollination is the norm. Many have elaborate mechanisms to prevent self-pollination:

- The stamens may ripen and discharge the pollen before the stigmas are fully developed.
- The stigma may die before the pollen of that flower has formed.
- Inhibition by a chemical specific to that particular flower may cause self-incompatibility.
- There may be special floral structures: for example, the stigma may be borne above the anthers.

The pollen of each species has its own specific characteristics, such as size of the grains, shape, sculpturing of the outer wall or surface chemicals which allow only the stigma of the correct species to accept it.

Fertilisation

Fertilisation is the union of two gametes to form a zygote.

Once a compatible pollen grain has landed on the stigma, a sucrose solution secreted by the stigma stimulates germination of the grain, which forms a pollen tube. The tube derives nourishment from the surrounding tissues and grows into the stigma, down the style and into the ovary by pushing between the cells. It does this by secreting digestive enzymes from the tip of the tube. The secretions are controlled by the tube nucleus.

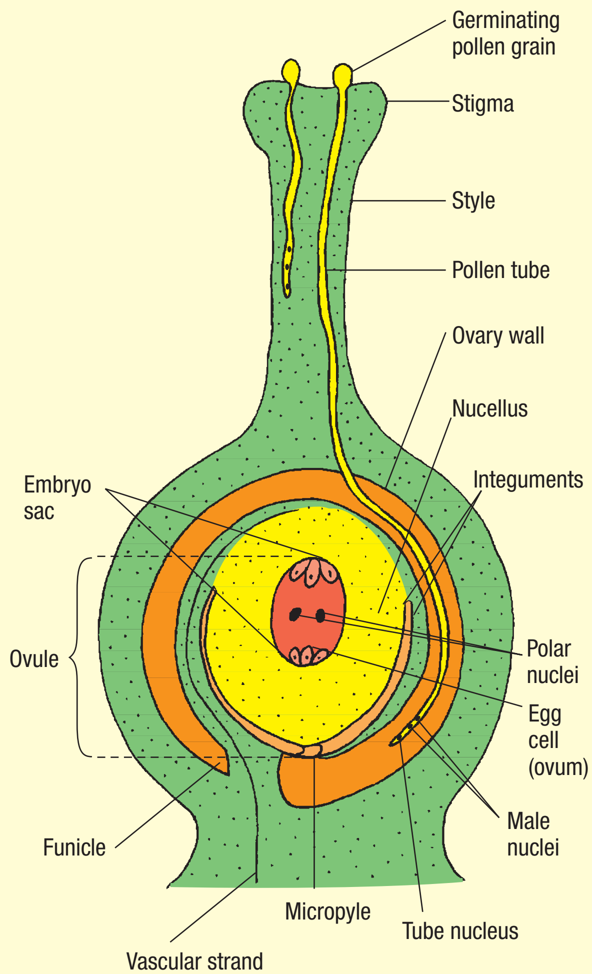


Figure 16.5 Fertilisation in a flowering plant. The contents of the pollen grain and pollen tube are equivalent to the male gametophyte; the embryo sac is equivalent to the female gametophyte

During the growth of the pollen tube, the generative nucleus divides by mitosis to produce two male nuclei which are the haploid male gametes. These follow behind the tube nucleus as the pollen tube grows downwards. Once it reaches the ovary, the pollen tube enters the ovule through the micropyle. As it penetrates the embryo sac, the tube nucleus degenerates and the tip of the tube bursts open to release the male gametes. One nucleus fuses with the female gamete or egg cell (n), forming a diploid zygote ($2n$). The other fuses with the two polar nuclei to form a triploid **endosperm** nucleus ($3n$).

Seed and fruit development

Immediately after fertilisation, the ovule becomes known as the **seed**. The ovary develops into the fruit. The zygote grows by mitotic division into a multicellular **embryo**. This consists of a shoot, the **plumule**, a root, the **radical**, and either one or two seed-leaves called **cotyledons** which may store food.

The triploid endosperm nucleus undergoes repeated mitotic division (producing thin-walled triploid cells) to form the endosperm. In some seeds, such as maize or corn, the endosperm becomes the primary food store. In others such as the pea, the endosperm is absorbed by, and stored in, the cotyledons. Normally only the cotyledons or the endosperm act as the food storage area.

The outer tissues of the ovule form a tough protective layer, but the micropyle remains open to allow exchange of respiratory gases and intake of water when the seed germinates. While the seed develops, the ovary matures into a fruit, the nature of which varies from species to species. Its function is to protect the seeds and aid in their dispersal. The remaining flower parts usually wither and die, but in a few cases some floral parts are retained. In the strawberry, the receptacle forms part of the fruit and so is called a **false fruit**.

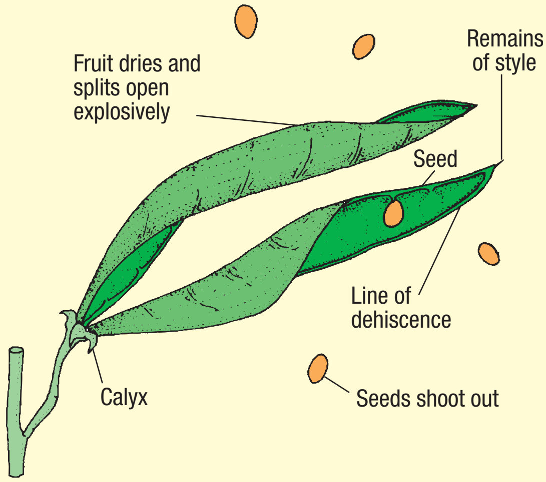
Fruit and seed dispersal

Dispersal of seeds is important to plants. Since they are stationary, there is great competition between plants for resources such as water, mineral nutrients and sunlight. The further the seeds are dispersed from the parent plant and from each other, the less likely it is that the seedlings will be competing for exactly the same resources. Dispersal may, however, take the seed out of a suitable area for germination and/or growth.

The three major agents of dispersal for fruit and seeds are wind, water and animals. There are also self-dispersal mechanisms, often involving the explosive release of seeds from drying fruit. Fruits which throw out their seeds by splitting open are known as **dehiscent fruit**.

Self-dispersal

Dehiscent fruits dry and break open, forcibly ejecting the seeds. Often the seeds are further modified for wind dispersal, having wings or feathery attachments.

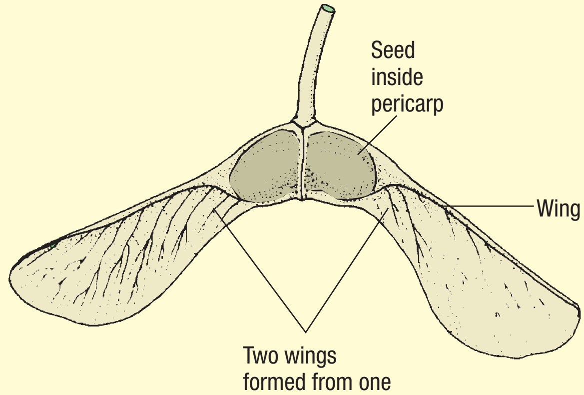


(a)

(b)

(c)

Figure 16.6 Self-dispersed seeds (a) Legume of the pea family; (b) unopened wattle pods; (c) dried wattle pods



(a)

(b)

(c) (d)

Figure 16.7 Wind dispersal mechanisms (a) wing mechanism (Sycamore; pines and some cassias); (b) winged pine seed; (c) dandelion head; (d) poppy (shaker)

Wind dispersal

Wind-dispersed seeds are light and usually have feathery attachments or wings which increase the surface area over which wind can act. Some, such as the poppy, are very small and light. The fruit capsule shakes out the minute seeds which are then picked up by the wind for dispersal (Figure 16.7).

Water dispersal

Water-dispersed fruit are buoyant, either because of air cavities (e.g. black bean pod) or by the presence of fibrous material (e.g. coconut).

Animal dispersal

Animal-dispersed fruits and seeds may have some mechanism by which they cling to the outer covering of passing animals. Nagoora burr, a noxious plant in Queensland, is spread by livestock over a wide area. Its tenacious hooks cling to the legs and face areas of cattle, sheep and horses. Often the fruits are not released until the hair is pulled from the animal as it passes through scrub. Cobbler's pegs are spread in a similar manner by smaller mammals such as bandicoots.

Some fruits or their seeds may be very sticky and adhere to the surface of animals. In many cases, however, the fruit is succulent and is eaten by animals. The seed is not digested, however, and is ejected with the faeces.

Many seeds have co-evolved with particular animals, and the seeds will not germinate unless they

(a)

(b)

Figure 16.8 Animal-dispersed fruits: (a) hooked cobbler's pegs; (b) succulent mulberry

Table 16.1 Advantages and disadvantages of reproduction by seeds

Advantages	Disadvantages
• The plant is independent of water for sexual reproduction.	• Seeds are relatively large due to their large food stores; therefore difficult to disperse.
• The seed protects the embryo.	• Seeds are often eaten by animals.
• The seed contains food for the embryo.	• External agents are necessary for pollination.
• The seed can remain dormant and survive adverse conditions.	• Seed survival is limited and there is a large wastage of seeds; this is energy-consuming for parent plants.
• The seed is physiologically sensitive to favourable conditions for germination.	• Two individuals are required in dioecious (single-sex) species and cross-pollinated monoecious species.
• Seeds will show genetic variations.	• Food supply of the seed is limited.

have been acted upon by the stomach acids of the animal. The sandpaper fig of the rainforest, for example, appears to depend on such animals as the ringtail possum for the distribution and germination of its seeds. The distribution of the mistletoe bird (*Dicaeum hirundinaceum*) is determined by that of the parasitic mistletoe on which it largely depends for food. These birds rapidly eat vast quantities of mistletoe berries, and within 25 minutes they void the sticky seeds. If they land on a suitable tree, the seeds become 'glued' to a branch and germinate.

16.2.2 Vegetative reproduction in flowering plants

Vegetative reproduction is a form of asexual reproduction, in that a new self-supporting and self-sufficient plant develops from a detached part of the parent plant. The form of reproductive structure varies from species to species. There are four main types:

- modified underground stems
- modified above-ground stems
- modified roots
- modified leaves.

Types of vegetative reproduction

Underground stems

Modified undergound stems are associated with storage of food, and thus function both in survival of the plant during unfavourable conditions and in vegetative reproduction. Like any normal stem, these structures have apical buds and nodes with axillary buds and leaves. It is from the axillary buds that new plants are formed and later detach from the parent plant. Three types of modified undergound stems are recognised: **rhizomes** (e.g. couch, spinifex, ferns), **corms** (e.g. crocus) and **stem tubers** (e.g. potato).

Above-ground stems

Runners (e.g. strawberry), suckers (e.g. mint) and stolons (e.g. blackberry) are examples of modified above-ground stems responsible for vegetative reproduction. Runners and stolons both develop from axillary buds on the parent stem, with new stems and roots arising from buds along their nodes. **Runners** are prostrate stems which lie along the soil surface. **Stolons** are thin branches with little structural support, which bend over and touch the

Figure 16.9 Modified underground stems

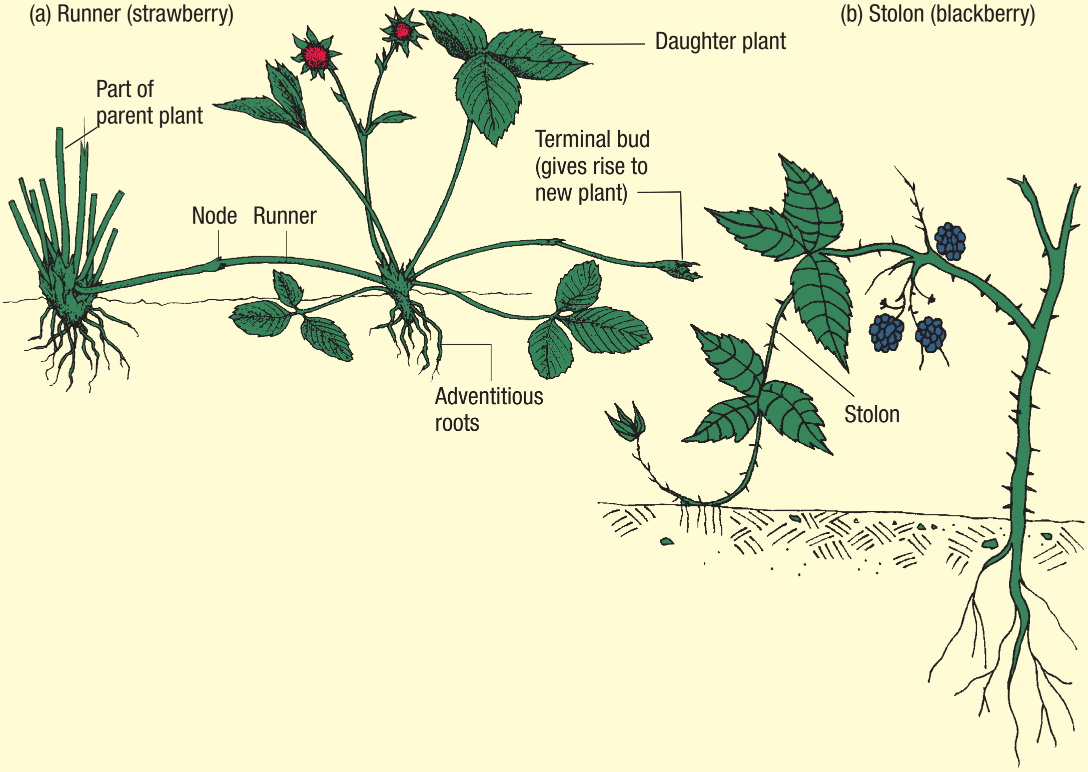


Figure 16.10 Modified above-ground stems

soil. Contact with the moist soil stimulates the axillary buds at the nodes to develop roots and stems. Because of this feature, blackberry thickets develop rapidly in southern parts of Australia, assuming pest proportions in some areas. **Suckers** develop below the soil level.

Modified roots

A modified root is a swollen adventitious root developed from an axillary bud at the base of the plant shoot. As with the modified underground stems, these roots function as food storage areas, as organs to aid survival of the plant in adverse conditions and as organs of vegetative reproduction. The **root tuber** of the dahlia is an example of such a modified root.

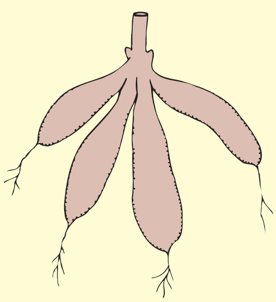


Figure 16.11 Dahlia root tubers

Modified leaves

Detached leaves—for example, the succulent sedum and African violet—often take root and grow into new individuals. The most common form of modified leaf (really a bud) used in vegetative reproduction is the **bulb**. In this case the stem is reduced to a flattened disc and the bulk of the bulb consists of fleshy, food-storing scale leaves. From the centre of the bulb, the apical bud sends out aerial shoots. Once the plant has flowered, food is stored in new

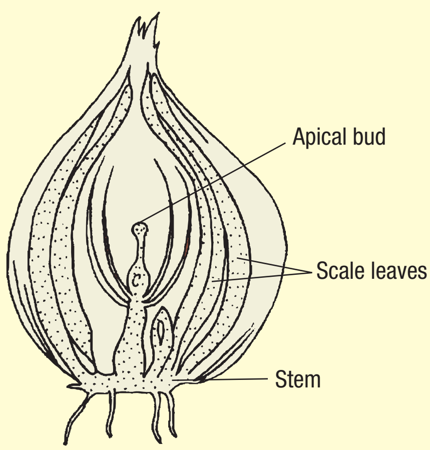


Figure 16.12 Longitudinal section through a bulb

buds which develop between the depleted scale leaves of the original bulb. Each bud then develops into a new bulb. Familiar examples are the onion and daffodil.

Commercial applications

Processes of vegetative reproduction are utilised by horticulturists to ensure that the new plants have exactly the same characteristics as the parent plant. There are five major types of artificial propagation: **layering**, taking **cuttings**, **budding**, **grafting** and **tissue culture**.

Layering

Layering is forced stolon formation. A cut is made halfway through the stem between two nodes, and the shoot pegged to the ground so that the cut makes contact with the soil. Once adventitious roots have developed at the cut, the new plant is completely detached from the parent.

Cuttings

Cuttings are taken from healthy aerial shoots by making an oblique cut through the shoot. The cutting is planted in soil, after first being dipped in a hormone powder to stimulate root growth.

Budding and grafting

For both budding and grafting a hardy stock plant is used as the base. This plant will have been grown from seed and thus the genetic composition will be variable.

For propagation by **budding**, a cut is made in a section of the bark of the stock plant. The bud to be propagated is removed from a plant with the desired properties. It is inserted into the cut in the stock plant, and the cut with inserted bud is then bound up. All buds on the stock plant are removed and the new bud takes over as the main aerial part of the plant.

Grafting involves removal of most of the stem of the stock plant and incising it to expose the cambium (undifferentiated tissue). A woody twig of the plant to be propagated is also cut to expose the cambium and then lined up with the cut surface of the stock stem and bound.

Tissue culture

Modern techniques have been developed which allow plant cells to be grown in culture. Different techniques are used depending on the way the culture is to be used. They may be grown as shoots, as suspensions of individual cells, as protoplasts which are plant cells without cell walls, as aggregates of cells called callus cultures, or as groups of particular tissues.

To grow a callus culture a specific part of a plant is selected, sterilised and placed in a controlled environment. The culture medium is an agar base in which plant growth regulators have been mixed. The cells divide under the influence of the regulators to produce a callus of unspecialised cells. This callus tissue is capable of regenerating a new plant which is genetically similar to the original plant. When many plants are produced from a single callus culture they form a **clone**.

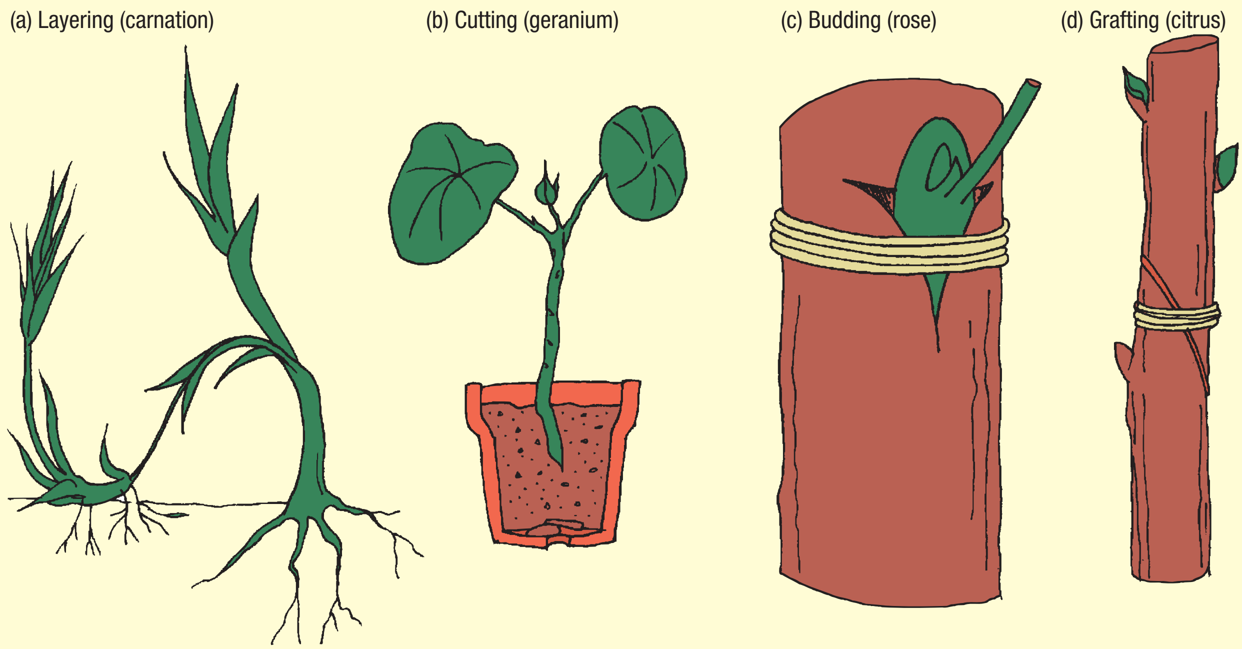


Figure 16.13 Methods of artificial propagation

Table 16.2 Comparison of sexual and vegetative reproduction

Sexual reproduction	Vegetative reproduction
Genetic variability achieved — an advantage in a changing environment	Genetic stability (clones) achieved — an advantage in a stable environment
Complex process involving formation of gametes and two parents	Simple process involving a single parent
Seed production depends on pollination and fertilisation	No seed production
Fruit and seed dispersed — external agents needed	No fruit or seed dispersal
More resistance to disease due to genetic variability	No resistance to disease affecting that genetic type
Less overcrowding and competition	Overcrowding and competition
Slow	Quick

Many commercial plants such as eucalyptus, bottlebrushes (*Callistemon*), orchids and carnations are reproduced asexually in this way. There are many advantages:

- Slow-growing plants can be produced in large numbers.
- Growth is independent of seasonal factors.
- Plants prone to virus infection (e.g. strawberries and potatoes) can be cloned in large numbers from virus-free plants.
- Sterile cultures can be readily transported from country to country.

Asexual reproduction in angiosperms is by vegetative propagation, which includes:

- modified underground stems (rhizome, corm, tuber)
- modified above-ground stems (runner, stolon)
- modified roots (tuber)
- modified leaves (bulb).

SUMMARY

The reproductive apparatus of angiosperms is the flower.

Male gamete nuclei in the pollen grains are produced in the anthers. The egg cell is formed within the embryo sac of the ovule. Both are haploid.

Pollination (transfer of pollen from anther to stigma) is achieved in a variety of ways (wind, insects etc.). Self-pollination occurs between anther and stigma of the same flower. Cross-pollination occurs between separate flowers.

Fertilisation is achieved by the formation and growth of a pollen tube which carries the male nuclei to those of the female through the micropyle of the ovule. One male nucleus fuses with the egg cell to form a zygote, and the other fuses with two haploid polar nuclei to form a triploid nucleus which later develops into the endosperm. This may function as a food reserve.

After fertilisation the zygote develops into the embryo, the ovule into the seed, the integuments into the seed coat and the ovary into the fruit.

Fruits are adapted in a variety of ways for seed dispersal — wind, water, animal, and self-dispersal.

? Review questions

16.5 Draw and label the parts of a flower and give a function for each part labelled.

16.6 The success of the flowering plants has been linked to several factors including:

(a) the reduction of the male and female gametophyte generations to a few cells

(b) the development of a means of fertilisation which does not rely on an external water medium for transport of male gametes

(c) a variety of modes of dispersal of pollen

(d) development of fruit

(e) utilisation of different agents for dispersal of seed.

Comment on each of these factors.

16.7 Describe the development of the mature embryo sac of an angiosperm.

16.8 Regardless of the agent employed, flowers which are adapted for cross-pollination may have pollen from many different species landing on the stigma. What features prevent pollination and thus fertilisation by the wrong species?

? **16.9** In most flowers and animals, meiosis results in four haploid nuclei in males but only one functional female egg. Give possible reasons for this phenomenon.

16.10 In table form, state three structural ways in which a wind-pollinated flower might differ from an insect-pollinated flower.

16.11 Draw the structure of a seed. Label and give a function for each of the following seed structures: micropyle, endosperm, embryo, cotyledon, radicle, plumule.

16.12 In a species of flowering plant the chromosome number of each cell in the radicle is sixteen. State the chromosome number of:

(a) the pollen tube nucleus

(b) a polar nucleus

(c) a cell of the endosperm

(d) a pollen mother cell

(e) an integument cell.

16.13 The seeds of *Hovea*, leguminous native shrubs, are contained in pods. Some time after their formation these pods can be seen open and empty and their walls very dry.

(a) What is the biological name given to the pod?

(b) Describe how the seeds of *Hovea* are dispersed.

(c) Name two other methods of seed dispersal, giving an example of each.

(d) Why is it important that seeds are dispersed?

16.14 Asexual or vegetative reproduction is common in flowering plants. List the four main types of vegetative reproduction and give one example of each.

16.15 Distinguish between layering, budding and grafting.

16.16 Compare and contrast vegetative and sexual reproduction in flowering plants.

16.3 Growth and development

A multicellular animal begins its existence as a fertilised egg. Further progress depends upon cell division and then organisation of cells into tissues, organs and systems.

All cells arise from pre-existing ones by cell division. In the production of a multicellular organism from a zygote, this cell division involves mitosis. **Growth** can be defined as an increase in dry mass of protoplasm. This definition accounts for increase in cell numbers as well as increase in size of the individual cells as they reach maturity after cell division. Growth is always associated with metabolic activity, and in particular with synthesis of protein. This is indicated by an increase in dry mass (= body mass minus water content). Growth may be positive or negative. Positive growth occurs when anabolism exceeds catabolism, whereas negative growth occurs when catabolism exceeds anabolism.

Development refers to the changes in the organism as it matures. Although there are obvious correlations between growth and development, the two processes are not mutually inclusive. Growth can occur without development and vice versa. During development, cells become specialised for particular functions within the organism, a process known as **differentiation**. Internal changes in cells are also correlated with modifications into tissues, organs and thus the entire body.

These processes occur early in the development of the organism. The organs and organ systems need

Table 16.3 Some factors influencing growth and development

External factors	Processes affected
Light (intensity, quality, duration)	Formation of chlorophyll Photosynthesis Phototropism Photoperiodism
Short-wavelength radiation (X-rays etc.)	Mutation
Nutrients	Plant deficiency diseases
Temperature	Enzyme activity Thermotropism
Oxygen	Aerobic respiration Active transport
Water	Essential metabolite
Seasonal influences	Bud and seed dormancy Leaf fall Reproduction Photoperiodism Thermoperiodism
Internal factors	**Processes affected**
Genes (DNA)	Protein synthesis; thus enzyme synthesis and cell control
Hormones and other growth substances	Many processes

to be integrated into cooperative working units. This control is supplied by hormones in plants.

The process of growth and development is ultimately controlled by the information contained in the organism's DNA, but it is also affected by interactions between the internal and external environment. Regardless of the genetic potential of an organism to reach a particular size, this cannot be achieved if environmental conditions are not met. These conditions may include external factors such as food, light, heat and water, as well as the internal availability of chemicals such as hormones and special proteins which influence gene expression.

16.3.1 Nutrient requirements for growth

All living organisms need to take many different substances into their cells. The taking in of useful substances is called nutrition. A nutrient is any substance used by an organism. Some nutrients can be synthesised by the organism from basic materials. Those nutrients that cannot be synthesised must be taken in from an outside source, and are termed essential nutrients.

The product of photosynthesis is carbohydrate in the form of glucose. Much of this glucose is not needed immediately by the plant for generating energy. Some of the excess can be stored in a colloidal form (e.g. starch) which does not exert an osmotic effect on the cell. A proportion of the excess glucose is converted into the other organic substances required by the plant. These include other carbohydrates such as sucrose and cellulose, amino acids for producing proteins such as enzymes, and chlorophyll, lipids, nucleic acids and vitamins. The manufacture of these substances requires the addition of certain mineral substances (e.g. nitrogen, sulfur and phosphorus for amino acids). Plants absorb these in the form of mineral ions dissolved in soil water. Many of these ions pass across the root hairs and into the xylem by passive diffusion, but active transport plays an important role when the concentrations of the ions in the soil are lower than those in the plant cells.

Deficiency diseases may occur if essential minerals are absent in the soil. (See Table 16.4.)

SUMMARY

Growth, the permanent increase in size of an organism, results from cell division, assimilation and cell expansion.

Growth is the irreversible increase in dry mass of protoplasm by cell division and cell enlargement.

Development consists of the changes undergone by an organism in growth from immature to mature form. It involves differentiation, histogenesis and morphogenesis.

Growth and development are determined by the interaction between genetic potential and environmental conditions.

Essential nutrients are substances which an organism cannot synthesise from basic units, and must therefore be taken in. Lack of certain nutrients leads to deficiency diseases which affect the growth and development of the organism.

Table 16.4 Mineral salts required by plants

Element	Needed in:	Deficiency disease
Nitrogen	protein production; nucleic acids; coenzymes	poor growth; yellow leaves
Sulfur	protein production	poor growth; yellow leaves
Phosphorus	ATP synthesis and nucleic acids	poor growth, especially roots
Magnesium	chlorophyll and cofactor for many enzymes	yellowing between veins of leaves
Iron	steps leading to chlorophyll production	yellowing in young leaves
Potassium	osmotic balance in leaves	mottled leaves
Copper	cytochrome production (electron carrier in respiration)	dieback of shoots
Zinc	formation of dehydrogenase for anaerobic respiration	malformed leaves
Molybdenum	formation of nitrogenase — for nitrogen fixation (prokaryotes)	retardation growth
Calcium	needed for cell enlargement and leaves	death of growing tips and yellowing of middle lamellae of cell wall

Review questions

16.17 Distinguish between growth and development in a multicellular organism.

16.18 Define cell differentiation.

16.19 Discuss factors which influence growth and development of a plant.

16.20 What is a deficiency disease? Name one plant deficiency disease, stating the deficient nutrient and the symptoms experienced by the plant.

16.3.2 Growth and development in the flowering plant

There are certain environmental requirements before the embryo of a seed will grow. These include availability of water, optimum temperature, light and oxygen. The seeds of some plants, however, will not germinate even if these conditions are met. Some other criteria must be met to ensure that premature germination does not occur and that germination is synchronised with the onset of favourable conditions for growth. There are various mechanisms involved in this process. Growth inhibitors such as abscisic acid may be present in the seed coat, requiring excess environmental water for their removal. Some seeds are impervious to water or light. The seeds may need to be rolled across stones by running water, subjected to the intense heat of bushfires or to a period of intense cold, to break down the seed coat and allow germination. Other seeds require the gastric juices of 'host' animals to initiate germination.

Germination

The sprouting of a seed is called **germination**. Water, oxygen and the proper illumination and temperature are required for this process to occur. The specific requirements for germination vary from species to species.

Germination starts with the rapid uptake of water by the seed. This causes the embryonic tissues to swell, rupturing the seed coat and allowing the growing plumule and radicle to emerge; the plumule grows upwards and the radicle grows down. The water also activates enzymes to bring about hydrolysis of the stored food.

There are two types of germination: **hypogeal** and **epigeal**. Hypogeal germination involves elongation of the base of the plumule. The plumule is thrust out of the ground, leaving the cotyledons behind in the ruptured seed coat. Seeds such as broad bean and wheat germinate in this way. The cotyledons provide the large food reserve required for growth until the first green leaves develop.

Epigeal germination occurs by rapid growth of the top of the radicle. Both plumule and cotyledons are thrust out of the ground. These seeds (e.g. sunflower and some beans) usually have a large endosperm to provide food for initial growth. The small cotyledons develop chlorophyll, and photosynthesise as soon as they are exposed to light.

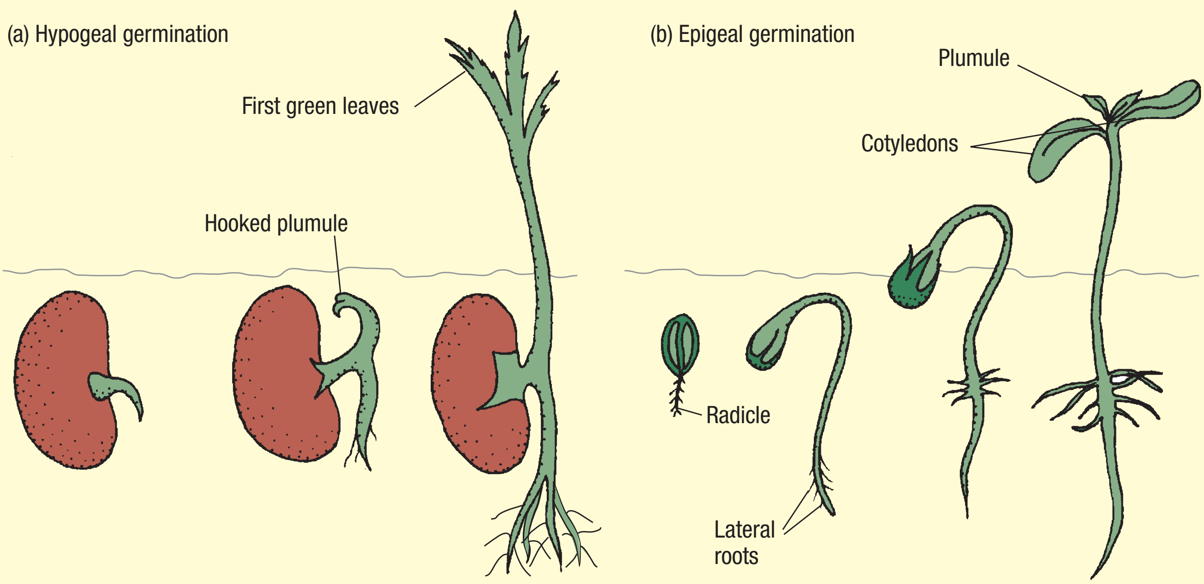


Figure 16.14 The two types of seed germination

Growth of the primary plant body

Growth in multicellular plants is restricted to certain regions known as **meristems**. A meristem is a group of cells which retain the ability to divide by mitosis. The daughter cells grow and form the permanent tissues. There are three types of meristem in flowering plants: apical, lateral (cambium) and intercalary. There are two types of growth: primary and secondary.

Primary growth is the result of cell division in the apical and intercalary meristem. It is involved in initial growth of the plant and increase in its length. In many plants, such as herbaceous dicotyledons and many monocotyledons, it is the only form of growth. Typically the cells of the apical meristem divide by mitosis. One daughter cell remains in the meristem, while the other increases in size and differentiates into permanent tissue. Thus growing shoots and roots usually display four distinct zones of cell activity:

- cell division
- cell elongation
- differentiation into specific plant tissue
- permanent tissues.

The plant grows taller and develops leaves, branches and flowers from cells formed by the apical meristem of the stem. The root gets longer and develops branch roots from cells formed by the apical meristem of the root. Three of the major tissues formed during primary growth are primary xylem, primary phloem and epidermis.

Woody plants grow taller by primary growth but their stems, branches and roots increase in width by means of **secondary growth**. Palms are the only monocotyledons that display secondary growth. Two types of lateral cambium are responsible for secondary growth: **vascular cambium**, which produces secondary growth of xylem and phloem, and **cork cambium**, which produces cork, the protective outer layer of woody plants.

The vascular cambium is a thin layer of cells between the primary xylem and the primary phloem. The cells of this cambium divide and specialise: those on the inside of the cambium become secondary xylem and those on the outside become secondary phloem. More xylem is produced than phloem, and this has the effect of pushing the vascular cambium away from the centre of the stem. As the vascular cambium moves, it crushes the old layer of phloem cells, which usually have died at the end of the previous growing season. The vascular cambium also produces horizontal conducting tissues called (**medullary**) **rays**. These radiate outwards from the centre of the stem and transport materials laterally from the xylem and phloem.

The prime function of the xylem is to conduct water from the roots to the leaves. As the woody stem ages, waste products accumulate in the xylem at the centre of the woody stem. This accumulation clogs the cells, preventing movement of fluid in them. Addition of tannins, resins, gums and waste products to these older cells hardens them and gives the wood a dark-reddish colouration. This hard, dark

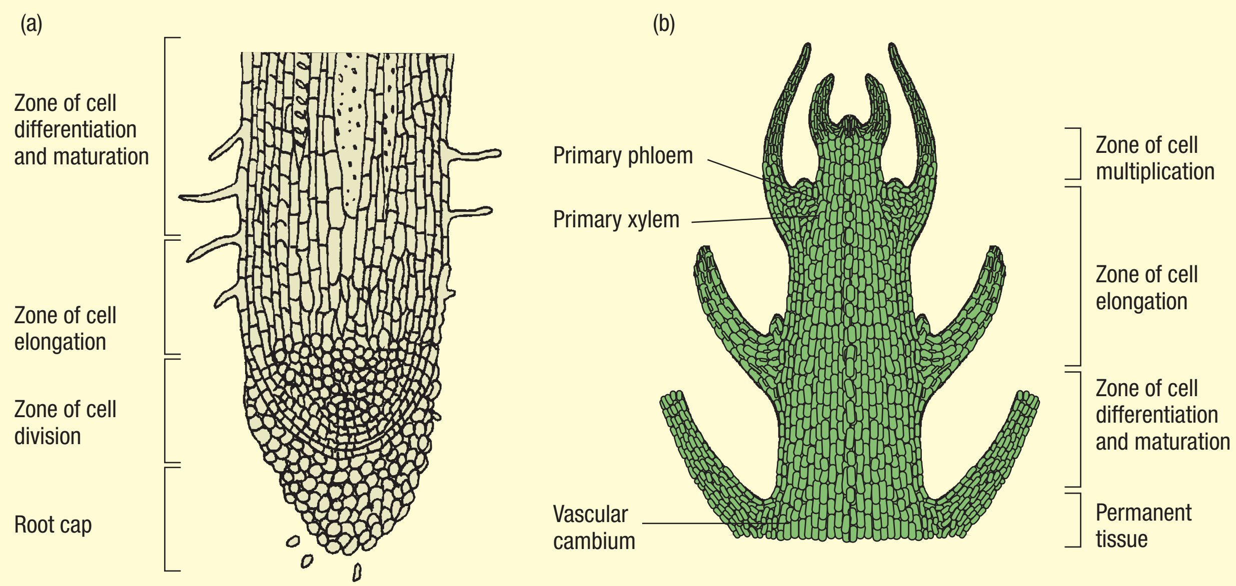


Figure 16.15 Longitudinal section through (a) root tip and (b) shoot tip of a flowering plant

Table 16.5 Types of meristem and their function

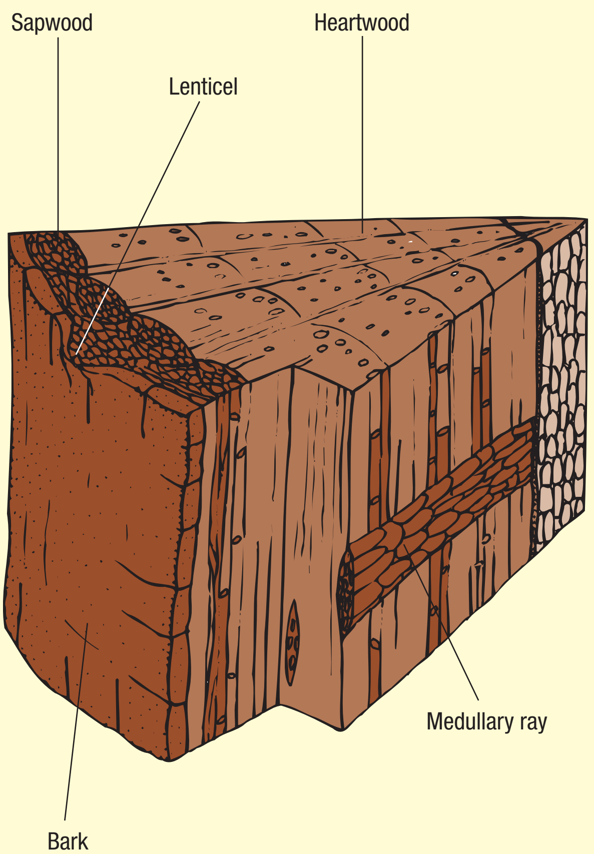
Type of meristem	Location	Role	Effect
Apical	Root and shoot apex	Primary growth	Increases length
Lateral (cambium)	Lateral in older parts; parallel to long axis of organs	Secondary growth; production of secondary vascular tissue; replacement of cork and epidermis	Increases girth
Intercalary	Between regions of permanent tissue, e.g. nodes of monocots	Allows increase of length in regions other than tips	Increases length

wood is known as **heartwood** and helps to support the tree. The xylem in which conduction of water and dissolved minerals occurs is lighter coloured and is called **sapwood**. Translocation of food occurs in the thin layer of phloem on the outer side of the stem.

The cork cambium is located near the outside of the stem and produces cork which is impermeable to water and gases. Lenticels in the cork enable exchange of water and gases with the interior of the plant.

The tissues outside the vascular cambium — the secondary phloem, crushed phloem, cork cambium, cork and layers of dead cork tissue — are collectively referred to as the bark. The inner bark is made up of living tissues, and the outer bark, which may be shed periodically, consists of dead tissues.

In areas with temperate climates, the growing season of a tree usually lasts from spring through to early autumn. In the optimum growing conditions of spring and early summer, the vascular cambium produces large xylem cells. In late summer and early



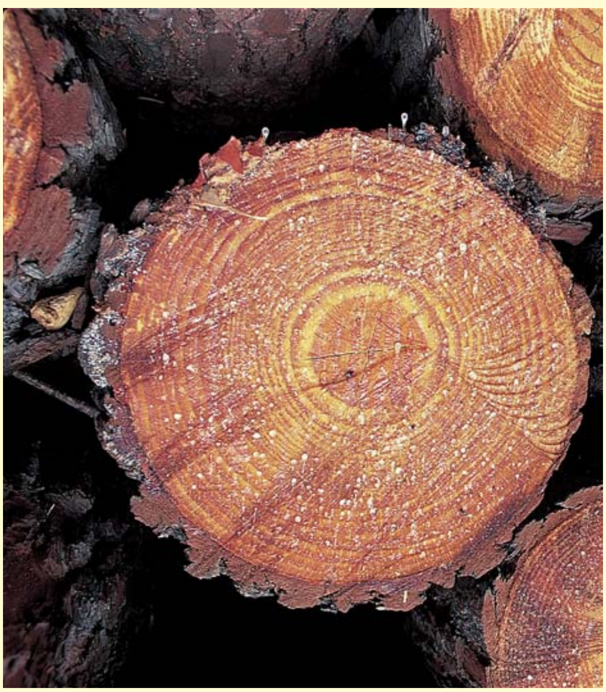


Figure 16.16 (a) Secondary growth in a woody plant; (b) cross-section of tree trunk showing growth rings

autumn, when growing conditions are less favourable, fewer and smaller xylem cells are formed. As a result, spring wood appears lighter in colour than late summer wood. The growth of the tree is marked by alternating light and dark rings. A light and a dark ring together is termed an **annual ring**. The number of these indicates the age of the tree.

The growing conditions that existed in previous years can also be indicated by the annual rings. A wide, light band indicates plenty of spring rain, whereas a narrow light ring indicates poor conditions which could be brought about by drought or disease. Due to climatic conditions in Australia, very few species of trees show distinctive annual growth rings.

SUMMARY

In flowering plants the zygote develops into an embryo within the seed. Development is then delayed until germination takes place.

Two types of germination are recognised: hypogeal (elongation of the base of the plumule) and epigeal (rapid growth at the top of the radicle). Germination depends on species-specific requirements of water, oxygen, illumination and temperature. Internally, a rapid mobilisation of food reserves (from either cotyledons or endosperm) takes place.

Growth and development of the shoot and root take place by cell division in apical meristems followed by cell expansion and differentiation. Primary growth results in the formation of primary tissues. Increase in girth takes place by secondary growth (cell division of secondary meristems) and the formation of secondary tissues. In a typical woody perennial there are two cambium layers: vascular (internal) cambium (producing secondary xylem and phloem annually) and external cambium (producing protective cork cells).

Review questions

16.21 What conditions are necessary for germination of a seed?

16.22 Compare and contrast hypogeal and epigeal germination.

16.23 Describe the formation of primary tissues in a plant.

16.24 In which plants does secondary growth occur? Describe the types of secondary growth.

16.25 Compare and contrast primary and secondary growth.

16.26 Figure 16.17 below represents a transverse section through a woody plant.

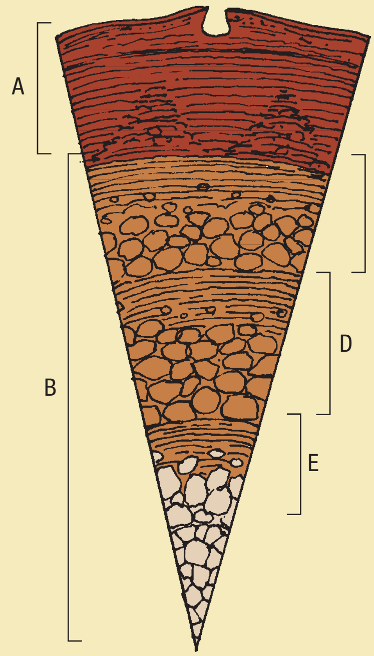


Figure 16.17

(a) Label the parts indicated.
(b) Estimate the age of the tree.
(c) Suggest the environmental conditions during any of the growth seasons of this tree.

16.4 Coordination and control in plants

Organisms must be able to monitor their environment. This may involve detecting changes in the chemicals within the body, such as the levels of glucose or carbon dioxide. Other important environmental aspects that must be monitored are outside the body. The direction of water currents; the relative position of light; temperature; detection of food sources; these are all important clues for an organism's ability to survive. Irritability — the ability to detect and respond to changes in the environment — is a characteristic of all living matter.

Detection of the stimulus involves changes in chemicals within the individual cell or in the specialised cells of a sense organ. A chemical message is then transmitted to bring about a response. The response is again a change in chemicals within a single cell or within an effector organ.

The basis of irritability is ultimately chemical. In simple organisms and plants only a hormone system operates, but in truly multicellular animals a more rapidly acting nervous system also comes into play.

16.4.1 Chemical control

Within any living cell, vast numbers of chemical reactions are occurring at any given moment. The chemical environment in every part of the cell is constantly undergoing slight changes, as some substances are synthesised and others are used, destroyed or removed. Any change in the chemical environment will affect subsequent chemical reactions and thereby exert some control over them. This simple relationship, which regulates most of the cell's reactions, forms the basis of more complex chemical regulatory mechanisms. It is from this basis that hormone systems are thought to have evolved. In this type of system certain cells have become specialised to produce and secrete specific regulatory chemicals.

Hormones are chemicals that regulate body functions in multicellular plants and animals. They are produced by cells in minute quantities and transported to other regions. Each hormone regulates the activity of a specific target structure. This may be an individual cell, or a group of cells.

Hormones may provide control in their immediate surroundings or at a distance. 'Distance' hormones are made in one part of the body and control another part. They must be transported to the target sites either in a transport system or by diffusion from cell to cell. The action of hormones, therefore, tends to be slow. Similarly, since there will be some of the released hormone still available even after its production has been 'switched off', the action is long-lasting.

A stimulus causes production and secretion of a hormone appropriate to that stimulus. The hormone is then carried throughout the body. When it reaches the target organ, recognition sites (glycoprotein molecules) on the cell membranes 'capture' the hormones, which then regulate the cells' activities through a specific chemical reaction. They do not initiate any unique cellular activities but instead modify the rates of existing activities. Hormones may:

- act on the cell nucleus to influence the activity of particular genes
- influence the permeability of the cells to particular solutes
- induce or repress cytoplasmic enzymes and thus specific chemical reactions.

Hormones are therefore often referred to as 'chemical signals', since they cause a change in activity of the target cells.

Hormones differ in their molecular structure. Some are proteins and others are steroids. Thus different hormones will be recognised by different target sites and bring about different chemical reactions.

SUMMARY

Irritability, a property of living organisms, is the ability to detect changes in the environment and respond to them. The environment may be internal or external. The response may be an overt movement, a change in some metabolic reaction or a growth pattern.

Irritability involves communication between different parts of the organism, the basis of which is ultimately chemical.

Metabolic activities are constantly occurring. Thus the chemical environment in every part of the cell (and thus the whole body) is constantly changing. This affects other chemical reactions.

Hormones are chemicals which regulate body functions in organisms. Each hormone has a specific target structure. A hormone is made in one part of the body and controls another. Action is slow but long-lasting.

Review questions

16.27 All communication systems in living organisms involve a stimulus, a transmitter and a response. Comment on these three parts in an angiosperm.

16.28 Define a hormone.

16.29 Outline how hormones carry out 'control at a distance'.

16.4.2 Chemical control in plants

Types of plant responses

Plants are more limited than animals in both the range of stimuli to which they can respond and in the type of response that can be made. Although most plants are fixed in position and therefore do not display locomotion, they do nevertheless show a range of physical responses. Examples of responses of plants to certain physiological conditions — for example the closure of stomata due to water stress — have been discussed in previous chapters. This section will deal with plant movements and how they are achieved.

Plant movements can be divided into those which are mechanical and those which involve the sensitivity of the plant to a particular stimulus. Mechanical movements are often **hygroscopic**, caused by tissues drying up in the air. The release of spores from moss capsules and the release of pollen from anthers of flowers are examples of purely mechanical movement.

Movements resulting from sensitivity are described as tropic, tactic or nastic.

Tactic movements (taxes)

Tactic movements are made by a whole organism, or a free part of the organism such as a gamete, towards or away from variations in a directional stimulus. Phototaxis is in response to light, chemotaxis to chemical concentrations, aerotaxis to oxygen concentrations and osmotaxis to osmotic conditions.

Nastic movements (nastes)

Nastic movements are made by a part of a fixed plant in response to a non-directional stimulus. They are brought about by growth curvatures or sudden changes in turgor pressure. Stimuli include changes in temperature, humidity and light intensity; for example, the 'sleep movements' of some flowers that close their petals at night. Other stimuli that bring about nastic movements are contact and shock.

Tropic movements (tropisms)

Tropisms are directional growth movements under the control of plant hormones.

The known plant hormones are produced most abundantly in the actively growing parts of the plant such as the tips of shoots and roots, and the young leaves or developing seeds. In addition to their specialisation to produce these chemicals, these cells continue to carry out the other functions typical of cells in that area. Plant hormones are almost exclusively involved in regulating growth and usually bring about a permanent change in the structure involved.

Plants respond to the hormone by differential growth towards or away from a variety of stimuli. Growth towards a stimulus is a positive tropism; growth away from the stimulus is a negative tropism. Stimuli include:

- light — phototropism
- gravity — geotropism
- water — hydrotropism
- touch — thigmotropism
- chemicals — chemotropism
- temperature — thermotropism.

There are four types of hormones that regulate growth in plants: auxins, gibberellins, cytokinins and abscisic acid. Each group of hormones is thought to consist of different types of chemicals, only a few of which have been chemically isolated and identified. The most commonly encountered chemical in the auxin group is indoleacetic acid (IAA).

Plant hormones

Auxins

Auxins are manufactured in shoot and root apices, young leaves, buds and seeds. They diffuse away from their source to the rest of the plant. As they diffuse through the plant, the auxins are progressively broken down by enzyme action. They do not accumulate in the plant.

At their target sites the auxins cause cell walls to soften. Auxins stimulate secretion of protons (hydrogen ions) and so increase the acidity of the extracellular solution. This stimulates an enzyme-controlled reaction which loosens the bonds between the cellulose microfibrils in the cell wall and softens it. This allows more water to enter the cell, and growth occurs through elongation of the cell.

Production of auxins is not dependent upon a stimulus. Provided there is adequate energy available for growth, cells will continue to grow, under the influence of auxins, to their optimum size. Uneven distributions of auxins, however, can result from an external stimulus. This leads to a changed growth pattern.

Investigations of the phototropic response (initially documented by Charles Darwin in 1880) led to the first evidence for, and isolation of, plant hormones. Most of the experimentation was carried out using **coleoptiles** of grasses such as oats. A

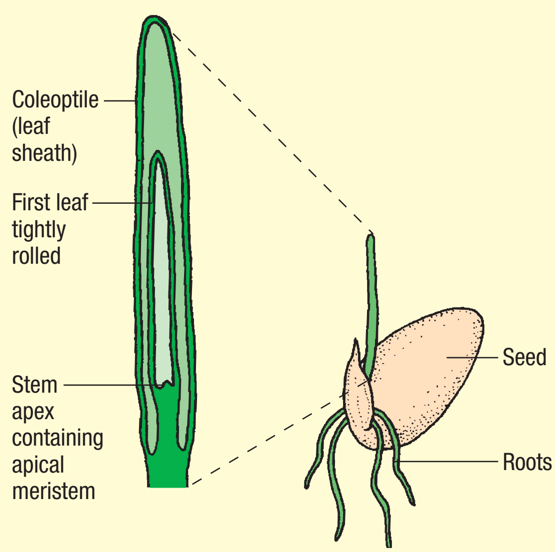


Figure 16.18 Structure of an oat seedling, showing the coleoptile

coleoptile is a tubular leaf-like structure, closed at the top, which surrounds and protects the first leaf of a monocotyledonous plant during its passage through the soil.

Experiments have shown that the distribution of auxins in the plant shoot resulting in preferential growth patterns depends on a light stimulus. Some of these experiments are summarised in Figure 16.19

If shoot tips are subjected to unilateral light, auxin migrates away from the light and accumulates in the shaded side. It is not certain how the light stimulus is detected by the shoot tip. Evidence suggests that riboflavins in the tip may cause photo-oxidation of the enzymes which synthesise the auxin on the lit side. Without these enzymes, auxins cannot be produced. On the shaded side riboflavins do not inhibit auxin production, therefore auxins accumulate there. This brings about elongation of the cells just below the tip on the shaded side. The shoot bends towards the light, showing positive phototropism. The result of such bending is that the shoot is no longer illuminated unilaterally; auxin again becomes equally distributed on all sides of the growing stem and the irregular growth response ceases.

If a potted plant or germinating seedling is laid on its side for some time, the shoot begins to bend upwards and the root downwards in response to gravity. The shoot displays negative geotropism and the root positive geotropism. It has been found that the root cap and endodermis of many plants contain mobile starch grains. They respond to the pull of gravity and so accumulate in the lower parts of the cell. Cellular inclusions which, by their changes in position, are presumed to affect the position of a part or an organ are called **statoliths**.

The accumulated, statolithic starch grains are believed to somehow change the permeability of the cells to auxins. Thus auxins are more concentrated in these cells. In shoots the auxin accumulation in the cells on the lower side causes them to elongate and thus the shoot bends upwards. The root cells, however, respond to the increased concentration of auxin by inhibition of growth. The cells on the

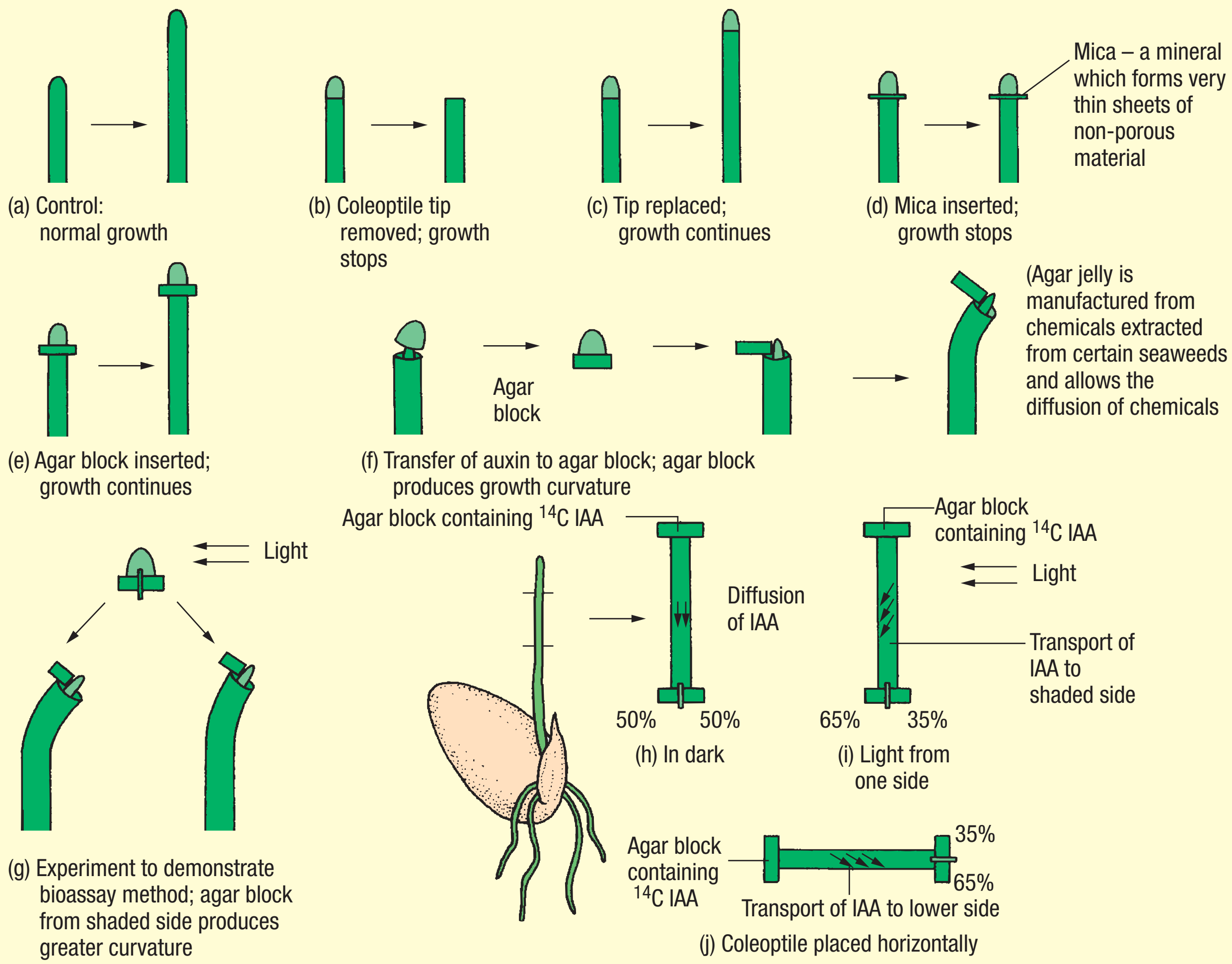


Figure 16.19 Some experiments investigating the phototropic response in oat coleoptiles

opposite side of the root therefore grow more rapidly than do the lower cells. The root bends downwards. Their orientation towards gravity corrected, the statoliths and thus auxins become evenly distributed again and growth continues normally.

It has been shown that different tissues of the plant have varying sensitivities to particular concentrations of auxins. Whereas one tissue will respond by growth, another will respond by inhibition to growth at the same auxin concentration.

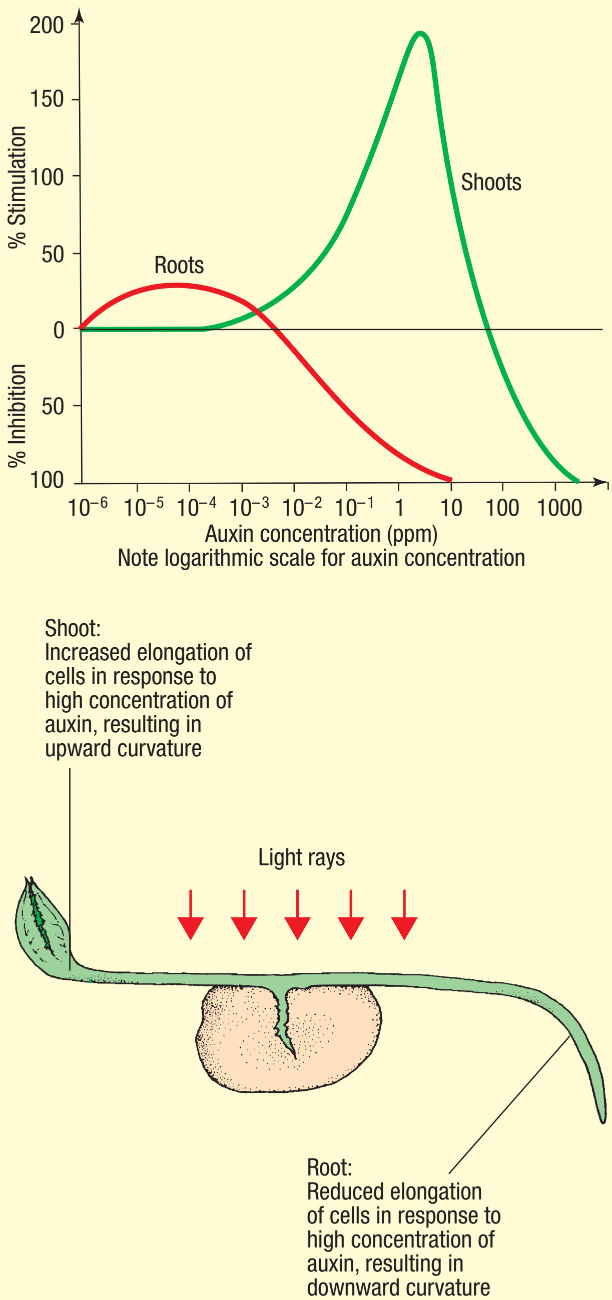


Figure 16.20 Effects of auxin on elongation in roots and shoots

Auxins produced in the terminal bud move downward in the shoot. They inhibit the development of lateral branches, while at the same time stimulating elongation in the main stem. Apical dominance ensures that the plant's energy is directed into the main stem to produce a tall plant with relatively short lateral branches. Longer side branches occur only lower on the plant where auxin concentrations are very much less. This is seen, for example, in trees that have not experienced storm damage. The leafy part of the tree is roughly triangular in shape, the lower branches forming the base of the triangle. Such an arrangement maximises the amount of sunlight reaching each leaf and so photosynthesis.

Removal of the terminal bud leads to breakdown in apical dominance and the development of strong side branches, until these new terminal buds then exert their own apical dominance. Eucalypt trees regenerate rapidly after a bushfire when all leaves and shoots have been burnt. This is because breakdown in apical dominance allows the development of protected axial buds. Gardeners deliberately remove the terminal buds of many plants to increase lateral shoot growth and thereby are able to increase production of flowers and/or fruit.

Auxins also induce cell division in certain tissues. They are responsible for the formation of adventitious and lateral roots, and the production of new xylem in spring. Commercial use has been made of applying auxins to cuttings of plants which would not normally grow by this method, to induce formation of adventitious roots. Auxins inhibit **abscission** (fall) of leaves and fruits.

Auxins produced by pollen tubes and seeds stimulate growth of the ovary wall to form fruit. Application of synthesised auxins to unfertilised ovaries can cause a seedless fruit to develop in some plants. This has had some commercial exploitation in crops of tomatoes, figs and cucumbers. It has also been used in supplementing normal pollination, thereby ensuring a bigger crop.

The weedkillers 2,4-D (2,4-dichlorophenoxyacetic acid) and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) have many of the properties of auxins. These herbicides cause broadleaved dicotyledonous plants to undergo rapid, uncoordinated and distorted growth in some parts, while the function of other parts is inhibited, and this leads to their death.

Gibberellins

Gibberellins were first isolated from a fungus which infects rice and causes uncharacteristic elongation of the stems. They are abundant in young expanding organs. Their principal effect is to act in conjunction with auxin in elongation of cells and thus of the stem. They also have some effects which are independent of auxins and uncharacteristic of them — they stimulate the production of new phloem cells, they often break seed and bud dormancy, and they stimulate flowering.

Gibberellins promote seed germination by stimulating the production of enzymes which direct the mobilisation of food reserves used by the developing embryo. Some seeds contain high concentrations of a germination inhibitor (abscisic acid) and it has been suggested that these may be inactivated by gibberellins. There is some evidence that gibberellins may exert their action by unlocking segments of DNA, thus allowing specific genes to operate.

Cytokinins

Cytokinins is the name applied to the general class of control compounds that promote cell division. The ratio of cytokinin to auxin appears to be the determining factor in the differentiation of the newly formed cells into tissues. In some tissues of the normal growing plant, cytokinins and auxins may act towards the same end. In other tissues the action of the two hormones is antagonistic.

It is believed that cytokinins are also involved in delaying senescence (aging) of leaves. They have commercial applications in:

- prolonging the lives of lettuces and flowers
- tissue culture.

Abscisic acid (ABA)

Abscisic acid (ABA) is produced in roots, leaves, stems, fruits and seeds. It moves to the rest of the plant through the phloem. ABA serves as a direct opponent to the action of the growth-promoting hormones. It inhibits cell elongation and seed germination, and it promotes dormancy in buds and abscission of leaves and fruits. Levels of ABA may increase dramatically in plants subjected to stresses such as drought, thereby decreasing plant growth and energy utilisation. ABA may also induce stomatal closure.

Bud dormancy in deciduous woody species is initiated by shorter days. In some way reduced day-length increases the levels of ABA in the bud. The ABA, which is gradually broken down by the cold conditions experienced through the winter, prevents frost damage to buds that might otherwise open too early. In spring there is an increased production of gibberellin which, in conjunction with the now decreased concentration of ABA, breaks the dormancy. Seed dormancy has also been shown to be broken by an extended period of cold in some plants.

Many desert ephemeral seeds will not germinate unless they are subjected to a large amount of water. This prevents them from germinating at a time when water supplies will be inadequate to see them through a complete cycle to new seed production. It is possible that these seeds may contain very high levels of ABA, which must be washed out of the seed coat by abundant water in the soil before the gibberellic acid present can act.

Senescence is an aging process. In plants, signs of senescence include reduced protein synthesis, loss of chlorophyll and breakdown of cell membranes. It may involve the whole plant, as in annuals that have one flowering season and then die, or just part of the plant, such as the leaves of a deciduous tree or a fruit once it has ripened.

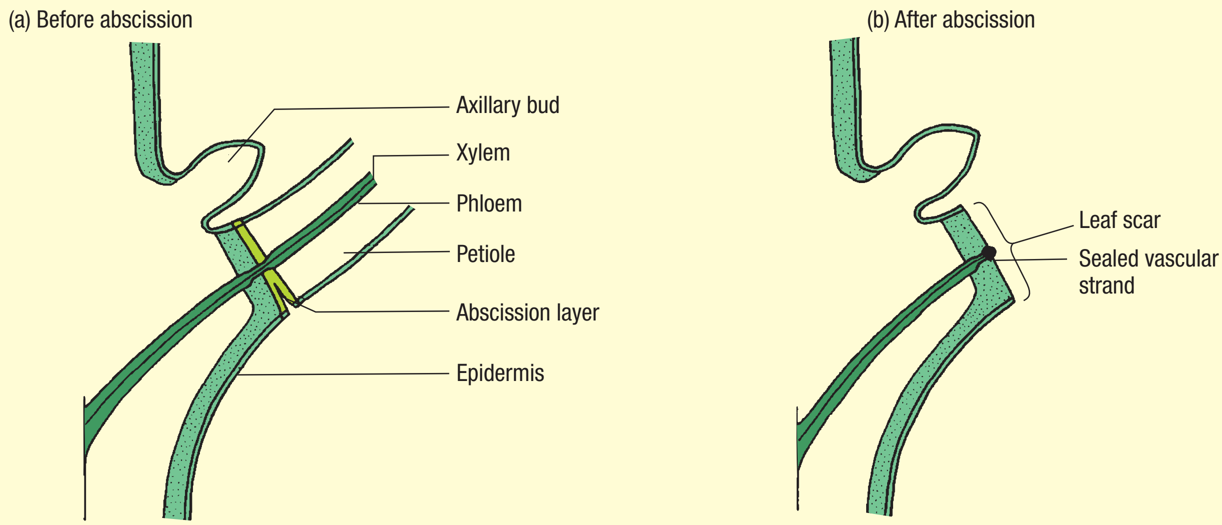


Figure 16.21 The abscission zone of a leaf

In whole-plant senescence, food is sent to the developing fruits at the expense of the dying vegetative parts to ensure complete development of the seed. Avocado trees infected with *Phytophthora*, for example, exhibit massive flowering just before they die.

With the senescence of only a part of the plant, an abscission layer is formed by the breakdown of cells in the abscission zone at the base of the 'organ'. The abscission zone is a special layer of cells in parts of the plant which periodically fall away from the main body of the plant. When fruit is ripe, for example, it comes away from the plant and the abscission layer seals the cells below it on the plant body. This prevents 'leakage' from the vessels and bacterial or fungal attack.

Abscission appears to be controlled by interactions between auxin and ABA. As the organ approaches abscission, the auxin levels decrease and the ABA levels increase. Once the process begins, however, it is accelerated by auxin, especially if there are young leaves growing nearby.

Another hormone, **ethene** (= ethylene), is also involved with senescence of leaves and fruit. Fruit ripening is often accompanied by a burst of respiratory activity in which ethene is produced. This chemical accelerates both the ripening process and abscission. The weakened zone of dead cells in the abscission layer causes easy shedding of the organ assisted by the wind. Unfertilised flowers will fall rapidly, whereas developing seeds cause auxin release and hold the fruit on the plant.

Both ABA and ethene are used commercially by fruit growers. ABA is sprayed on fruit crops to control fruit drop. Ethene is used to:

- stimulate ripening of fruit
- induce flowering in pineapples, petunias, carnations and peas
- bring about uniform ripening of tomatoes on the plant (under the name 'Ethephon').

Ethene inhibitors, such as carbon dioxide, are used to retard ripening of stored fruit.

Phytochrome

Winter bud formation is a response to the shortening days of autumn. Many other examples of the effects of light on plant growth have been demonstrated. Some seeds will germinate only if exposed to light, and it has been demonstrated that the part of the visible spectrum to which most of them respond is red light in the range of 580–660 nm. Far-red light (700–730 nm) inhibits germination. Plants absorb red light using a blue pigment, **phytochrome.**

Phytochrome can exist in two interconvertible forms called P_{660} and P_{730}. The numbers refer to the wavelength at which each shows maximum absorption. Absorption of light by one form of phytochrome converts it rapidly to the other form. Since sunlight contains more red than far-red wavelengths, P_{660} is converted to P_{730} during the day and at night is gradually converted back to P_{660}. The P_{730} activates various enzymes via hormones, some of which stimulate growth (cell elongation and/or

Table 16.6 Summary of the growth hormones in plants and their actions

Process affected	**Auxin**	**Gibberellin**	**Cytokinin**	**ABA**	**Ethene** (= ethylene)
Stem growth	Promotes cell enlargement and cell division at the cambium	Promotes this in presence of auxins	Promotes cell division in apical meristem and cambium	Inhibits this, especially during physiological stress (e.g. drought)	Inhibits this, especially during physiological stress (e.g. drought)
Root growth	Promotes at low concentrations but inhibits at high concentrations	Inactive	Inactive or inhibits primary root growth	Inhibits	Inhibits
Root initiation	Promotes growth of roots from cuttings	Inhibits	Promotes lateral root growth	–	–
Fruit growth	Promotes	Promotes	Promotes	–	Stimulates fruit ripening
Apical dominance	Promotes	Enhances auxin action	Antagonistic to auxins	–	Breaks apical dominance
Abscission	Inhibits	Inactive	Inactive	Promotes	Promotes

division) and some of which inhibit it. Thus in red light certain seeds germinate but in far-red light the P_{730} is converted to P_{660} and germination is inhibited.

Table 16.7 Effects of red and far-red light on plant growth

Red light	Far-red light
• stimulates seed germination	• inhibits seed germination
• inhibits stem elongation	• stimulates stem growth
• inhibits lateral root growth	• stimulates lateral root growth
• stimulates leaf expansion	• inhibits leaf expansion

Photoperiodism

The response of plants to varying lengths of day and night is called **photoperiodism**. The regulation of flowering by variations in day length ensures that plants of the same species flower at the same time and thus promotes the chances of cross-pollination. Light is absorbed in the leaves by phytochrome. This causes the release of a transmitter to the flower apices via the phloem, and flowering is stimulated. Although it has never been isolated, it is thought that the transmitting agent is a hormone which has been hypothetically named '**florigen**'. Plants can be divided into three groups:

- **long-day plants**, which flower only when day length exceeds 10 hours (e.g. lettuce, petunia, barley, oats, spinach, broad bean)
- **short-day plants**, which flower only when day length is less than 12 hours (e.g. chrysanthemum, poinsettia, strawberry, coffee, hemp, cotton, corn)
- **day-neutral plants**, which flower irrespective of the day length (e.g. tobacco, rice, corn, potato, tomato).

Experiments have shown that in short-day plants, P_{730} inhibits flowering. They are really long-night plants, since they require a sufficiently long period of darkness (far-red light) for the P_{730} to be converted back to P_{660}. If the plant is provided with the required length of darkness but it is even momentarily interrupted by a flash of light, the plant will not flower. Enough P_{730} is formed in that short time to be inhibitory.

In long-day plants the accumulation of P_{730} stimulates flowering. Short nights are required to keep most of the phytochrome in this form.

Vernalisation

Bud break and seed germination in some species needs a period of cold before these growth processes can proceed. This is thought to be associated with breakdown of ABA. Similarly, many plants from regions with cold winters, such as tulip and hyacinth bulbs, must be subjected to low temperatures (around 4°C) before they can germinate and/or flower. **Vernalisation** is the term used to describe such cold-temperature treatment. It is the plant's mechanism to prevent flowering at an inappropriate time of the year. The cold stimulus is detected by the mature stem apex or the embryo of the seed, and this stimulates an increase in gibberellins. Flowering is then subsequently controlled by photoperiodism.

SUMMARY

Irritability in plants is displayed as:

- tropisms (directional movements mediated by hormones)
- taxes (movement of the whole organism or part of it in response to a directional stimulus)
- nastes (movement resulting from a non-directional stimulus).

Movements may be towards or away from directional stimuli.

Auxin brings about growth of a stem towards light (positive phototropism) by bringing about cell elongation below the apex on the side opposite the light. Negative phototropism is displayed by the roots.

The effects of different hormones on plant growth patterns are summarised in Table 16.6 on page 417.

Light stimulates phytochrome, which exists in two interconvertible forms, one of them sensitive to red light, the other to far-red. A variety of plant responses to light are determined by the balance between these two forms of phytochrome.

Photoperiodism is the response of an organism to day length. Flowering plants can be divided into long-day (flowering when day length is greater than 10 hours), short-day (flowering when day length is less than 12 hours) and day-neutral plants. The transmitting substance is believed to be a hormone, which stimulates flowering.

Vernalisation is the term used to describe a period of cold required by some plants before they can flower. It is an adaptive mechanism which prevents flowering at an inappropriate time.

Review questions

16.30 Distinguish between tropic, tactic and nastic movements.

16.31 Auxins and cytokinins are both growth hormones. How do they differ in the way that they affect growing cells in a plant?

16.32 Give one example of the commercial use of plant hormones.

16.33 A student grew a bean seed at home in the kitchen. Regardless of how the pot was turned, the plant always grew towards the lighted window. Explain (giving chemical details) why this occurred.

16.34 It is believed that statoliths are responsible for differential growth of parts of a plant by changing the permeability of cells to auxin. Explain how this accounts for the positive phototropism of shoots and negative phototropism of roots.

16.35 Describe the physical and chemical actions involved in leaf fall.

16.36 Define vernalisation. What is the significance of this process?

16.37 Explain why:

(a) decapitated coleoptiles do not respond to unilateral light

(b) petunias flower in summer but chrysanthemums flower in autumn.

16.38 Explain the possible mechanism of photoperiodism in plants.

EXTENDING YOUR IDEAS

1. UB In Costa Rica, black-faced solitaires (*Myadestes melanops*) are the main agents for the dispersal of the seeds of the shrub *Witheringia solanacea*. This is a pioneer plant which grows in gaps in the forest, so dispersal away from the parent plant is important. The birds eat the fruits and the seeds pass out with the faeces. Studies have revealed that the longer the seeds stay in the gut, the lower is the germination rate. Analysis of the fruit has shown that the juice has a laxative effect.

   (a) Suggest why dispersal is so important for this plant species.

   (b) How might the laxative juice of the fruit aid in species survival?

2. UB The diagrams in Figure 16.22 show cross-sections of two different types of flower.

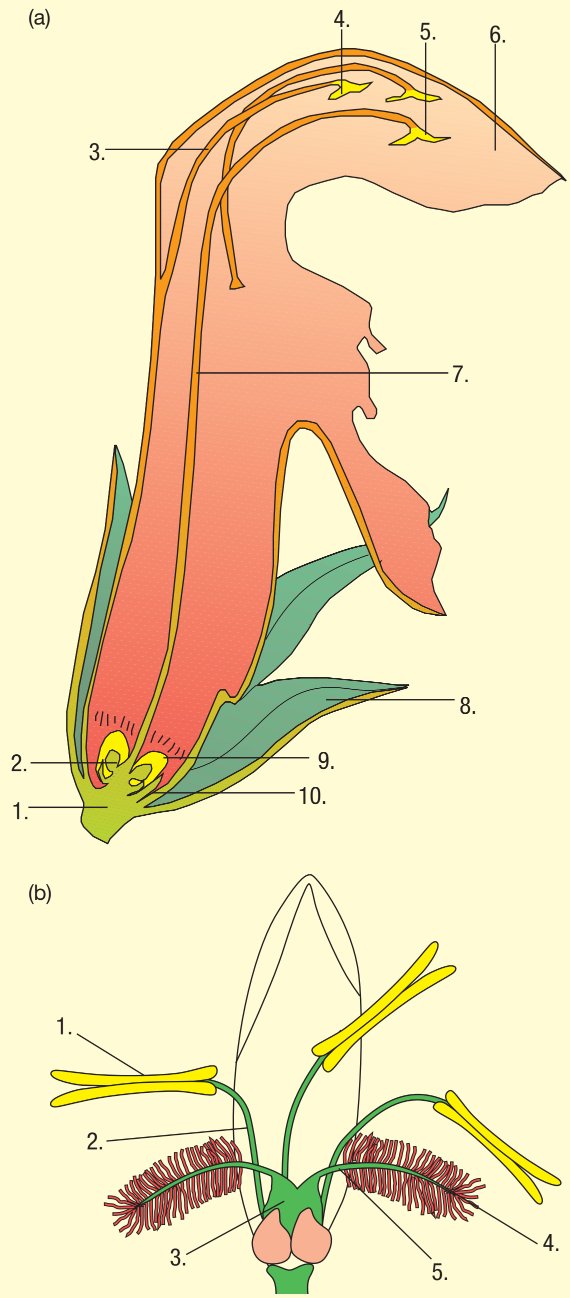


Figure 16.22

   (a) Using the numbers, identify the structures of each flower.

   (b) List features that are similar in each flower.

   (c) List features that are different in each flower.

   (d) Using the information in these two lists, compare and contrast the structures of the two flower types.

   (e) Suggest, with reasons, how each flower is pollinated.

3. UB Primula plants produce flowers which are typically pollinated by insects such as bees. Two different types of flower, pin-eyed and thrum-eyed, are produced. Figure 16.23 shows the structure of the two types of flower, and their pollen grains and stigmatic surfaces.

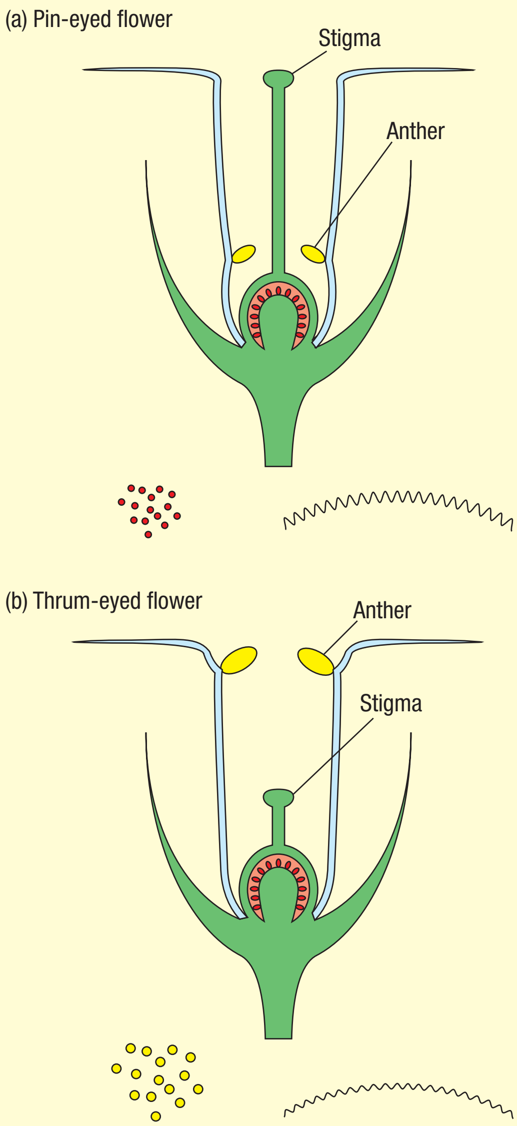


Figure 16.23

(a) Using the information in the diagrams, suggest two ways in which cross-pollination between the two types of flower is favoured.

An experiment was carried out to determine the percentage of successful fertilisation in flowers which were artificially fertilised. The results are shown in the table.

Type of pollination	Percentage of pollinated flowers which produced seeds
Thrum pollen on pin stigma	67
Pin pollen on thrum stigma	61
Thrum pollen on thrum stigma	7
Pin pollen on pin stigma	35

(b) Describe, briefly, what you would need to do to ensure that pollination occurred only as intended in the experiment.

(c) Suggest a non-structural mechanism to account for the lower success rate of fertilisation between flowers of the same type.

(d) Refer to the data in the table. Suggest a hypothesis which might account for the greater success of fertilisation from artificial self-pollination of pin flowers than of thrum flowers.

4. UB Many plant species are pollinated solely by bees. If too much pollen is transferred at one time, however, the bee grooms and so displaces much of the pollen it is carrying. The anthers of some species of plants have evolved a mechanism which responds to the vibrations of the bee's flight muscles to release pollen. Shooting star (*Dodecatheon conjugens*) is a herbaceous perennial. Its anthers are tuned to frequencies above that of the buzzing. Because the frequencies are not well matched, only small amounts of pollen are released. The longer a flower has to wait for the first visit by a bee, the greater is the amount of pollen released.

Suggest an explanation for the differences in pollen release by the shooting star.

5. UB Bumblebees in Alaskan heathlands chew holes in the base of panicled bluebells and 'steal' nectar without passing over the anthers and thus collecting pollen. The flowers of this plant, however, are still pollinated by the bees. Each starts off as a pollen-rich pink flower that turns blue within a few hours and produces a rich nectar. Any single plant has both blue and pink flowers. Bees require both pollen (a protein source) and nectar (for high-energy carbohydrate and as a glue to bind the pollen in carrying it back to the hive).

Propose a hypothesis for the production of two types of flower by the Alaskan panicled bluebell.

6. Suppose you carve your initials 1 metre above the ground on the trunk of a mature tree that is growing vertically at an average of 15 cm per year. How high will your intials be at the end of (a) 2 years? (b) 20 years?

UB

7. Most trees increase in girth, due to secondary growth, as they increase in height. What limitations in form and mechanical support would be imposed if secondary growth did not occur? Explain your answer.

UB

8. The table below shows the height of an annual flowering plant measured over a period of 90 days from germination.

IB

Time (days)	Height (mm)	Growth rate
0	0	
10	20	
20	80	
30	280	
40	760	
50	1240	
60	1660	
70	1960	
80	2000	
90	2000	

(a) Using the data, calculate the growth rates. What units are used for these growth rates?

(b) Plot a growth rate curve from your calculations.

(c) From the graph determine the period of greatest increase of height and the period of least increase.

(d) Suggest what might happen to the height of the plants if the readings were continued for a further 90 days. Explain your answer.

17 ANIMAL PHYSIOLOGY

17.1 Animals as energy converters

All living organisms need to take into their cells many different substances which will be used for maintenance, growth, repair and reproduction. A **nutrient** is any substance used by an organism. **Non-essential nutrients** are those that can be synthesised by the organism from basic materials. Some nutrients cannot be synthesised, and must be taken in from an outside source; these are termed **essential nutrients**.

Photosynthetic and chemosynthetic organisms are able to fix atmospheric carbon into complex organic molecules. Heterotrophs cannot synthesise organic compounds from inorganic matter and must therefore obtain their carbohydrates, proteins, lipids, nucleic acids and vitamins by eating other organisms.

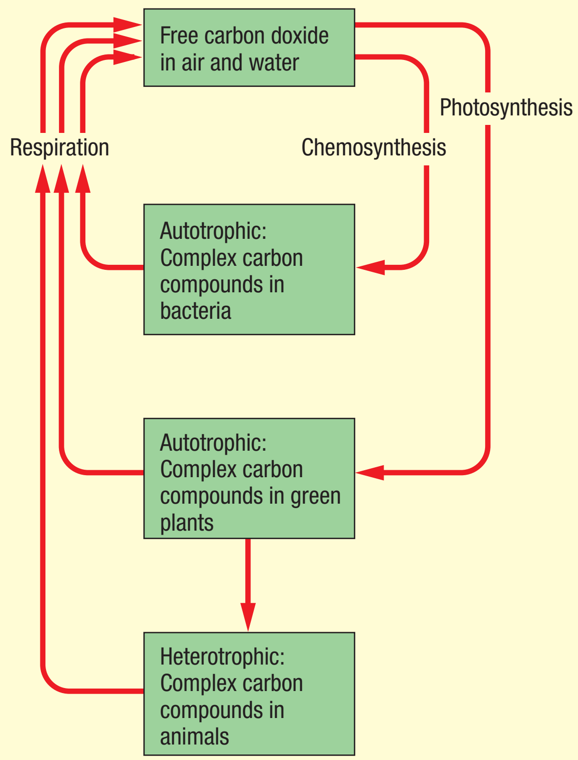


Figure 17.1 The movement of carbon through the ecosystem

Cell respiration releases chemical bond energy from organic molecules. This results in the production of carbon dioxide. The exchange of oxygen and carbon dioxide between the environment and the cells of the body is therefore important for energy conversions. Carbon, in the form of carbon dioxide, is cycled through the ecosystem in these processes.

17.1.1 Types of heterotrophic nutrition

Heterotrophic organisms include animals, fungi, most bacteria and a few flowering plants (those that are carnivorous, insectivorous or parasitic). Heterotrophic nutrition in animals may be described according to the manner in which the nutrients are obtained.

Animals that feed on other organisms

Many organisms feed on solid organic matter obtained from the living bodies of other organisms. This type of nutrition is often further classified on the basis of the type of solid matter that they ingest.

Chunk feeders

Some heterotrophs take in large pieces of food and are known as 'chunk feeders'. These are further subdivided into:

- herbivores—feed on green plants
- fructivores—feed almost exclusively on the fruits of plants
- carnivores—feed on other animals
- insectivores—feed on insects
- omnivores—feed on a varied diet of plant and animal matter
- scavengers—feed on the dead remains of other organisms.

Particle feeders

These organisms feed on small particles of food suspended in water, such as bacteria, protozoans and plankton.

Fluid feeders

Other heterotrophs ingest food in fluid form.

Parasites

Parasites are organisms that feed on the organic compounds present in the body of another living organism (the host). Parasites may feed on either solid or liquid organic compounds.

Whatever the method of taking in food, all heterotrophs obtain prefabricated high-energy organic nutrients which originally came from autotrophs.

17.1.2 The process of heterotrophic nutrition in animals

Before organic nutrients can be used in the cells of animals, they have to be acquired and taken into the body. In some cases, such as a tapeworm, this is simply a case of absorbing the required nutrients from the host across the entire body surface.

In all animals, other than sponges and some specialised parasites, the processing of food into a usable form is carried out by the digestive system. Sponges are filter-feeders. The central cavity is lined with flagellated collar cells which create a feeding and respiratory current by drawing water and microscopic food through pores in the body wall.

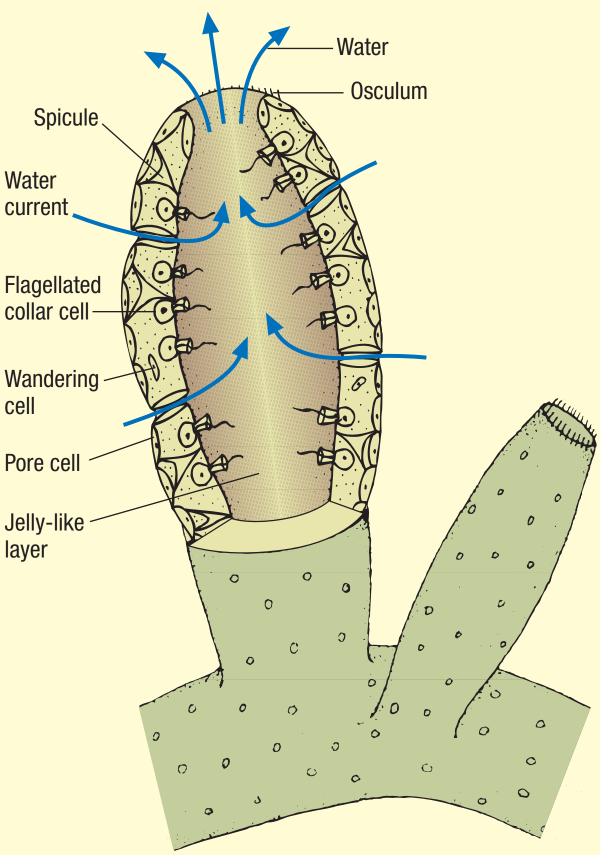


Figure 17.2 Cutaway view of a simple sponge

These cells capture and digest the food particles. Water, carrying waste products, is expelled through the osculum, a large pore at the top of the animal.

In simple animals (the Cnidaria and flatworms) digestion occurs in a gastrovascular cavity with a single opening. There is no independent muscle layer associated with the cavity, and so movement of the food within it is dependent on movement of the entire body.

In most Cnidaria (sea anemones, jellyfish and corals) feeding is assisted by tentacles that surround the mouth. These tentacles have stinging cells that paralyse the prey and, all acting in cooperation, pull it into the mouth. The mouth then closes. Digestive enzymes are secreted into the cavity and digested particles absorbed into the surrounding cells. Some cells can also actively take up very small particles of food by phagocytosis. The undigested food is expelled—by means of contraction of the body – through the re-opened mouth.

Free-living flatworms such as the freshwater planaria, suck bits of dead animals into a branched digestive system. Food is digested by cells lining the cavity and undigested food is eliminated through the single 'mouth' opening.

In the majority of animals the alimentary canal is a muscular tube which runs through the centre of the animal and has two openings to the outside. Food enters by one opening, the mouth, and passes through the tube in which processing occurs. Nutrients released by these actions are transferred from the alimentary canal to the body cells. Any material which is not processed is released through the other opening, the **anus**. The matter in the alimentary canal flows in one direction—from the mouth to the anus.

Ingestion

Chunk feeders must have a means of obtaining food and then breaking it down into molecules small enough to pass across the cell membranes. A variety of structures have evolved which aid in obtaining food. These include teeth, tentacles, claws and other appendages. These structures are involved in the process of ingestion or placing food into the digestive system.

The alimentary canal

Once the food is ingested, muscular contractions move this food mass through the system as well as physically breaking and churning it. In animals such as cnidarians and flatworms, which do not have a body cavity, food in the alimentary canal can move only if the whole animal is moving. In these animals, therefore, the entire length of the alimentary canal

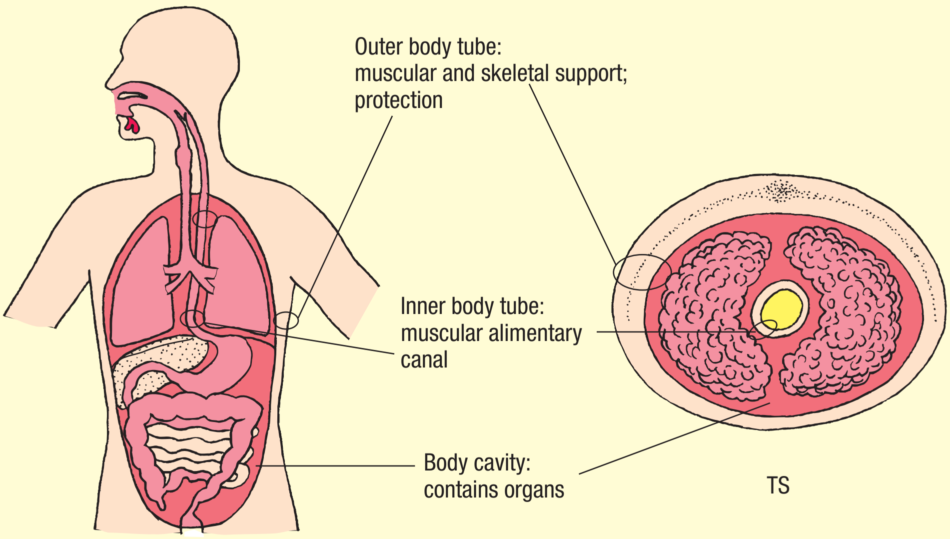


Figure 17.3 In animals with a true body cavity, the body can be thought of as comprising two tubes, one inside the other.

functions in digestion and absorption, and the amount of food actually digested before elimination occurs is related to the rate of movement of the animal.

The body cavity, which is found in the majority of animals, separates the alimentary canal from the body wall. In this case the body can be thought of as consisting of two tubes, one inside the other. The outer tube, which is in contact with the external environment, protects the inner organs and provides a framework for support and movement. The outer tube is connected to the inner tube only at the two openings to the external environment, the mouth and the anus. For the rest of its length the outer tube is separated from the inner tube by a space in which are found many organs such as the heart, liver, lungs and kidneys. The inner tube, the alimentary canal, can act independently of the outer tube because it has its own muscular system. This arrangement is shown in Figure 17.3.

Two muscle layers are found throughout the length of the alimentary canal. One layer, the circular muscle, is oriented around the circumference. When these muscles contract, the diameter of the tube is reduced. The second layer, the longitudinal muscle, is oriented along the length of the tube. When this muscle layer contracts, the tube becomes shorter. Waves of contraction and relaxation of these muscle layers move the food through the canal. The muscles just in front of the food relax, providing an enlarged area into which the food can pass. The muscles just behind the food contract and push the food forward. As the food moves, the muscles it passes then contract so that a region of

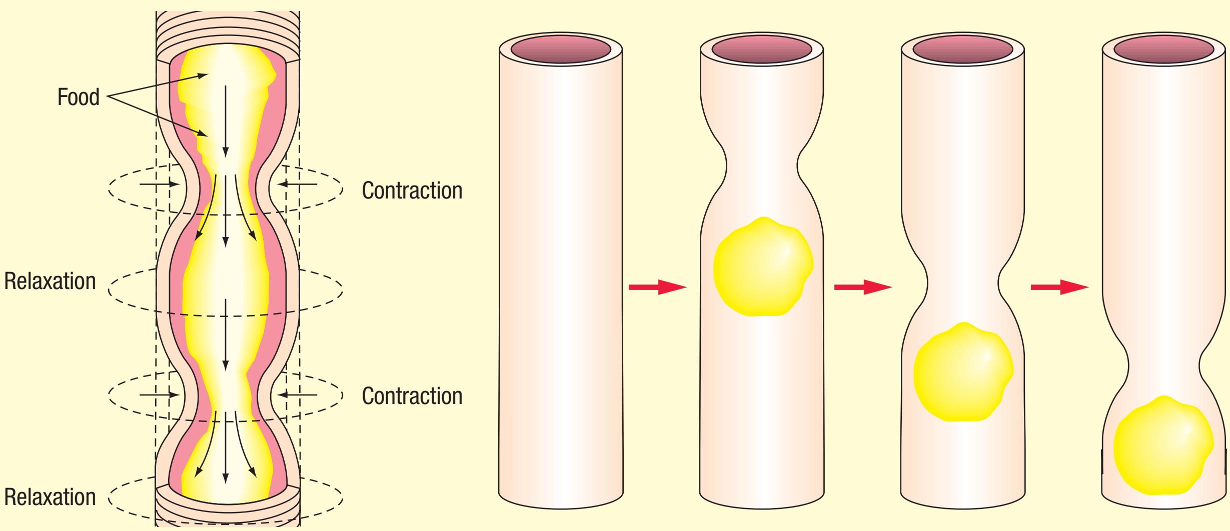


Figure 17.4 Peristalsis moves the food in the alimentary canal.

contraction follows the food and constantly pushes it forward. These actions are called **peristalsis.**

The separation of the muscular alimentary canal from the body wall has allowed the development of specialisation of parts of this canal for different functions. Some parts of the gut have developed into storage areas, others for digestion, absorption or elimination.

Within the alimentary canal, the solid food is subjected to a variety of actions that convert it into soluble compounds which can then be absorbed.

Physical digestion

The large pieces of food are broken down into smaller pieces during **physical digestion**. Special structures such as the rasp-like tongue (**radula**) of the snail and teeth of vertebrates help in this process. The movement of the muscles of the alimentary canal play a major role in breaking the food into very small particles.

As the pieces of food become smaller, their ratio of surface area to volume increases. This gives a greater surface area for the action of enzymes which bring about chemical digestion of the food, and makes digestion more efficient.

Chemical digestion

The decomposition of the large organic molecules making up the food into their basic units is known as **chemical digestion**. Complex carbohydrates are broken down into monosaccharides, proteins into amino acids, lipids into fatty acids and glycerol and nucleic acids into nucleotides.

A different enzyme mediates the chemical digestion of each type of carbohydrate, protein, lipid or nucleic acid. Some of these enzymes are produced in the wall of the alimentary canal; others are formed in specialised glands (e.g. salivary glands) and pass through ducts into the cavity of the alimentary canal.

Digestion that occurs outside the cells is termed **extracellular** digestion. Chemical digestion may also occur within the cells of the body, and this is termed **intracellular** digestion.

Absorption

The molecules produced by digestion are small enough to pass through cell membranes. In larger animals these molecules generally pass from the alimentary canal to a circulatory system which transports them to the appropriate cells.

Assimilation

Once in the cells, nutrients are assimilated. They are built up into complex compounds needed by the body, converted to other required forms or into storage products for later use, or broken down for energy release during cellular respiration.

Elimination

Any undigested food is eliminated from the gut as faeces in the process of egestion.

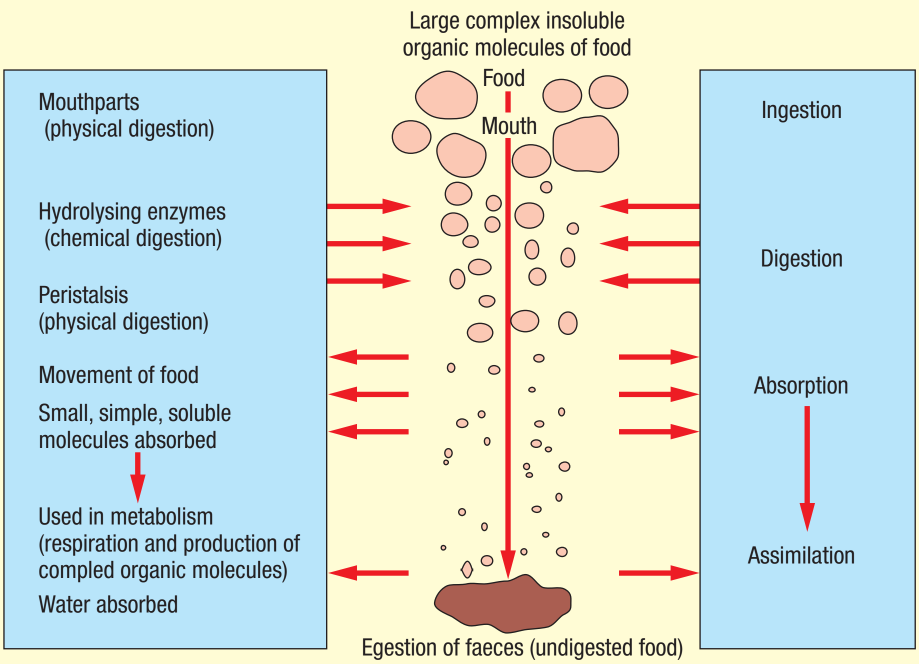


Figure 17.5 Stages in the acquisition of nutrients

Table 17.1 The method of digestion among representative organisms

Group	Type of nutrition	Major type of digestion	Digestive system
Bacteria	autotrophic	intracellular	none
Bacteria—decomposers	heterotrophic	extracellular	none
Cyanobacteria	autotrophic	intracellular	none
Fungi	decomposition	extracellular	none
Plants	autotrophic	intracellular	none
Plants—insectivorous	autotrophic and heterotrophic	extracellular	none
Plants—parasitic	heterotrophic	intracellular	none
Protozoa	heterotrophic	intracellular	food vacuoles
Cnidaria	heterotrophic	extracellular	gastrovascular cavity; two-way with one opening
Platyhelminthes	heterotrophic	extracellular	branched, undifferentiated gut; two-way: in the mouth, out the mouth
Nematoda	heterotrophic (particulate feeders)	extracellular	unbranched and undifferentiated gut; one way: in mouth, out anus
Annelida Arthropoda Mollusca Echinodermata Vertebrata	heterotrophic; all types displayed	extracellular	degree of differentiation dependent on type of food source; one way: in mouth, out anus

In the generalised vertebrate, the stomach is an area for food storage, physical digestion and chemical digestion of proteins into polypeptides. The small intestine is involved in chemical digestion of all food types and absorption of the small, soluble molecules formed. In the large intestine, bacterial decomposition and water absorption results in compaction of the undigested food in preparation for voiding.

SUMMARY

Heterotrophs derive their food, and thus energy requirements, from other organisms. Different sources of organic matter are available to heterotrophs from living and dead organisms. Since the food eaten contains particles too large to pass through the cell membrane, it must be broken down into small molecules. All heterotrophs must take in, digest, absorb and assimilate organic matter. Undigested material is egested.

Review questions

17.1 Distinguish between the following pairs of terms:
(a) 'nutrition' and 'nutrient'
(b) 'autotroph' and 'heterotroph'
(c) 'intracellular digestion' and 'extracellular digestion'
(d) 'chemical digestion' and 'physical digestion'.

17.2 Why is digestion of food necessary?

17.3 Explain how the development of a true body cavity has allowed specialisation of the alimentary canal.

17.4 Explain how the food is moved along the alimentary canal.

17.5 Most animals have a similar basic strategy in obtaining their nutritional requirements. Describe this.

17.1.3 Feeding adaptations

The size of any population is limited by competition for resources. Food and water are critical resources for survival. Over the course of time, therefore, there has been selection pressure to maximise food resources. Evolution has resulted in a myriad of heterotrophs specialised to feed on a specific type or group of other organisms. A plant, for example, can support many different types of heterotrophs. Aphids may tap into the phloem to obtain already digested sugars. Grasshoppers may chew the leaves. Bees and nectar-feeding birds obtain their nourishment from the flowers. Grubs attack the roots and fruits. Different feeding strategies are necessary for each type of food obtained from the one plant. The evolution of a new species, with a different mode of nutrition, paves the way for the evolution of more species which can exploit this new resource.

Different modes of nutrition, therefore, are exhibited by heterotrophic animals. These are invariably associated with mouthpart modifications for particular feeding requirements. Some of the essential structural differences associated with mode of feeding are summarised below.

Herbivores

Problem

Nutritional components of the plant are locked within the cellulose cell wall and very few organisms produce the enzyme cellulase to digest cellulose.

Solutions

- A method of grinding the plant material to break open the cell walls and thus release the cell contents

  Examples:

  1. Radula of the snail
  2. Ridged teeth of herbivorous mammals
  3. Gizzard of seed-eating birds

- Mutualistic relationship with an organism that can produce cellulase, living in some part of the alimentary canal

  Examples:

  1. The protist flagellate *Trichonympha* living in the intestine of wood-eating termites
  2. Bacteria in the rumen of cattle
  3. Bacteria in an enlarged caecum of the horse

Mammalian herbivores

The teeth of mammalian herbivores are adapted for eating large quantities of vegetable matter, especially grass. Although some herbivores, such as horses and kangaroos, have upper and lower incisors, these are absent in the ruminants (sheep, goats, cattle, camels etc). In these animals the upper incisors are replaced by a thick horny pad against which the lower incisors bite. Grass is pulled into the mouth using the long flexible tongue, held firmly between the lower incisors and pad, and sheared off by movements of the head rather than nipped off. Canine teeth may be absent, very small, or present as tusks which are adapted for digging for roots.

A gap, the **diastema**, is found between the front teeth or gum pad and the premolars in herbivores. This gap allows manipulation of the vegetable matter in the mouth by the tongue, thus ensuring a better chewing action.

The premolars and molars have a broad grinding surface with alternating ridges of hard enamel and soft dentine. The ridges of the teeth in the upper jaw have a shape which fits exactly against the ridges of the teeth in the lower jaw. Jaw articulation in ruminants is very loose and permits extensive movement forwards, backwards and sideways.

The grinding of plant material is of great importance. Plant material is usually strengthened and hardened, and mammals do not have enzymes which chemically digest the cellulose of the cell walls. One method utilised by herbivores to release the nutrient contents of the plant cells is to physically break the cell walls by the grinding action of the teeth.

The ruminants have a complex stomach consisting of four chambers. Grass is swallowed whole and passed to the first chamber, and then on to the second chamber where it is fermented by bacteria and moulded into round balls of 'cud'. The cud is regurgitated and chewed to a fine consistency. During this time much of the cellulose of the plant cell walls is ground up and then the cud is re-swallowed.

This material passes into the third chamber and finally into the true stomach. In the wild these feeding habits make it possible for the animal to feed very quickly and then retire to a safe place to complete physical digestion.

Other herbivores have a simple stomach but have a large appendix or caecum outpocketing from the intestinal wall. Microbial breakdown of cellulose occurs in this area. The position of the caecum, however, is such that the animal cannot derive maximum benefit from the microbial action. Thus, even though horses have an enormous caecum, much coarse, undigested plant material remains in their faeces.

A compensating adaptation has evolved in ringtail possums, which form two types of faecal pellets. One type, containing partly digested caecal material, is released during daylight hours in the nest. These pellets contain high levels of protein and B-group vitamins. They are re-eaten directly from the anus and exposed to further digestion and absorption. The other type of faecal pellet, formed after the second passage of food through the digestive system, is deposited outside the nest at night time, while the animal is foraging.

Carnivores

Problem

Catching and ingesting prey

Solutions

- Mouthparts capable of piercing, killing and biting off pieces of the prey (e.g. the great cats)
- Appendages or extensions for capturing, holding and ingesting prey

  Example: Tentacles bearing nematocysts (which may involve a toxin) in Cnidaria

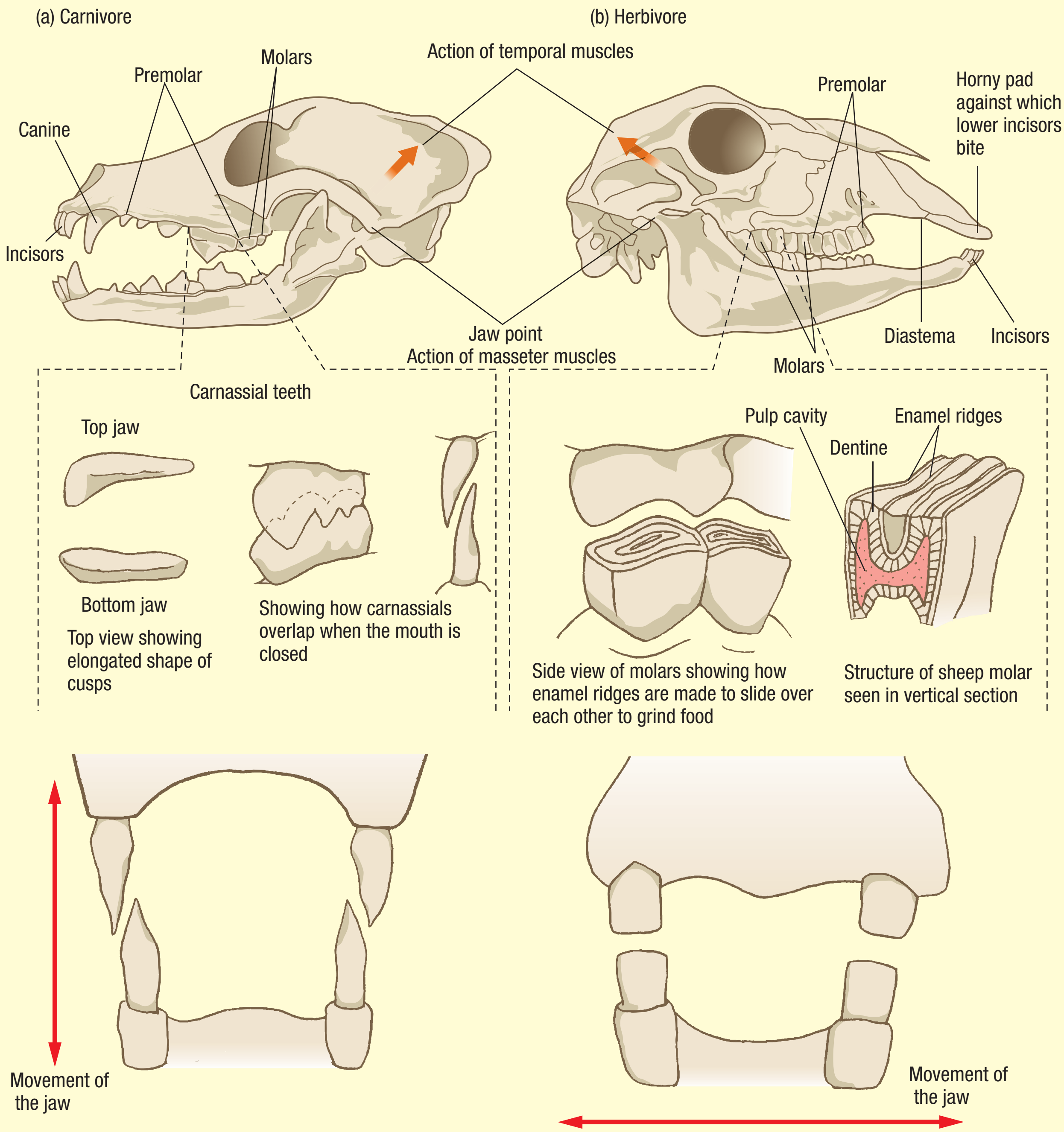


Figure 17.6 Comparison between (a) carnivore and (b) herbivore dentition and jaw action

- Immobilise prey and then ingest whole.

  Examples:
  1. Cnidaria
  2. Carpet snake
- Digestion of food outside the body

  Examples:
  1. The spider injects digestive enzymes through its fangs, into the prey.
  2. The flatworm everts its pharynx and pours digestive enzymes over the food, the subsequent fluid mass being drawn into the pharynx by a sucking action.
  3. Starfish and sea urchins evert the stomach over their food, externally digesting and absorbing nutrients.

Mammalian carnivores

In the course of evolution mammalian carnivores have become highly specialised and efficient at catching and killing other animals. A typical carnivore has small, closely-fitting incisors. These are used to clean fur and to cut away pieces of flesh close to the bones. The canines are particularly prominent and are used to pierce prey when it is captured, thus preventing its escape and often killing it. The huge **carnassials** (premolar/molar combinations) are adapted to shearing flesh from bones and cracking them open so that the bone marrow is exposed. Carnivores have comparatively small molars and spend little time chewing food into small pieces. They simply cut food into pieces small enough to swallow. The jaw articulation is a closely fitting hinge joint which permits only up-and-down movement and so prevents lower jaw dislocation or breakage when the prey struggles.

Insectivorous and fish-eating animals, such as bats and dolphins, have numerous pointed teeth. The principal function of these is to capture and hold prey, which is then swallowed whole. Some insectivorous mammals—for example, the echidna—no longer have teeth and the mouth is extended into a long snout. The tongue, which is sticky, cylindrical, mobile and extremely long, is used to 'lick up' prey such as ants. The snout is invariably used as a sensing instrument to expose the prey and has special adaptations to protect it from ant bites and stings.

Vertebrate carnivores tend to have a relatively short small intestine as a result of a largely protein diet.

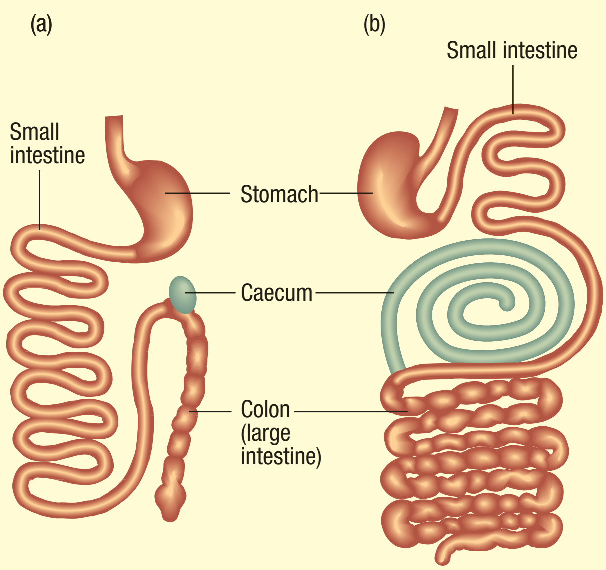


Figure 17.7 The digestive systems of (a) a carnivore (dingo) and (b) a herbivore (koala)

Fluid feeders

Problem

Access to nutritional requirements

Solutions

- Adoption of an internal parasitic lifestyle and thus absorption of the host's digested food

  Example: Tapeworm, which has secondarily lost its digestive system and absorbs simple, soluble molecules across the entire body surface
- Secretion of digestive enzymes into or onto the food source, then absorption of the resulting fluid

  Examples: Saprophytic fungi and bacteria
- Sucking or piercing mouthparts to obtain direct fluid access to a host organism, and a suctorial pharynx action to draw fluid up

  Examples:
  1. Mosquito (saliva contains an enzyme which prevents blood clotting)
  2. Aphids tap into the phloem of plants.
  3. The housefly secretes saliva over food and the digested fluid food so formed is drawn by capillary action into the pharynx. (See Figure 4.34 on page 76.)

Particulate feeders

Problem

Collecting, sorting and concentrating particles

Solutions

- Use of pseudopodia to engulf food

  Examples:
  1. *Amoeba*
  2. Cells of the endodermis in Cnidaria and non-parasitic flatworms

- Use of external mucus traps which are periodically ingested with trapped food

  Examples:
  1. Some gastropods (e.g. *snails*)
  2. Some midge larvae
- Water, containing fine particulate matter, is pumped by muscular action through a special filtering apparatus.

  Examples:
  1. Collar cells in the inhalant pores of the sponge draw water through them into the central cavity. These cells also secrete mucus which traps small particulate matter. This can then be taken up by phagocytic action of cells.
  2. Mucus traps plankton in the pharynx of the lancelet as it passes through the gill slits. Cilia on the internal pharyngeal surface pass the food trapped in mucus back to the intestine.
  3. Whalebone (baleen) whales and many fish use muscular contractions of the pharynx to set up feeding currents from which plankton can be filtered.
  4. Cilia on gill filaments of bivalve molluscs filter out food particles.
- Setae (hairs) can be swept through the water, collecting small particles and transferring them to the mouth.

  Examples: Many small aquatic Crustacea such as copepods and barnacles

The mouthparts of animals, therefore, give a fairly good indication of the type of food eaten.

SUMMARY

Selection pressures to reduce competition have resulted in a vast array of different heterotrophs which utilise different food resources. Different structures and strategies have evolved to produce this diversity. Different adaptations for obtaining and preparing food for ingestion occur in animals depending on a specific type of food source. Most of these adaptations are associated with mouthparts. The teeth of mammals show a variety of adaptations to different diets.

Review questions

17.6 Compare and contrast the dentition of a carnivore with that of a herbivore.

17.7 An insect was found to have short, hard mouthparts which were sharply serrated. Suggest a possible food source.

17.8 Some insects insert a long proboscis into the flowers of plants and ingest nectar. Suggest the structure and functions of their digestive system.

17.9 Herbivores incorporate some form of microbial fermentation in their digestive process. What does this achieve, and why is it necessary?

17.2 Gas exchange

17.2.1 General features

Respiration, which occurs in all cells of all organisms except viruses, releases energy from complex organic molecules such as glucose. Respiration may be either anaerobic and not use oxygen in the process, or aerobic, in which case it needs oxygen to proceed. Anaerobic respiration yields little energy and organisms which rely entirely on this process are very sluggish and limited in size. Aerobic respiration completely metabolises glucose to carbon dioxide and water, and in so doing releases a great deal of energy which was locked in the chemical bonds of the glucose molecules. Respiration is fully described in Chapter 14.

Aerobic respiration demands a continuous flow of oxygen into cells, accompanied by the rapid removal of the carbon dioxide they produce. These two processes involve gas exchange or external respiration. Respiratory gases pass into and out of cells by diffusion along a concentration gradient in an aqueous solution. Diffusion in water is relatively slow. The efficiency of diffusion is determined by:

- the area over which diffusion takes place
- the distance over which the concentration gradient must operate (i.e. the length of the diffusion pathway)
- the concentration gradient. In the case of oxygen this depends on the external oxygen concentration and the rate at which oxygen is used up.

The type of gas exchange system employed by an organism, therefore, depends on two factors: the size of the organism, and the environmental medium.

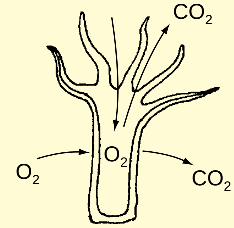
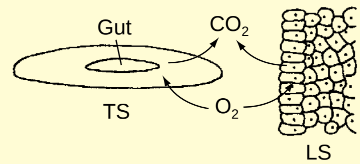
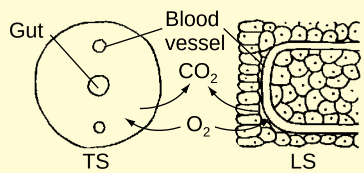
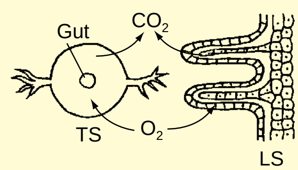
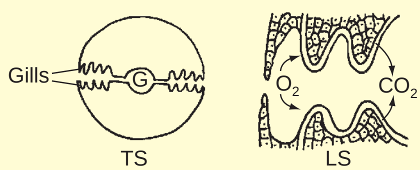
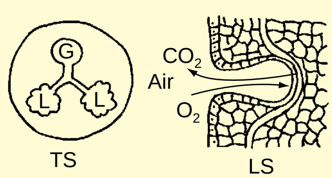
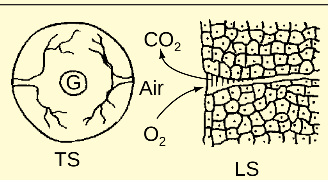
The effect of size

The surface area of the organism and the distance from the surface to the innermost respiring cells determine whether diffusion through the body surface can supply its gas exchange needs. If both of these conditions are appropriate, then this type of gas exchange occurs.

Among animals, diffusion as the sole means of gas exchange is used only by Cnidaria, flatworms and certain other small animals whose ratio of surface area to volume is large. As animals increase in size this ratio decreases, and diffusion alone becomes inadequate to supply all the cells. Thus roundworms and earthworms, although they exchange gases across the body wall, also require a transport system to ensure that all cells will have adequate gas exchange.

Proportionately, the body surface of larger, more active animals, or of those living in an oxygen-depleted environment, is usually too small to supply respiratory needs, even with the presence of a transport system. In such circumstances large, specialised gas exchange surfaces, such as lungs, trachea and gills, either supplement or replace respiration through the skin. The surface is often associated with some kind of ventilating mechanism. Ventilation ensures a constant renewal of either air

Table 17.2 Major types of gas exchange surfaces in animals

Description	Example	Sketch
Gaseous exchange over entire body surface; no transport system	Cnidaria and Porifera	
Gas exchange over the surface of a flattened body (increases surface area:volume ratio)	Flatworms	
Gas exchange over entire body surface; transport system circulates	Earthworms	
External gills and body surface; increases surface area for exchange, but unprotected	Marine worms	
Highly vascularised internal gills, involving a ventilation system drawing water over the gill surfaces	Fish	
Highly vascularised lungs connected to the pharynx, involving a ventilation system which pumps air in and out	Tetrapod vertebrates	
Gas exchange at the water-filled ends of fine tracheal tubes which penetrate all body tissues	Many arthropods	

or water at the gas exchange surface to maintain the concentration gradient.

Effect of surrounding medium

The medium in which an animal lives has a significant bearing on its gas exchange system. Since gases must pass across the cell membranes in solution, aquatic animals have no need for a mechanism to keep exchange surfaces moist. In terms of respiratory gases, there are two major disadvantages to living in water:

- Oxygen is not very soluble in water—only about 1 per cent compared with 21 per cent in air.
- Water is very viscous (about 50 per cent more so than air) and this limits the flow of water across gas exchange surfaces to one direction. Too much energy would need to be expended to reverse the flow of water as can be achieved with air flow in many terrestrial animals.

The greatly increased amount of oxygen in air allows a higher metabolic rate in terrestrial and air-breathing aquatic animals. There is a greater degree of physiological complexity, therefore, than in their purely aquatic counterparts. The structure of the respiratory surfaces in terrestrial animals must, however, counteract the drying effects of air and its lack of support (low buoyancy).

SUMMARY

Cellular aerobic respiration, which provides energy for living organisms, requires gas exchange between the organism and the environment. Gases diffuse into and out of cells by diffusion along a concentration gradient. The efficiency of this diffusion depends upon:

- the concentration gradient
- the area over which diffusion takes place
- the length of the diffusion pathway.

The size of the organism and the environment in which it lives determine whether special gas exchange surfaces and/or a transport system are required to supply all cells of the body with adequate gas exchange.

Small aquatic animals are able to exchange gases over the entire body surface and do not need a transport system. Larger aquatic animals have highly vascularised gills. Land animals usually have highly vascularised lungs, tucked inside the body, to decrease evaporative water loss from their surfaces.

Review questions

17.10 What factors determine the efficiency of diffusion?

17.11 How does the medium in which an animal lives determine the type of gas exchange system utilised?

17.2.2 Gas exchange in insects

In insects the integument or cuticle on either side of the thorax and abdomen is perforated by a series of pores or **spiracles** which open into a system of **tracheal tubes**. The spiracles are guarded by valves which prevent the loss of water and entry of dust and parasites.

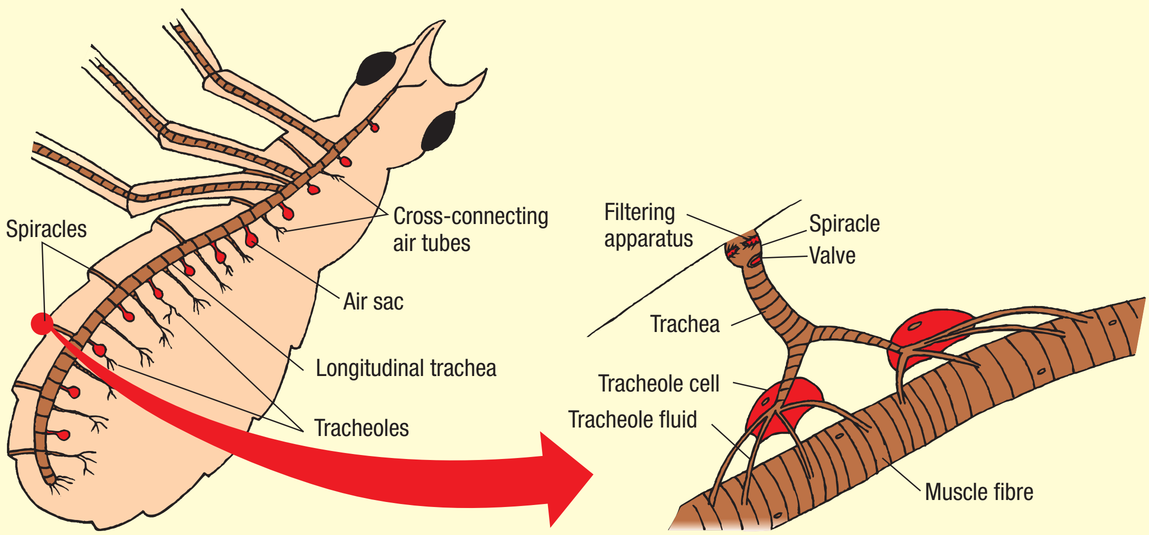


Figure 17.8 The tracheal system of insects

The tracheal tubes are lined with cuticle and rings of chitin which keep them open. There is usually a pair of longitudinal tracheae running the length of the body, and from these other tracheae branch and pass to all regions of the body. The finest branches, the **tracheoles**, are fluid-filled extensions that push into the membranes of the respiring cells and thus effect gas exchange. Each body cell is in close proximity to a tracheole.

Simple diffusion of gases along the tracheae, although adequate for the respiratory needs of small and relatively inactive insects, does not provide enough oxygen or remove carbon dioxide efficiently enough for large, more active ones. In these, diffusion is aided by ventilation. This is achieved by the contraction and relaxation of the abdominal muscles pushing against the tracheae. Since the ends of the tracheoles do not have rings of chitin, they can easily be compressed to create air flow. This brings about differential opening and closing of the spiracles. Air is drawn in through the thoracic spiracles and leaves via the abdominal spiracles.

The rate at which oxygen is delivered to the tissues is controlled in the tracheoles which contain fluid. In extreme muscular activity such as flight, lactic acid accumulates in the tissues, causing an osmotic imbalance. The result of this is that water is drawn out of the tracheoles, which has the effect of opening up these air passages. More rapid diffusion of oxygen into the air passages is thus achieved.

17.2.3 Gas exchange in fish

In fish, gaseous exchange takes place between the water and highly vascularised **gills**. These consist of several paired gill arches lying on either side of the buccal cavity, protected from the external environment by the **operculum**. From each gill arch extend two rows of **gill filaments** or primary lamellae which spread out and separate the buccal cavity from the opercular cavities.

The filaments bear tiny rows of shelf-like secondary lamellae on either side. Each of these contains a capillary network where gas exchange takes place. The total surface area over which gas exchange occurs is extremely large. It may be as much as ten times the body surface area. The more active the species of fish, the larger is the gill filament area.

A constant stream of water must be passed over the gills to maintain an oxygen supply to the body. When the fish is actively swimming, this can be achieved by keeping the mouth open; water will then be forced through the buccal cavity and across the gills. When the fish is inactive, however, water does not automatically keep moving through the buccal and opercular cavities. Most fish, therefore, use muscular movements of the operculum and buccal cavity to ventilate the gills.

For inspiration, the buccal floor is lowered. This reduces the pressure in the buccal cavity and causes water to pass in through the open mouth. The mouth is then closed and the floor of the buccal cavity is raised. This increases the pressure in the buccal cavity and causes water to pass across the gills into the opercular cavity. The movement is aided by the simultaneous action of the opercular flaps bulging outwards while the opercular valves are kept closed. The pressure in the opercular cavity is decreased in relation to that in the buccal cavity.

During expiration the opercular flap moves inwards, increasing the pressure in the cavity and forcing water out through the opercular valves. Backflow of water to the buccal cavity is prevented by the higher water pressure in that area. Thus an almost continuous one-way flow of water is achieved across the gills by the double pumping mechanism.

Oxygen diffuses from the water into the lamellar capillaries along a concentration gradient, and carbon dioxide diffuses in the opposite direction.

The concentration gradient is maintained at the surface of the gills by:

- the continuous removal of oxygen from solution by haemoglobin in the red blood cells
- blood flow which removes oxygenated blood from the gills
- continuous ventilation of the gill surface.

The flow of water through the gills is in the opposite direction to the flow of blood through the capillaries, forming a counter-current system. The counter-current flow significantly increases the efficiency of gas exchange. The oxygen concentration in the water exceeds that of the blood along the entire length of the lamella. Thus as blood flows across the respiratory surface it meets water which has less and less oxygen extracted from it, and a steep concentration gradient is maintained along the entire surface. This enables blood to remove as much as 96 per cent of the oxygen from the water passing through the gills. This is important because of the low solubility of oxygen in water.

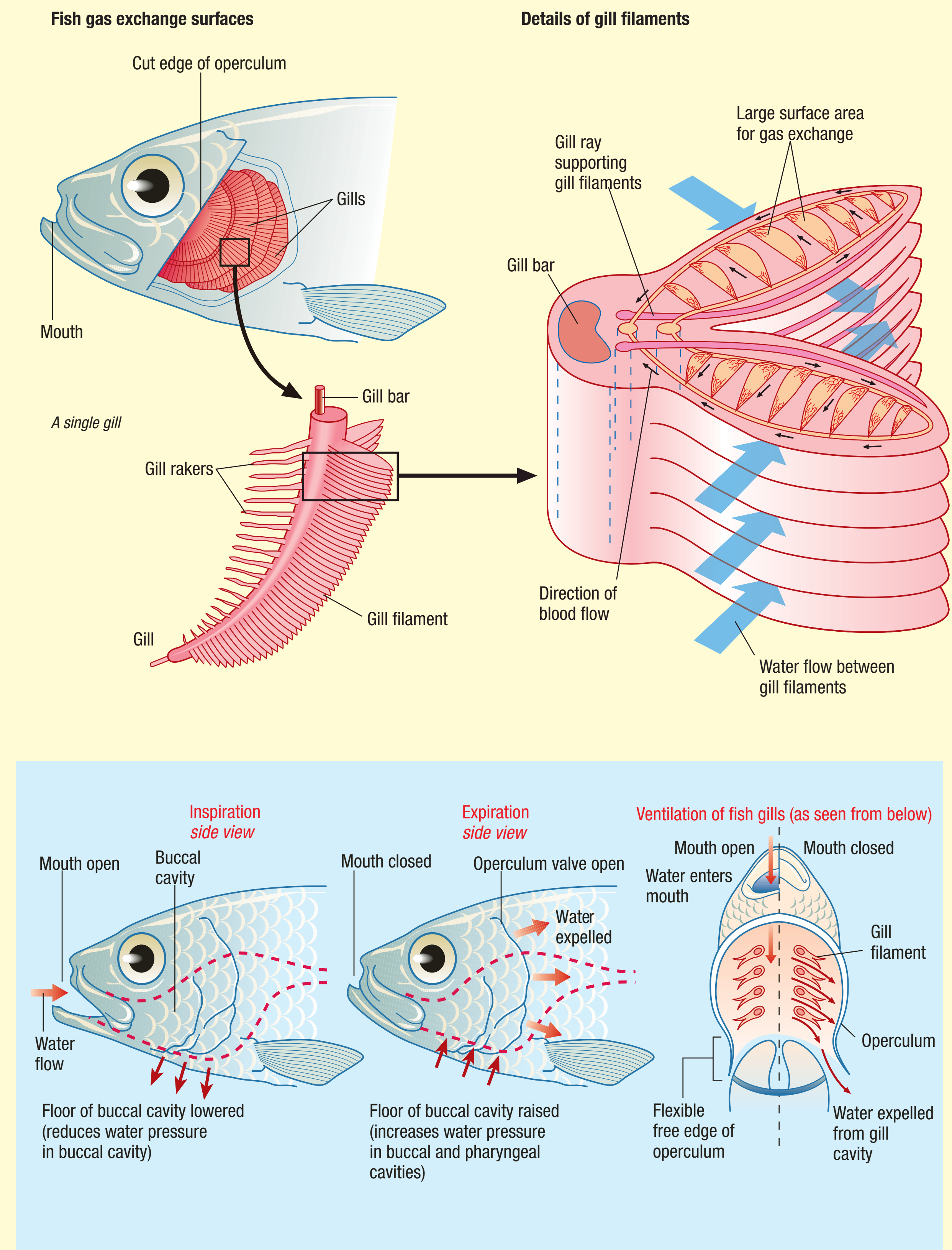


Figure 17.9 Gas exchange in bony fish

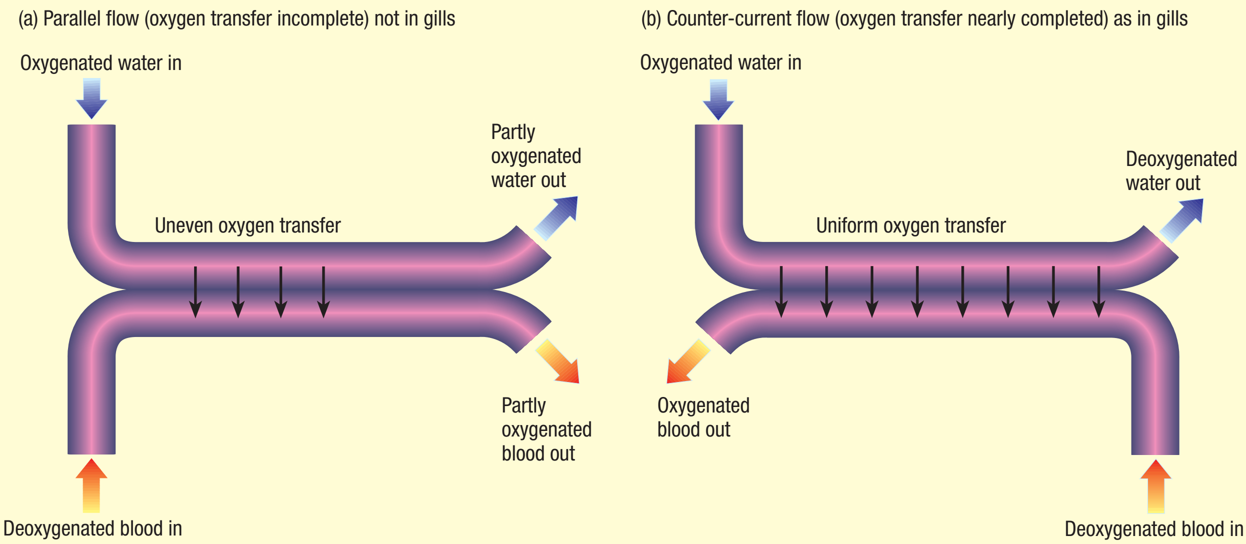


Figure 17.10 A comparison of gas exchange in (a) parallel flow and (b) counter-current flow systems

17.2.4 Gas exchange in the frog or toad

Amphibians, as the name suggests, generally spend part of their life in water and part on land. Some species live their entire lives in water. In water, gills are the primary surfaces for gas exchange.

The lung of a terrestrial amphibian, such as a frog or toad, is a relatively simple sac-like structure with very few internal subdivisions. As a consequence, the surface area available for gas exchange is limited (approximately one-fifteenth of that in humans) and is supplemented by exchange through the moist skin and buccal cavity.

Ventilation of the lungs involves a buccal pump similar to that utilised by a fish. The mouth is closed and the floor of the buccal cavity is lowered. This decreases air pressure, and thus draws air into the

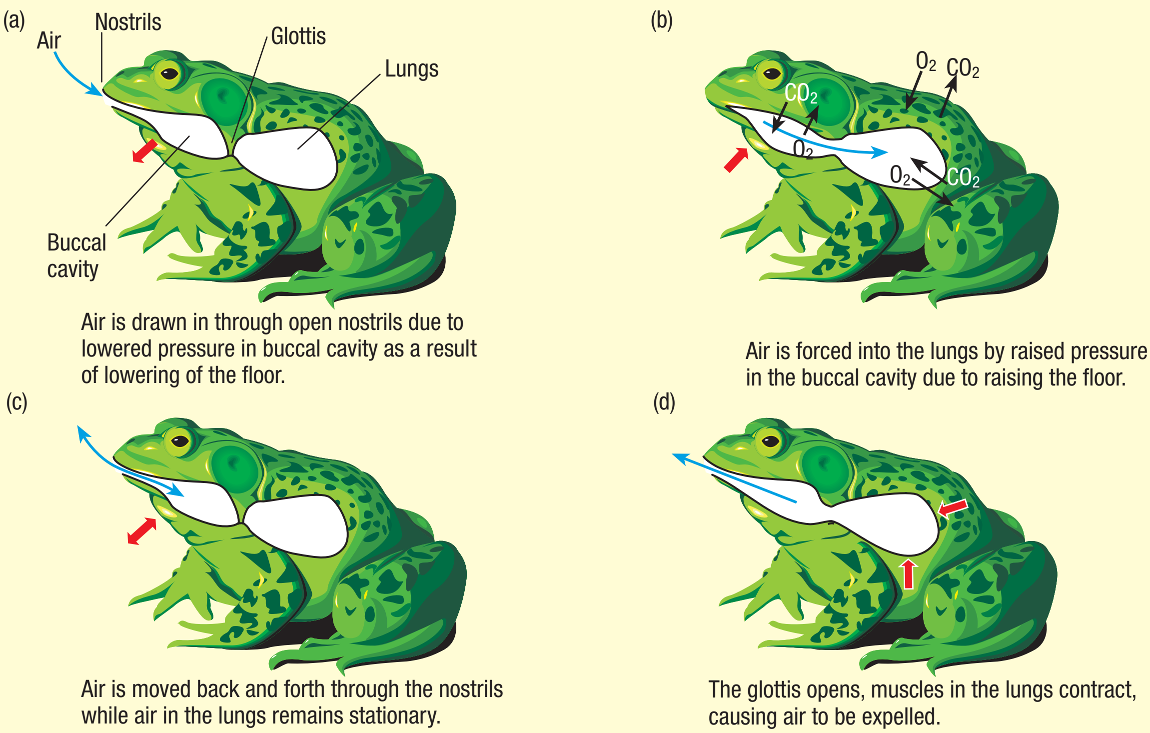


Figure 17.11 Ventilation in the frog

nostrils. The nostrils are then closed and the buccal cavity floor raised, driving the air through the open glottis into the lungs. The glottis then closes and the air is retained within the lungs for a period of time to allow for full extraction of oxygen. Since the lungs are only partially subdivided, there is a fairly high degree of air turbulence in them and this brings air into direct contact with the lung surfaces.

While the air is still held in the lungs, there is continued pumping of air in and out of the nostrils by the buccal pump. It is thought that, although this may involve an olfactory (smelling) function, it may be a significant behaviour associated with gas exchange across the moist surfaces of the buccal cavity itself.

The glottis finally opens and the lungs dispel the air by contractions of the smooth muscles in their walls, aided by contraction of the skeletal muscles in the thoracic wall. The buccal pump mechanism in these animals is important because there is no diaphragm, and changes in thoracic pressure therefore cannot have any significant effect.

Case study 17.1: Skin breathing in vertebrates

Amphibians rely to a large extent on gas exchange in the skin. This is associated with a relatively inefficient surface area in the lungs, and a circulatory system in which there is potential mixing of oxygenated and deoxygenated blood in the single ventricle. Although the use of the skin as a gas exchange surface is best documented for amphibians, it occurs to some extent in all vertebrate groups.

Skin breathing is limited by several factors, all of them associated with diffusion.

The diffusion gradient. This is usually greater for carbon dioxide than for oxygen in terrestrial environments, and thus there is a greater loss of carbon dioxide than uptake of oxygen across the skin in these animals.

The thickness of the diffusion barrier. Less skin breathing will be possible in animals with thick scales, shells and skin than in those with a thin integument.

The distance between the medium outside the skin and the cutaneous capillaries. The greater the distance of the capillaries from the environment the less will be the extent of skin breathing.

Gases must be in solution to diffuse across cell membranes. The more restricted the environment with respect to water availability, the greater will be the dehydration of the outer skin cells and the less gas exchange will occur.

Frogs have been found to be capable of supplying all their gas exchange needs via the skin during winter months when they are inactive. During the summer months, however, the animal is metabolically more active and the lungs play a significant role in affording a greater surface area for gas exchange.

Courtship behaviour imposes higher metabolic demands on male frogs, and thus a greater requirement for oxygen. In many species, male frogs have been found to increase the amount of skin by forming folds or 'hairs', particularly on the legs, during the breeding season. Ventilation of these protrusions is achieved by flapping them to increase the air circulation around them.

An increase in capillary supply to the skin occurs in situations where the environmental oxygen supply is lowered. Studies of the American bullfrog (*Rana catesbiana*) have shown that the skin supplies approximately 21 per cent of the animal's oxygen needs and removes about 80 per cent of the carbon dioxide it produces.

The success of skin breathing in amphibians is associated with a very thin and highly vascularised skin which is constantly kept moist. These structural features, however, limit the habitat and behaviour of the organism to situations which will not cause excessive drying out of the skin.

There are vertebrates with relatively thick and/or dry skin and scales that can carry on significant cutaneous gas exchange. Some lizards have cutaneous capillaries either underlying the skin between the scales or running under the scale hinge where the scale is thinnest. In some snakes the cutaneous capillaries even penetrate the scale itself. In many fish the dermal scales are covered with living tissue carrying cutaneous capillaries above the diffusion-resistant scales.

It has been found that all of the respiratory gases consumed and produced by human skin cells (approximately 1 per cent of the total), as well as some carbon dioxide from blood flowing into the skin, are exchanged directly between the skin and the air.

The permeability of the human skin is utilised medically when drugs are administered by applying patches to the skin; examples include motion sickness drugs and oestrogen patches. Many aerial sprays contain potentially deadly substances that can inadvertently be absorbed through the skin of humans and other mammals.

In most terrestrial vertebrates the greatest proportion of skin gas exchange is the loss of carbon dioxide to the environment. Thus bats may lose up to 12 per cent of their carbon dioxide through the membranous wings but take up only about 2 per cent of their oxygen requirements by this route.

SUMMARY

In insects gaseous exchange occurs in the tracheal system. Air reaches the tissues by diffusion, aided in some species by rhythmical movements of the thorax or abdomen.

In fish, gas exchange occurs between water and highly vascularised gills. Pressure differences are created in the buccal cavity, causing water to be pumped from the mouth, over the gill filaments, and out through the operculum. In this way ventilation is achieved. Water flows over the filaments in the opposite direction to the flow of blood in the capillaries, thus creating a counter-current and maximising extraction of oxygen from the water.

Movements of the buccal cavity are responsible for ventilation of the lungs of amphibians. The alveolar surface of these organisms is very small and inadequate for their respiratory needs. Gas exchange in the lungs is supplemented by gas exchange in the buccal cavity and skin.

Review questions

17.12 In table form, compare and contrast the gas exchange systems and methods of ventilation in an insect, a fish and a frog.

17.13 Although some degree of skin breathing is exhibited by all vertebrates, among terrestrial tetrapods it is most significant in the amphibia. Suggest reasons that may account for this.

17.3 Transport

Digested food material and respiratory gases must be transported from the external environment to animal cells. Metabolic wastes must be removed from the cells to the exterior. In the majority of animals, special systems have evolved for the transport of materials and for regulating the chemical contents of the body.

In small animals, transport often involves diffusion only. Larger animals need a transport system to move materials around the body. Table 17.3 summarises the ways in which transport is achieved in the major phyla of animals.

Table 17.3 Summary of the modes of transport in animals

Phylum	Major transport system
Porifera	Diffusion
Cnidaria	Diffusion
Platyhelminthes	Diffusion
Nematoda	Diffusion
Annelida	Closed blood (circulatory) system
Arthropoda	Open circulatory system
Mollusca	Open circulatory system
Echinodermata	Rudimentary circulatory system
Chordata	Closed circulatory system

17.3.1 Transport systems

During the course of evolution the role of transporting fluid has passed from the water that surrounds an animal to special complex tissues such as blood. This fluid both increases the transporting capacity and serves a protective function. The structure of the mammalian transport system is basically the same as that of humans and will be described in Chapter 18.

Several different types of circulatory mechanism can be recognised in animals:

Intracellular transport

Cytoplasmic streaming moves materials between inner and outer regions of the cell.

Movement of the external medium

In Porifera and Cnidaria, for example, special flagellated cells keep the surrounding water moving around their cell layers.

Fluid in the body cavity circulated by body movement

In nematodes, the fluid of the pseudocoelom acts as the transport medium and is propelled by contractions of the body wall musculature.

Movement of fluid in an open circulatory system

In arthropods and many molluscs, haemolymph is the transporting fluid. It is pumped by a dorsal muscular heart through vessels into tissue spaces, constituting the **haemocoel**, which obliterates the true coelom. In insects, special muscles attached to

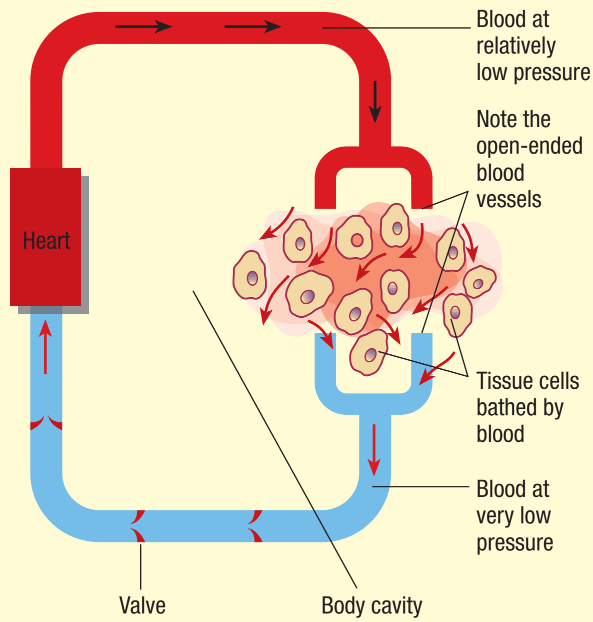


Figure 17.12 An open circulatory system

the heart contract to expand to the heart, creating a negative pressure which draws blood back into it from the haemocoel.

Movement of fluid in a closed circulatory system

In most annelids, cephalopod molluscs and vertebrates, the transporting fluid is blood. It is circulated in a system of closed tubes of varying diameter by one or more muscular hearts. The tissue fluid

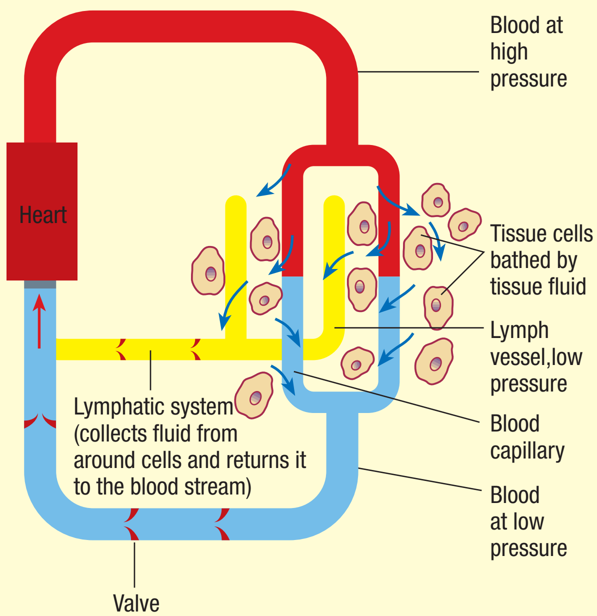


Figure 17.13 A closed circulatory system

bathing the cells, although derived from blood, is distinct from it. In vertebrates the tissue fluid is returned to the blood vascular system at the venous end of the capillaries or through another system of vessels, the lymphatic system. Blood pressure and circulation are generally higher in a closed system. This allows a higher metabolic rate and thus increased activity and size in animals that possess it. A closed system also lends itself to vasoconstriction, a property which allows more blood to flow to active areas of the body than to inactive parts.

Circulation in fish

Fish have a ventral heart with two muscular chambers, a single undivided **atrium** and a **ventricle**. A thin-walled **sinus venosus** collects venous blood. It acts as a pressure booster and contains **pacemaker** material that controls the rate at which the heart beats. The sinus venosus passes blood to the atrium and thence to the muscular ventricle.

The muscular **bulbus arteriosus**, found at the arterial opening of the ventricle, serves to even out arterial pressure waves. Thus the heart consists of 'chambers' in series. Blood follows a straight passage which is interrupted only by the heart valves.

The blood is pumped under pressure into a ventral aorta which branches into **afferent** (= carrying towards) branchial vessels to the gills. Capillary beds in the gills ensure oxygenation of the blood but also result in a decrease in blood pressure. **Efferent** (= carrying away from) branchial arteries re-form from these capillary beds. They unite to form the dorsal aorta which supplies the head, the body musculature and organs with oxygenated blood. In contrast to the mammalian system, blood returning from the tail fin and posterior trunk may pass directly to the kidney for removal of wastes in the renal portal vein. Thus the fish has a single circulation with blood passing from the heart to the gills to the body and back to the heart.

Circulation in the frog and toad

As in the fish, the frog's heart receives venous blood from the body in the sinus venosus. The atria in the frog's heart are, however, divided into left and right sides. The right atrium receives blood from the general body (systemic) circulation, whereas the left receives blood from the lungs (pulmonary circulation).

Blood from the atria passes into a single ventricle. Potentially, therefore, oxygenated and deoxygenated blood mix within the ventricle. This mixing is not complete because the two types of blood have different viscosities which keep them partially separated. It has also been found that

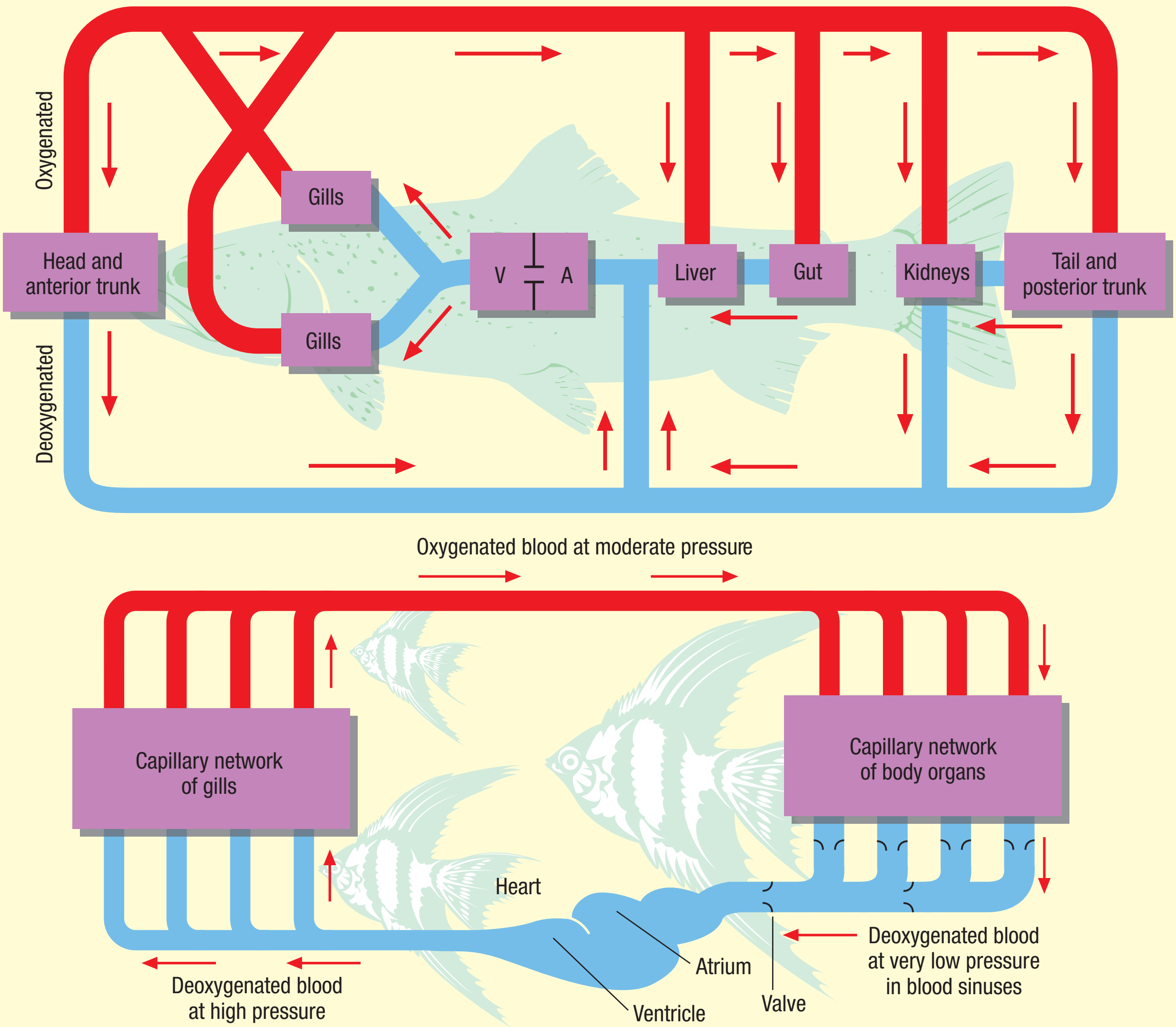


Figure 17.14 Pattern of circulation in the fish

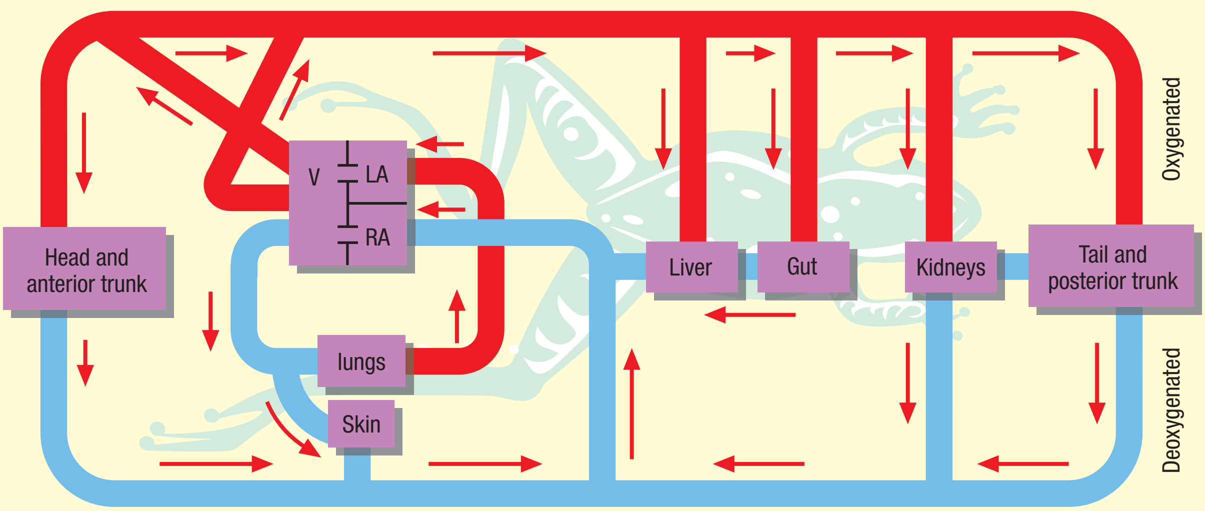


Figure 17.15 Pattern of circulation in the adult frog

contraction of the ventricle results in blood from the right atrium being pumped out first and directed towards the pulmonary arteries and thus lungs. Blood from the left atrium follows and is directed towards the aorta and thus body tissues. This is due to the action of a spiral valve in the ventricle.

Some mixing of blood does occur. The amphibian lung is not particularly efficient. It has a relatively low ratio of surface area to volume, and thus a small area for gas exchange. Oxygenation of the blood is supplemented by an array of capillary beds (plexi) in the skin and buccal cavity. Venous blood returning to the sinus venosus, therefore, is partially oxygenated from the skin circulation.

The frog heart, like that of the fish, has a bulbus arteriosus between the aorta and the ventricle which serves to produce an even arterial blood pressure. A renal portal vein directs blood to the kidneys from the posterior part of the body.

SUMMARY

A variety of materials (e.g. digested food, waste products) need to be transported in animals. This may involve movement within cells or between cells and tissues. Simple animals do not have specialised transport systems but depend on diffusion for this movement of materials.

The circulation of most animals with tubular blood vessels is described as a closed circulation. This contrasts with the open circulation of insects where blood flows through large cavities and sinuses (haemocoel), with the heart acting to keep the fluid moving.

Fish have a single circulation with a two-chambered heart.

Amphibia have a double circulation but there is a single ventricle (three-chambered heart) and thus there is some mixing of oxygenated and deoxygenated blood in the heart. Oxygenation of the blood is supplemented from capillary beds in the skin and buccal cavity.

Review questions

17.14 Define the following terms:
- (a) single circulation
- (b) open circulation
- (c) haemocoel.

17.15 What is the function of the sinus venosus?

17.16 The pressure in the arteries taking oxygenated blood to the body of the fish is low. Explain.

17.17 What factor, other than lung capacity, contributes to buccal and skin breathing in amphibia?

17.4 Regulation of body fluids

The concentrations of chemicals dissolved and suspended in the cytoplasm, intercellular fluid and circulating fluid must be maintained within a particular range. This is achieved by **osmoregulation** and the **excretion** of metabolic wastes. In the majority of animals, an excretory system is involved in both processes.

Much metabolic waste material is removed from the animal through surfaces in contact with the environment. Carbon dioxide diffuses from the blood to the gas exchange and skin surfaces. Salts may be removed through the skin; for example, by sweat in mammals. Salts are also secreted into the large intestine.

Animals are motile heterotrophs. They expend energy, in addition to that involved in general life functions, in locating a food source and processing the food into chemicals required by the body. The proportion of protein in the body of an animal is therefore very high. Proteins provide structural elements such as the muscles that bring about locomotion. As a result of their high metabolic demands, a large number of enzymes are required, and these too are proteins. Proteins, therefore, are significant nutrients for animals. Many omnivores and carnivores cannot synthesise all of the amino acids they require for the production of specific proteins, and these essential amino acids must be obtained from another animal source.

Amino acids derived from cell replacements and those taken in as surplus to the body's requirements cannot be stored, and are broken down by the liver in vertebrates. In this process the nitrogen-containing amino group is removed. The products either enter the respiratory pathway or are converted to a storage material and the nitrogenous compound ammonia.

Ammonia is highly toxic to animal cells and must either be rapidly removed from the body or converted to a less toxic compound such as urea or uric acid.

17.4.1 Excretion

Animals are classified according to which of the three nitrogenous compounds—ammonia, urea or uric acid—is most prolific in their excreta.

Ammonotelic animals (which include marine and freshwater invertebrates, bony fish, and larval and permanently aquatic amphibians) excrete mainly ammonia. Ammonia is readily soluble and diffuses rapidly out through any permeable surface in contact with water—for example, the gills of bony fish. Excretion of ammonia, because of its high toxicity, occurs only in animals living in an environment where there is no water stress.

Urea is less toxic than ammonia and can be retained in the body for limited periods before removal. Being more soluble than ammonia, it requires less water for its elimination, but energy is required to convert the ammonia to urea. **Ureotelic** animals include mammals and most adult amphibians.

Terrestrial insects, molluscs, birds and most reptiles excrete uric acid. They are **uricotelic**. Like the formation of urea, production of uric acid is a complex, energy-requiring process which is an adaptation to water conservation. Uric acid is virtually insoluble in water and is non-toxic. Birds excrete a thick paste of uric acid crystals (the white

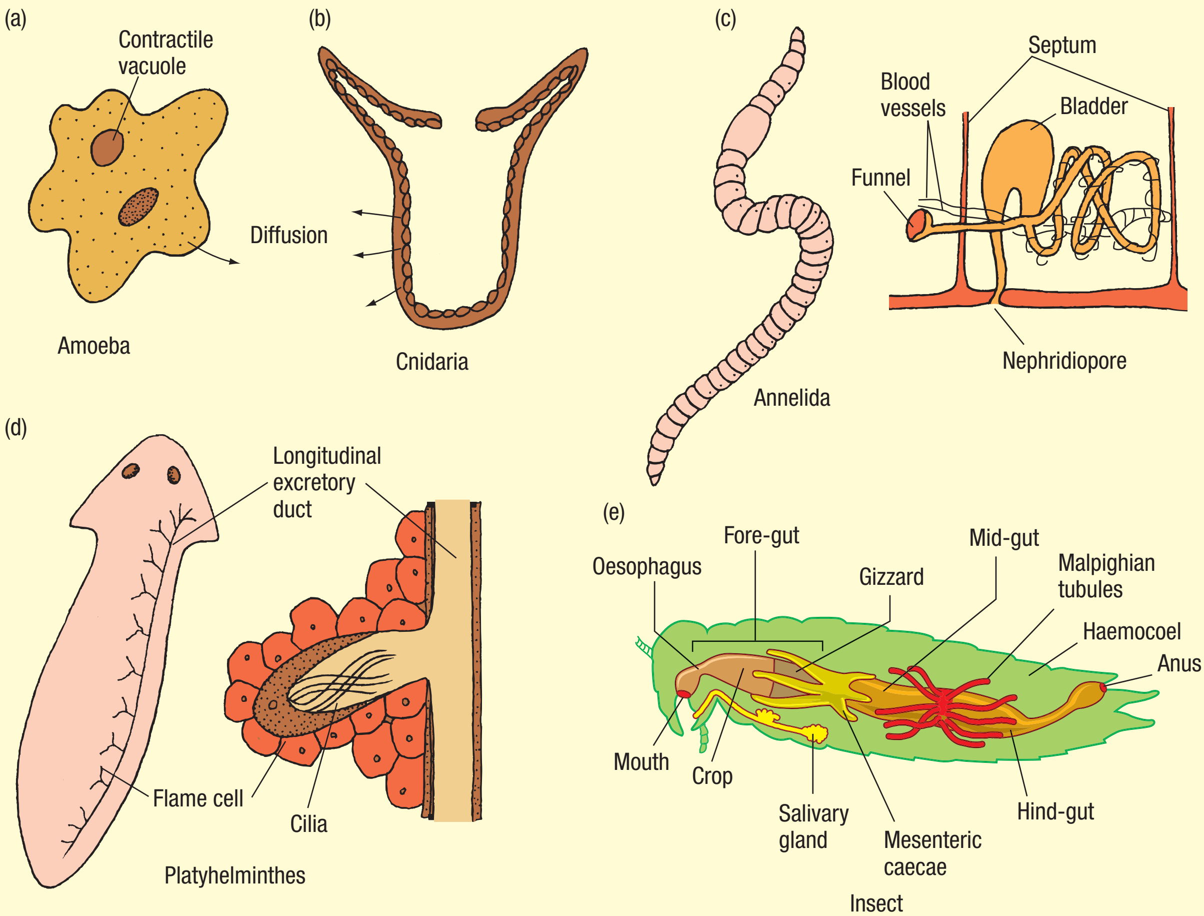


Figure 17.16 Examples of excretory systems in animals and the animal-like protist, *Amoeba*

Table 17.4 Excretory products

Excretory product	Where made	How made	Where excreted in animals
Carbon dioxide	all living cells	respiration	gas exchange surfaces
Oxygen	green plant cells	photosynthesis	
Nitrogenous waste	'liver' in animals	breakdown of amino acids	excretory organs
Bile pigments	liver in mammals	from red blood cell destruction	in the bile to the alimentary canal
Tannins	plant cells	general reactions	
Water	cells	respiration and condensation	evaporation; excretory organs

part of the dropping). Insects conserve even more water and excrete solid pellets of uric acid. It has been suggested that the evolution of uricotelism was a prerequisite for the development of the shelled egg of birds and reptiles, since it allows long-term storage of a non-toxic excretory product.

Most animals possess excretory organs that eliminate 'urine': for example, nephridia in annelids and flatworms, antennary glands in crustacea, Malpighian tubules in insects, and kidneys in molluscs and vertebrates. In addition to their role in nitrogenous excretion, these organs play a significant part in osmotic and ionic regulation.

17.4.2 Osmoregulation

Water can move into and out of an animal in response to osmotic gradients between its internal and external environments. Similarly, salts (solutes) can diffuse into and out of aquatic animals in response to diffusion gradients. They can be lost from terrestrial species by way of the kidneys, intestine and skin. Both water and salts can be ingested as part of the diet of both aquatic and terrestrial animals.

These passive movements of water or salts into or out of the body cannot be regulated physiologically, or are subject to minimal regulation. For example, the air leaving the lungs is always saturated with water. If the absolute humidity of the atmosphere is high, water loss from the lungs will not be great. At a very low atmospheric humidity, water loss can be considerable. Similarly, water and salt loss through the skin of terrestrial species is unavoidable, especially in those animals which control body temperature through sweating. And there will always be some faecal water loss.

The kidney and its invertebrate precursors are the only organs that have any real control over salt and water balance. From the point of view of osmoregulation, animals fall into two groups: those that cannot regulate their osmotic pressure at all, and those that can do so to some degree. The former group are all marine.

Marine organisms

Many marine animals, especially invertebrates, have body fluids that are isotonic with sea water. As a consequence, they have no need to osmoregulate. However, they may need to engage in specific ion regulation if there are differences between the internal and external environments.

Some marine species live in a more inhospitable estuarine environment. In these habitats the concentration of the external medium may change dramatically from very saline to fresh within short periods of time. Many of these animals have some powers of osmoregulation. They tend, however, to allow their body fluids to equilibrate with the external environment as far as is safely possible before initiating regulatory mechanisms. This reduces the amount of energy that needs to be expended in water and salt control.

The shore crab, *Carcinus*, eliminates water through a pair of glands found at the base of the antennae. These sac-like glands take up nitrogenous waste and excess water from the surrounding blood and excrete these to the exterior. There is no control of salt excretion by these glands. As a result, salt uptake by the gills is very important in maintaining ion concentrations.

Other species, known as **osmoconformers,** allow the concentration of their body fluids to fluctuate with external salinity; for example, the spider crab *Maia* and the lugworm *Arenicola*. The true brackish dwellers have well-developed osmoregulatory powers and can maintain a relatively constant internal environment over a wide range of external salinities. They are termed **osmoregulators**.

Marine bony fish are believed to have evolved in fresh water and then returned to the sea. These animals have a body fluid which is hypotonic to the environment and thus there is a tendency for water to be extracted from the tissues, leading to dehydration. Three processes are involved in maintaining the correct water and ion concentrations:

- An impermeable coating of scales restricts major water loss to areas such as the gut and the gills.
- A very low kidney filtration rate, which results in scant production of urine containing highly concentrated non-toxic nitrogenous waste.
- Drinking sea water replaces body water, and the increased salts that are taken up are actively extruded by special glands in the gills.

Freshwater organisms

Animals in freshwater (hypotonic) environments are faced with continual flooding and leaching of their salts. An impermeable body covering, such as fish scales or the arthropod cuticle, restricts water intake to permeable areas such as the gills and gut. Excretory organs, such as the antennal glands of crustacea and vertebrate kidney, eliminate excess water and usually reabsorb ions which would otherwise pass out with the water. Replacement of leached ions is usually accomplished by uptake by the gills and/or gut.

The freshwater crayfish is able to produce a hypotonic urine. Unlike *Carcinus,* its antennal glands are able to reabsorb salts. Freshwater bony

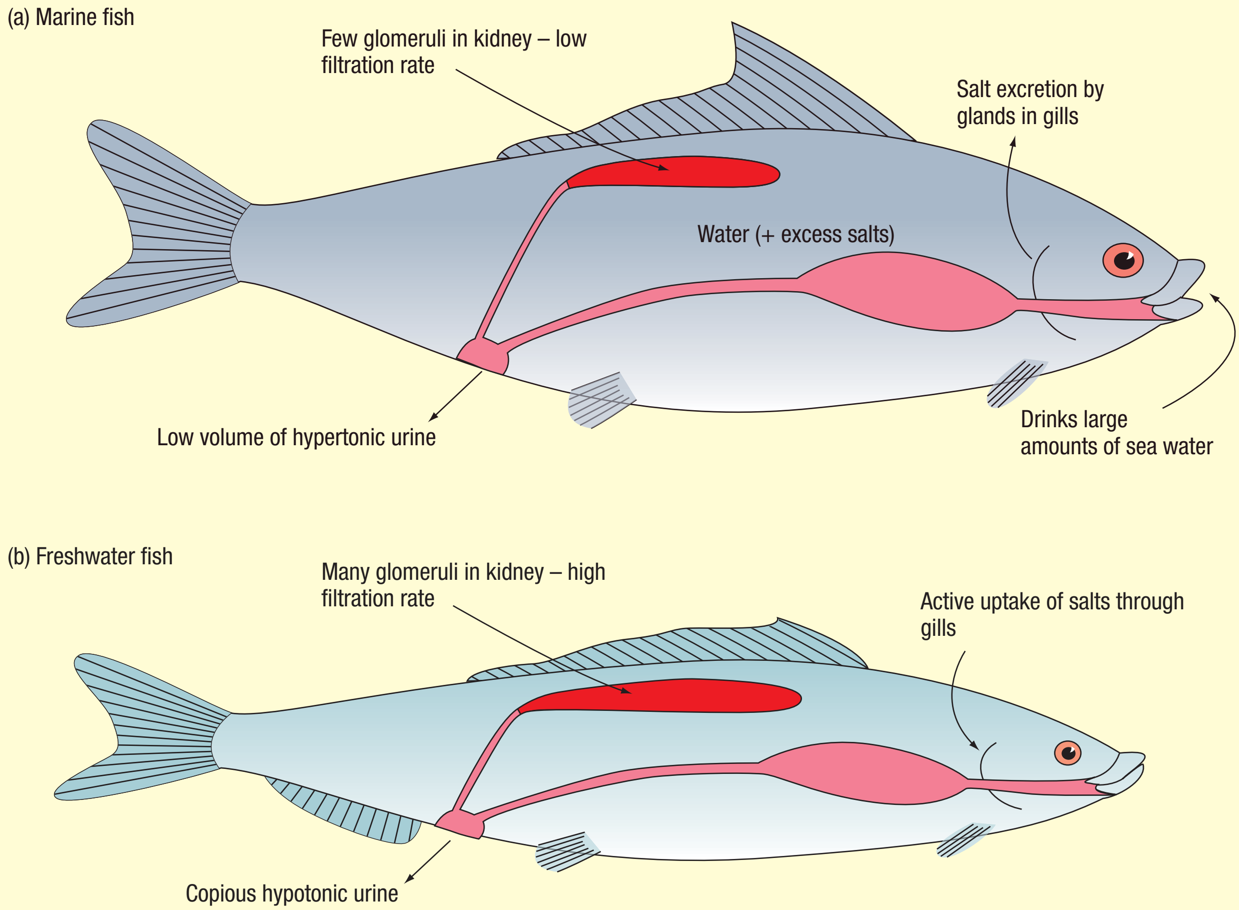


Figure 17.17 Comparison of the osmotic controls exhibited by (a) marine and (b) freshwater bony fish

fish, unlike their marine counterparts, have a very high kidney filtration rate and thus a copious volume of dilute urine is produced. Due to the release of this volume of water, toxic ammonia can be safely washed from the body. No further energy need be expended in converting it to a less toxic form.

Terrestrial organisms

Terrestrial animals must take in water to replace that which is continually lost in the processes of eliminating wastes, and by evaporation from the respiratory tract and body surface. Adaptations that reduce water loss include the following:

Waterproof integument

Examples include the keratinous scales of reptiles, the cornified, dead layers of epithelium in mammals and the waxy cuticle of insects.

Reduction of kidney filtration rate

This is accompanied by reabsorption of water from urine in vertebrates, or by the rectal gland of insects.

Modification of behaviour

Behaviour modifications include burrowing during the heat of day, and going into aestivation during drought periods.

Using metabolic water produced during cell respiration

The yield of metabolic water is greater from fat than from carbohydrates. Many desert animals therefore utilise fat to a large extent. This reduces evaporative loss of water from surfaces, and produces highly concentrated urine and dry faeces.

Tissues tolerant to water loss

In the camel, for example, fat storage in the hump allows a high level of production of metabolic water, most of which is lost by sweating and expiration. The capacity of the camel to survive long periods without water (up to 2 months) is related to the ability of its tissues to withstand higher levels of dehydration than can other animals—10 per cent more than humans, for example.

Table 17.5 Some water conservation mechanisms shown by terrestrial animals

Organisms	Water conservation mechanisms
Insects	Impermeable cuticle Trachea and spiracles Malpighian tubules Uric acid as nitrogenous waste Shelled egg
Reptiles	Scales and keratinised skin Lungs Kidney Uric acid as nitrogenous waste Cloacal reabsorption Shelled egg Behavioural responses to heat Physiological tolerance to dehydration
Birds	Feathers Lungs Kidney Uric acid as nitrogenous waste Shelled egg Cloacal reabsorption
Mammals	Keratinised skin and hair Lungs Kidney Hypertonic urine containing urea Internal development of young Behavioural response to heat Restricted ecological range Physiological tolerance to dehydration

SUMMARY

Animals cannot store amino acids that are excess to their normal requirements, and so they are broken down. The nitrogen-containing amino group is converted to a chemical which may enter the respiratory pathway or be changed to a storage material plus ammonia. Ammonia is highly toxic to animal cells and must either be rapidly removed in a very dilute form or converted to the less toxic urea or uric acid.

Many marine organisms, especially invertebrates, have body fluids isotonic to sea water. These organisms have no need for osmoregulation but may need specific ion regulation.

Estuarine organisms live in an environment which is osmotically variable. Many species tend to allow body fluids to equilibrate as much as possible before bringing in energy-requiring osmoregulation.

Marine bony fish (thought to be secondarily marine, i.e. they evolved in fresh water) have body fluid that is hypotonic to their environment and thus have a tendency for osmotic water loss.

In contrast, freshwater fish must rid their bodies of excess water.

Dehydration is a problem for terrestrial animals.

In each of these situations, the organisms show specific adaptations to maintain correct water and salt balance.

Review questions

17.18 Distinguish between osmoregulation and excretion.

17.19 Explain why animals produce a high level of nitrogenous wastes.

17.20 Distinguish between ammonotelic, urotelic and uricotelic animals. Where would you find each?

17.21 Many marine organisms are said to be isotonic to their environment. What does this mean?

17.22 Marine bony fish must conserve water. Explain why. What methods do they use to conserve water?

17.23 Giving examples, distinguish between an osmoregulator and an osmoconformer.

17.24 Complete the following table:

Organisms	Main nitrogenous waste substance	Main site of nitrogenous excretion
Freshwater Protozoa		
Adult insects		
Freshwater fish		
Mammals		

17.5 Reproduction

With rare exceptions, higher animals exist as diploid multicellular organisms through most of their life cycle and reproduce sexually. At the time of reproduction, specialised reproductive cells undergo meiosis to produce haploid gametes which, when their nuclei unite in fertilisation, form the diploid zygote. The zygote then divides mitotically to produce the new diploid multicellular individual. The gametes are therefore the only haploid stage in the animal life cycle.

Although asexual reproduction may occur in the lower animal phyla where body organisation is relatively simple, most animals reproduce only

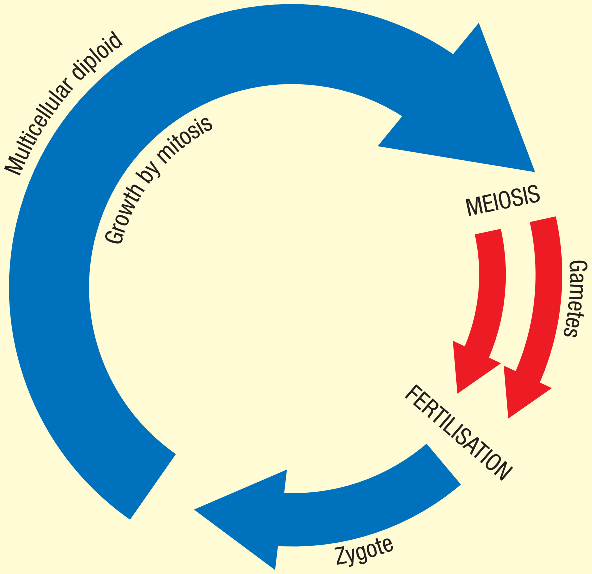


Figure 17.18 Life cycle of animals

sexually. In those animals which utilise both sexual and asexual reproduction, there is no alternation of generations as in plants. Members of the phylum Cnidaria are more plant-like in this respect, although the asexual polyp and the sexual medusa are both diploid.

17.5.1 Sexual reproduction

Almost all sexual reproduction in animals involves separate males and females which have gonads specialised for the production of gametes. The female gametes—eggs or ova—are formed in ovaries. The male gametes—spermatozoa (singular spermatozoon)—are produced in testes.

A few kinds of animals (e.g. flatworms, earthworms and snails) are hermaphrodites, having both ovaries and testes in the same individual. These animals, however, generally cross-fertilise with another animal of the same species. Self-fertilisation does occur, however, in some internal parasites such as the tapeworm.

Successful reproduction depends upon the fertilisation of the egg and development of the zygote into a mature organism. Fertilisation may be either internal or external. For both types of fertilisation, four conditions must be met:

- proper timing of release of gametes so that both sperm and eggs are present at about the same time
- protection of the gametes
- a pathway for sperm to reach the eggs
- a liquid medium in which sperm can swim to the eggs.

External fertilisation

External fertilisation takes place outside the body. The gametes of both sexes are liberated into the environment. Since the gametes are very susceptible to dehydration, external fertilisation is practical only in aquatic species or those, such as the amphibia, that return to the water to reproduce.

Although mechanisms exist to maximise the effectiveness of external fertilisation, there are usually great losses of gametes either to predators or due to physical factors such as temperature and currents. In addition, there is little protection of the fertilised eggs and their developing embryos, and many are eaten by predators.

Some fish have developed quite complex behaviours which minimise losses. Some species build nests to house the developing eggs. The male mouth-breeding fish actually collects the fertilised eggs in his mouth, keeping them there until they have hatched. More usually the fertilised eggs are left to face the elements alone. As a consequence, animals utilising external fertilisation need to produce large numbers of gametes in order to ensure continuation of the species.

Internal fertilisation

In most terrestrial animals **internal fertilisation** occurs. Sperm are introduced into the female and fertilisation occurs within the female reproductive tract. This usually involves the use of some kind of **intromittent organ** such as a **penis.** In some animals a package of sperm called a **spermatophore** is released by the male. This may be:

- transferred directly from the male to the female genital opening (e.g. long-horned grasshopper)
- taken up by a male appendage which then inserts the package into the female genital opening (e.g. redback spider).

Internal fertilisation increases the chances of the sperm meeting an egg and diminishes the need for an external watery medium for transfer. Sperm still need a fluid environment for transport to the egg cell, but the volume necessary is relatively small and is supplied by internal accessory reproductive glands. Internal fertilisation also provides an environment in which protective egg casings can be produced after the egg has been penetrated by the sperm. This prevents desiccation of the developing embryo after leaving the female's body.

The timing of reproduction

The timing of the release of gametes is important regardless of the method of fertilisation. In most animals, gamete production and mating are restricted to specific times directly associated with environmental conditions. This ensures that there will be suitable nutrients and favourable conditions for the developing young. Grunion, for example, are small fish which spawn in the shallow waters on Californian beaches at the times of new and full moon, when the height of the water at high tide is greatest.

Many animals have a distinct seasonal reproductive season and thus do not produce gametes at other times. Once a year, for a few days only in the third lunar quarter in October or November, the palolo worms in Fiji and Samoa spawn. Their posterior ends break off and rise to the surface of the sea, where they release gametes.

Corals on the Great Barrier Reef have an annual mass spawning. It occurs during spring or early summer, a few nights after a full moon. The neap tides at this time produce little tidal movment and so the seas are calm and do not move far from the reef. Packets of eggs and sperm are released and rise to the surface waters, where fertilisation takes place. The fertilised eggs develop into free-swimming larvae within a day. A few days later, the larvae descend and find a suitable surface on which to complete development into a new coral colony.

Male frogs migrate to a suitable aquatic environment, when conditions are suitable, and call to the females. Each species has its own specific water requirements. Thus the dwarf tree frog (*Litoria fallax*) breeds in swamps, streams and ponds, whereas Kefferstein's toadlet (*Pseudophryne coriacea*) can breed in water-filled depressions such as those made by cattle hoofprints. The male of each species has a very distinctive mating call. The male cane toad (*Bufo marinus*), for example, sounds like a stick being rattled inside a tin can. Females respond to the male's call and when both are in the water the male clasps her around the abdomen. This physical contact, called amplexus, stimulates both the sexes to release their gametes into the water.

Figure 17.19 The male dwarf tree frog (*Litoria fallax*) calling

In the higher animals, elaborate courtship behaviours may signal reproductive activity. Courtship, particularly in birds, consists of strikingly obvious movements and is species-specific. Courtship is a mutual behaviour, demanding the communication of information from one animal to the other and directing the partner's responses. The essential information to be communicated in courtship is the gender and species of the performer and his or her receptiveness. In general, readiness to mate or respond to courtship signals depends upon internal factors; in particular, hormone levels.

Figure 17.20 The courtship 'dance' of carpet snakes

In some courtship, such as the display of the birds of paradise, or the Scottish grouse, the males display avidly to the females. Many male grouse stake out circular areas for a common mating ground or lek. The male struts around his 'territory' with throat sac puffed up, making a 'whooping' sound. Females are attracted to the lek. The male with the best display is selected by the most females as a mating partner.

In other species of both birds and mammals, the courtship is much longer and leads to the formation of a permanent pair-bond. In this situation both members of the pair are involved in nest building and care of the young, with consequently greater survival rates of offspring.

In female mammals such as dogs and cats, there is a definite **oestrous cycle**. This involves a series of physical and chemical changes leading to the production of mature eggs. When 'on heat' the female undergoes physical and behavioural changes which indicate to the male her readiness to mate. This fertile period is called **oestrus**. Associated with these changes is the production of pheromones (hormones which have an external influence on other members of the species) which are strong attractants to the males, and which may exert their influence over a large distance. Species with a distinct oestrous cycle will, therefore, mate only when mature eggs are present.

The length of time between each oestrus varies according to the species. Deer undergo a single period of sexual activity during the year. Dogs have a 6-month cycle. Horses have a 28-day cycle; and cats, particularly in warm climates, come into oestrus every 21 days.

The primates are an exception. Mating serves an important mate bonding function, and is not restricted to propagation of the species.

SUMMARY

Most animals reproduce only sexually. The structure of the ova and spermatozoa are related to their functions: the spermatozoa are motile vehicles for the male's genetic material; the egg receives this material and provides nutrition for the prospective zygote. In the process of fertilisation the spermatozoon penetrates the egg membrane. Its haploid nucleus unites with the haploid nucleus of the egg to form a diploid zygote.

For many aquatic animals, fertilisation is external. Most terrestrial animals have internal fertilisation.

All sexual reproduction in animals requires:

- properly timed release of gametes
- protection of gametes
- a pathway for sperm to reach the eggs
- a liquid medium for transport of sperm to eggs.

In the primates, which include humans, mating is associated with maintenance of the pair bond as well as reproduction. It can occur at any time. Other mammals have a specific breeding season, the timing of which is controlled by a combination of environmental and hormonal factors.

Review questions

17.25 What four factors are necessary for fertilisation to occur in animals?

17.26 Distinguish between external and internal fertilisation. Under what conditions are each likely to be found in animals?

17.27 Define the term 'hermaphrodite' and name one animal as an example.

17.28 What is/are the function(s) of courtship behaviour? Using library or internet resources for reference, describe the courtship behaviour of a specified animal.

17.5.2 Asexual reproduction

Parthenogenesis (virgin birth) is the development of a new individual from an unfertilised egg. The most common form of this results in the production of daughters only, because the females:

- circumvent meiosis altogether; or
- modify meiosis by an additional doubling of the chromosomes at interphase; or
- modify meiosis by fusion of the products after first or second meiotic division; or
- double their chromosomes early in the development of the embryo

with the result that the offspring have a full complement of chromosomes and are genetic clones.

For parthenogenesis to occur in many animals, the egg must be able to initiate development without the trigger usually provided by sperm penetration. These conditions have been met, in the vertebrates, by a few species of reptiles but no known birds or mammals. Several species of amphibians and fish have the appropriately changed meiosis, but still require interaction with sperm to initiate development.

Parthenogenesis in insects is more common. Many of these organisms may alternate between normal sexual reproduction and parthenogenesis. The individuals formed by parthenogenesis generally have haploid body cells. Thus in bees and wasps, fertilised eggs develop into females and unfertilised eggs develop into males. In insects, the sex of the individual depends upon the number of 'sex' chromosomes.

In earthworms and aphids, however, parthenogenesis occurs in specialised diploid eggs. In the summer months wingless female aphids produce eggs by mitosis and these develop into further wingless females. This is a rapid and efficient means of increasing numbers without necessitating the presence of males.

The more usual methods of asexual reproduction in animals are **budding** and **fragmentation**. These forms of asexual reproduction are, however, restricted to animals which do not have complex organ systems.

During the process of budding, a cell or group of cells in the parent's body produces a miniature version of the parent. When the bud is first formed it is attached to the parent. Once it is detached, it becomes a self-supporting individual. Budding is common in *Hydra* and certain flatworm species. (See Figure 1.8 (a) on page 10.)

In organisms that reproduce by fragmentation, small pieces of the organism's body grow into a new organism. Thus sponges, battered and broken by

Figure 17.21 Regeneration of a starfish from a single arm (the large arm in the photograph)

wave motion, can grow into several new individuals. The ability to reproduce by fragmentation depends on the organism's powers of regeneration, an ability restricted to lower phyla.

SUMMARY

Asexual reproduction occurs in some animals. This may include:

- parthenogenesis—development from an unfertilised egg
- budding
- fragmentation.

Review question

17.29 Discuss instances of asexual reproduction in animals.

17.30 What determines an organism's ability to reproduce by fragmentation?

17.6 Growth and development

Growth can be defined as the increase in dry mass of protoplasm. This occurs as cells increase in number and with the increase in size of individual cells due to maturation. In both cases energy and nutrients are required to achieve growth. **Development** refers to the changes that cells and organisms go through in the maturation process. This is initiated by cell **differentiation**—specialisation for a specific function (**histogenesis**)—that leads to tissues, organs and systems during the formation of a new individual (**morphogenesis**). Later development occurs as the animal reaches adult form.

17.6.1 Measurement of growth

Many different parameters can be used to measure growth. In Chapter 7 the growth of populations was discussed. It was found that when data for population growth of density-dependent organisms were graphed, a sigmoid or S-shaped curve displaying four distinct phases was typical. No matter what parameter is used to measure growth of individual organisms (e.g. dry mass, height or increase in volume), similar sigmoid curves result.

The initial lag phase is a brief period in which little growth occurs. This is followed by a very rapid increase in growth, the log phase. After a while the increase slows down, and the point at which this occurs is referred to as the inflexion point. Some environmental factor (internal or external, or a combination of both) becomes limiting during this deceleration phase. The final plateau phase marks the period when overall growth has ceased and the parameter being measured remains constant.

The precise nature of the curve may vary according to the parameter being measured, the species under investigation, and the environmental conditions. In some cases the plateau phase does not

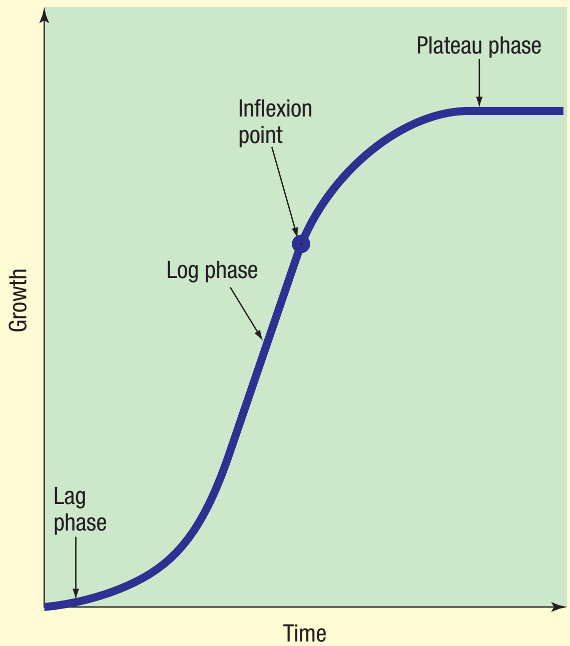


Figure 17.22 Typical sigmoid growth curve showing the four phases

actually occur and the organism continues to grow slightly until it dies. This is the situation for many invertebrates, fish and reptiles. Positive growth is maintained.

In certain cnidarians, there is a definite and continuous plateau phase after initial growth. Many mammals, including humans, display negative growth after a period of stability in the plateau phase: there is a real decrease in the parameter being measured. This is a sign of physical senescence associated with increasing age.

17.6.2 Patterns of growth

Different patterns of growth are exhibited in different types of organisms. Growth may be **limited,** in that the organism may have a maximum size it can attain; examples include annual plants, insects, birds and mammals. Alternatively, growth may be **unlimited**, continuing until the death of the organism: for example, seaweeds, woody plants, fish and reptiles. In those situations where change of size is not accompanied by a change in shape or external form, growth is said to be **isometric**. **Allometric** growth, on the other hand, produces a change in shape with increased size (see Figure 1.6 on page 9).

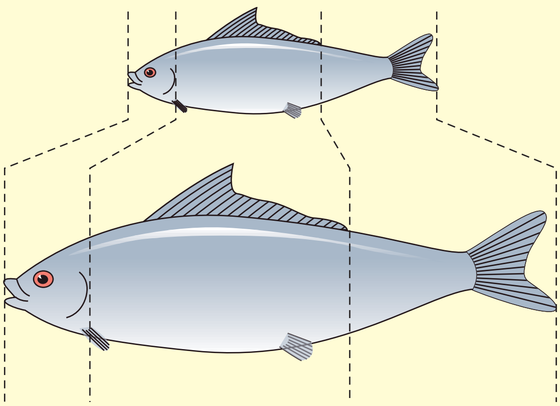


Figure 17.23 Isometric development in a fish

Many arthropods, because of their inflexible exoskeleton, undergo a series of growth spurts interspersed with moults. After the old exoskeleton is cast off, the animal engorges itself with water. As the new skeleton hardens, it makes room for new growth. A period of growth then follows until the skeleton has been 'filled', after which the next moult will occur. This process goes on throughout the life of crustaceans and some insects. In other insects, such as beetles, moulting occurs only during the larval stages.

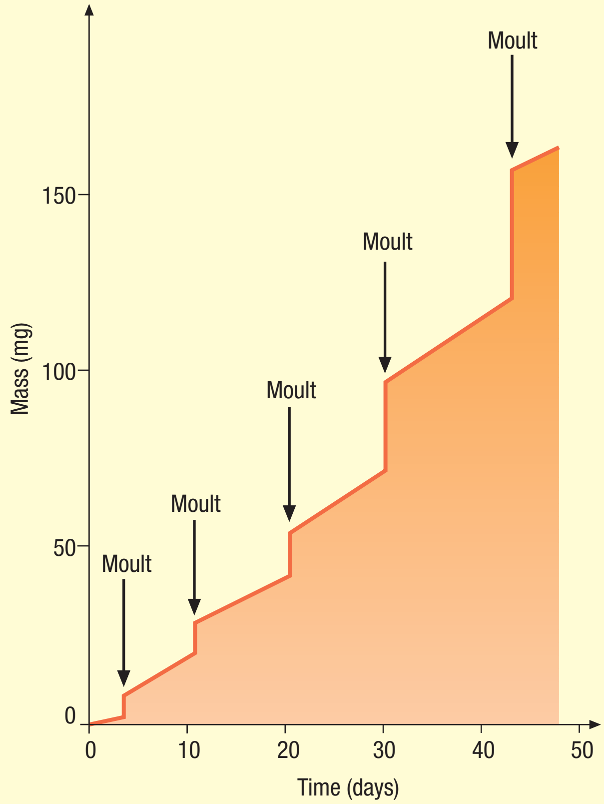


Figure 17.24 Arthropod growth curve

17.6.3 Control of growth and development

The process of growth and development is ultimately controlled by the information contained in the organism's DNA, but it is also affected by interactions between the internal and external environment. Regardless of the genetic potential of an organism to reach a particular size, this cannot be achieved if environmental conditions are not met. These conditions may include external factors such as food, light, heat and water, as well as the internal availability of chemicals such as hormones and special proteins which influence gene expression.

The type and amount of nutrients available are significant determinants for correct growth and development. The specific nutrient requirements vary from organism to organism. All animals require water and oxygen as well as the following broad groups:

- carbohydrates
- proteins
- fats
- vitamins and minerals
- nucleic acids.

A diet containing all of these things in the correct amounts and proportions is called a **balanced diet.**

Carbohydrates, fats and proteins form the bulk of an animal's diet. Vitamins and minerals are an important, if small, component. Vitamins are organic compounds which act as coenzymes or parts of coenzymes. Organisms can synthesise many but not all of the vitamins that they require. Organisms differ in their ability to do this. A vitamin which may be an essential nutrient for one organism (i.e. it cannot synthesise it) may not be essential for another. An organism lacking essential vitamins, or having an inadequate supply of them in its diet, will suffer from a deficiency disease.

The amount of any particular nutrient that is necessary in a balanced diet depends on the age, sex and physical activity of the individual. A greyhound, for example, requires higher carbohydrate and protein intake than a house dog who has minimal physical activity. More nutrients of all types are required when the body is undergoing active growth than when it is in a plateau phase.

SUMMARY

Growth, the permanent increase in size of an organism, results from cell division, assimilation and cell expansion.

Growth is the irreversible increase in dry mass of protoplasm by cell division and cell enlargement.

Development consists of the changes undergone by an organism in growth from immature to mature form. It involves differentiation, histogenesis and morphogenesis.

Growth can be expressed in terms of a growth curve. In most organisms this follows a smooth and regular pattern. In arthropods, however, growth is intermittent due to moulting.

Growth may be either:

- isometric, where all body parts grow in an even and regular pattern; or
- allometric, where different parts of the body grow at different rates.

Growth may also be limited (species that have a maximum size) or unlimited (species that continue to grow until death).

Growth and development are determined by the interaction between genetic potential and environmental conditions.

Essential nutrients are substances which an organism cannot synthesise from basic units, and must therefore be taken in. Lack of certain nutrients leads to deficiency diseases which affect the growth and development of the organism. In animals a balanced diet has the correct proportions and amounts of carbohydrates, proteins, lipids, vitamins and minerals.

Review questions

17.31 Distinguish between growth and development in a multicellular organism.

17.32 Define cell differentiation.

17.33 With the aid of a diagram, describe the four phases of growth.

17.34 With the use of examples, differentiate between:
(a) limited and unlimited growth
(b) positive and negative growth
(c) isometric and allometric growth.

17.35 How does the growth of an arthropod differ from that of other animals?

17.36 Discuss factors which influence growth and development of an animal.

17.6.4 Growth and development

The study of the development of multicellular animals is termed **embryology**. Embryological development may be internal or external.

External development occurs whenever there is external fertilisation, and in invertebrates and some vertebrates that utilise internal fertilisation. In all cases, some form of egg casing encloses the developing young and a food supply. In aquatic animals, this casing is thin and relatively permeable. The eggs of terrestrial animals, however, are subject to dessication. The egg casing must prevent water loss. The development of the amniotic egg of reptiles and birds (see Section 4.6.4) was a major evolutionary step in external development.

In some animals the embryo is retained within the female body and the young are born at a comparatively advanced stage of development. This is known as **vivipary**, and is seen in some fish and snakes. In these animals the nourishment for development is obtained from the egg yolk. In eutherian mammals, **internal development** involves the formation of a placenta between the maternal uterus and the embryo. The placenta allows exchange of materials between the mother and developing young. The embryo is well protected, while also having a constant food supply and a route for removal of metabolic wastes. Due to the lower losses of both gametes and developing young, those animals with internal fertilisation tend to produce fewer, larger eggs.

Embryological development is normally triggered by the act of fertilisation. In the majority of animals the changes which occur from fertilisation through to the formation of the new individual fall into three stages:

- **cleavage**—division of the zygote into daughter cells
- **gastrulation**—establishment of the basic body form; arrangement of the cells into three germ layers (ectoderm, mesoderm and endoderm)
- **organogeny**—formation of organs and organ systems.

Table 17.6 Origins of tissues and organs

The primary germ layers		
Ectoderm	**Mesoderm**	**Endoderm**
• skin	• skeleton	• lining of alimentary canal, trachea, bronchus, lungs
• nervous system	• muscles	
• hair, nails	• kidneys, ureters	• lining urethra and bladder
	• blood and blood vessels	• glands (including liver and pancreas)
	• dermis	
	• reproductive organs	

The amount of yolk present in the fertilised egg determines the type of cell division that can occur. Yolk provides food for the developing embryo. Complete development within the egg case can only occur if large amounts of yolk are present. If the zygote has only a small or moderate amount of yolk, two different types of developmental strategy can exist: metamorphosis or placental development.

Metamorphosis

The young may hatch in an 'embryonic' form, such as a larva, and complete their development as independent individuals obtaining food from the environment. This form of development is termed metamorphosis.

Complete metamorphosis involves hatching larvae which are very different from the adults and exploit a different niche. Competition for resources is thereby reduced. The larvae eventually develop into the adult form. Many insects and amphibians develop in this way; examples include butterflies and frogs.

Incomplete metamorphosis involves hatching nymphs which, although having general similarities to the adult, must undergo a series of growth and development phases to reach maturity. This is seen, for example, in the grasshopper.

The marsupials undergo a special kind of metamorphosis. They generally do not form a placenta. Embryonic development within the uterus cannot, therefore, continue once the yolk supply of the egg has been exhausted. The young of these animals are born in an embryonic state, but with well-developed head and forearms relative to the rest of the body. After birth, the tiny animal crawls from the vaginal opening up the female's abdomen into a pouch. There it attaches itself by the mouth to

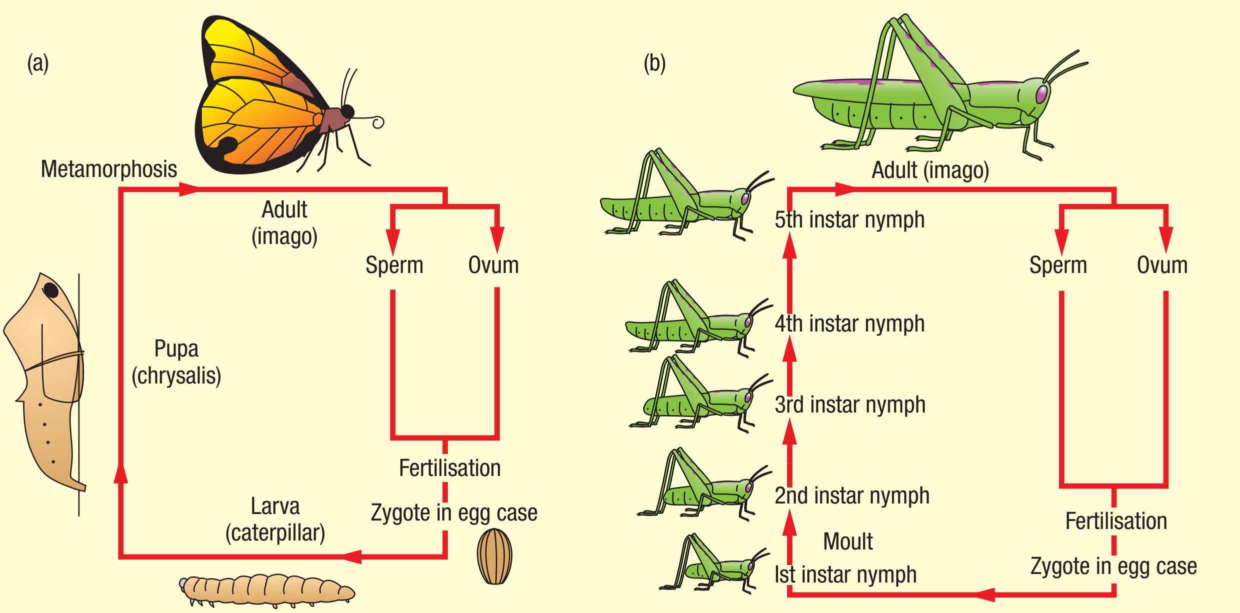


Figure 17.25 Metamorphosis: (a) complete and (b) incomplete

one of the nipples, where its embryonic development is completed. The nutrients required for development are derived from the milk produced by the mother.

Red kangaroos show reproductive adaptations which are linked to the fall of rain. In good seasons, the red kangaroo reaches sexual maturity between 18 and 24 months. At any one time the female may have a joey at heel still suckling and a smaller pouch joey. A dormant blastocyst (very early embryo) can be held in reserve in the uterus. The older joey will suckle from one nipple which produces the high-protein milk it requires, while the younger joey suckles from another teat which produces a milk of different composition. Within the first 6–10 weeks of a drought, many of the pouch young die, and after 5 months most of the females stop breeding totally. With the onset of rain, the females immediately resume reproduction.

Placental development

This strategy occurs in only one group of chordates: the eutherian or placental mammals. Tissues develop from the zygote to form a specialised structure, the placenta. These tissues are called **extra-embryonic** tissues and are attached to the embryo. The placenta allows diffusion of materials between the developing embryo and mother.

Some of the membranes grow around the whole embryo, as a fold of tissue, and fuse in the mid-line. The outer membrane is termed the **chorion**, the inner one the **amnion**. An extra-embryonic coelom occurs between these two membranes. Another cavity is formed between the amnion and the embryo, and becomes filled with **amniotic fluid**. This fluid bathes the embryo and prevents it from drying out, just as sea water bathes oceanic embryos. The combined effect of the amnion, chorion and two intervening cavities is to act as a buffer, protecting the embryo against mechanical shock.

Another membranous cavity, the **allantois**, forms. Part of this comes to lie adjacent to the chorion, and fuses with it.

The **allanto-chorion** develops into the **placenta**. The chorion develops finger-like outgrowths, the **chorionic villi** (singular *villus*), which project into blood spaces in the walls of the mother's uterus. These blood spaces are formed by the breakdown of maternal capillaries. Capillary loops through which

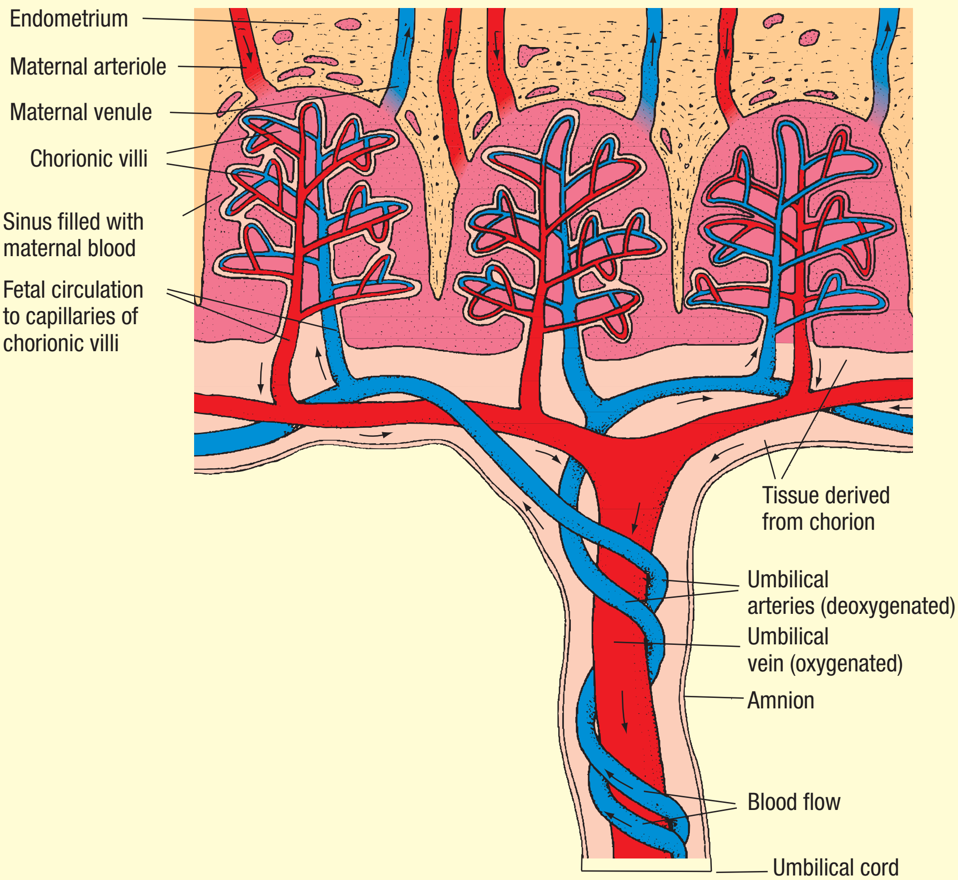


Figure 17.26 Parts of the eutherian placenta

blood circulates from and to the embryo form within the villi. Exchange of materials takes place between the embryonic and maternal blood across the thin walls of the villi. The stalk of the allantois becomes the **umbilical cord**, which connects the embryo with the placenta, and through which blood vessels pass.

The embryonic and post-embryonic development of a representative placental mammal (the human) is further described in Chapter 19.

SUMMARY

The study of development from fertilisation to birth in animals is termed embryology. In chordates, different phases can be identified: cleavage, gastrulation then organogeny.

Cleavage is the rapid division of undifferentiated cells. Gastrulation results in the general body plan: a tube within a tube composed of three germ layers—ectoderm, mesoderm and endoderm—surrounding a central cavity. Different organs and systems arise from different parts of the germ layers—in particular, the mesoderm—during organogenesis.

Many animals undergo a process of development termed metamorphosis. The young have not reached final form when they are born and complete development outside of the egg or mother's body.

In eutherian mammals, the placenta arises from extra-embryonic membranes and provides nourishment for the embryo by allowing diffusion of substances between the maternal and embryonic blood.

Review questions

17.37 Distinguish between internal and external development.

17.38 How does the amount of yolk present in the fertilised egg determine the type of embryological development that takes place?

17.39 Outline the general results of the following phases of embryonic development:
(a) cleavage
(b) gastrulation
(c) organogenesis.

17.40 Compare and contrast complete and incomplete metamorphosis.

17.41 Why can marsupial development be considered a form of metamorphosis?

17.42 What are extra-embryonic tissues?

17.43 Explain how a placenta functions in supplying nutrients to an embryo.

17.44 The mortality rate amongst invertebrate young is usually much higher than among birds and mammals. Suggest reasons for this.

17.45 How might 'fanning' the eggs with water by 'nest-building' fish increase the chance of the survival of the developing fish fry?

17.7 Coordination and control

Organisms must be able to monitor their environment. This may involve detecting changes in the chemicals within the body, such as the levels of glucose or carbon dioxide. Other important environmental aspects that must be monitored are outside the body. The direction of water currents; the relative position of light; temperature; detection of food sources; these are all important clues for an organism's ability to survive. Irritability—the ability to detect and respond to changes in the environment—is a characteristic of all living matter.

Coordination occurs when different body parts work together to maintain a steady internal state or homeostasis. There are two coordinating systems in the bodies of multicellular animals—the nervous system and the hormonal or endocrine system.

These two systems are mediating areas between a stimulus and a response; that is, between detecting a change in the internal or external environment and an appropriate reaction. The reaction may then act as another stimulus to either stop or maintain the behaviour. In this case, feedback occurs.

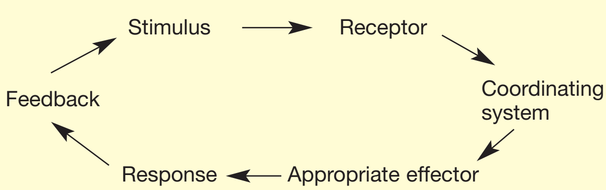


Figure 17.27 The stimulus–response model

Detection of the stimulus involves changes in chemicals within the individual cell or in the specialised cells of a sense organ. A chemical message is then transmitted to bring about a response. The response is again a change in chemicals within a single cell or within an effector organ.

17.7.1 Chemical control

Within any living cell, vast numbers of chemical reactions are occurring at any given moment. The chemical environment in every part of the cell is constantly undergoing slight changes, as some substances are synthesised and others are used, destroyed or removed. Any change in the chemical environment will affect subsequent chemical reactions and thereby exert some control over them. This simple relationship, which regulates most of the cell's reactions, forms the basis of more complex chemical regulatory mechanisms. It is from this basis that hormone systems are thought to have evolved. In this type of system certain cells have become specialised to produce and secrete specific regulatory chemicals.

Hormones are chemicals that regulate body functions. They are produced by cells in minute quantities and transported to other regions. Each hormone regulates the activity of a specific target structure. This may be an individual cell, a muscle or another gland.

Hormones may provide control in their immediate surroundings or at a distance. 'Distance' hormones are made in one part of the body and control another part. They must be transported to the target sites either in a transport system or by diffusion from cell to cell. The action of hormones, therefore, tends to be slow. Similarly, since there will be some of the released hormone still available even after its production has been 'switched off', the action is long-lasting.

A stimulus causes production and secretion of a hormone appropriate to that stimulus. The hormone is then carried throughout the body. When it reaches the target organ, recognition sites (glycoprotein molecules) on the cell membranes 'capture' the hormones, which then regulate the cells' activities through a specific chemical reaction. They do not initiate any unique cellular activities but instead modify the rates of existing activities. Hormones may:

- act on the cell nucleus to influence the activity of particular genes
- influence the permeability of the cells to particular solutes
- induce or repress cytoplasmic enzymes and thus specific chemical reactions.

Hormones are therefore often referred to as 'chemical signals', since they cause a change in activity of the target cells.

Hormones differ in their molecular structure. Some are proteins and others are steroids. Thus different hormones will be recognised by different target sites and bring about different chemical reactions.

SUMMARY

Irritability, a property of living organisms, is the ability to detect changes in the environment and respond to them. The environment may be internal or external. The response may be an overt movement or a change in some metabolic reaction. It involves coordination of body parts.

Irritability involves communication between different parts of the organism, the basis of which is ultimately chemical.

Metabolic activities are constantly occurring. Thus the chemical environment in every part of the cell (and thus the whole body) is constantly changing. This affects other chemical reactions.

Hormones are chemicals which regulate body functions. Each hormone has a specific target structure. A hormone is made in one part of the body and controls another. Action is slow but long-lasting.

Review questions

17.46 Explain what is meant by 'coordination' of the body. Predict what would happen if there were no coordinating system.

17.47 What is a feedback system?

17.48 All communication systems in living organisms involve a stimulus, a transmitter and a response. Comment on these three parts in:
(a) a unicellular organism
(b) a multicellular animal.

17.49 Define a hormone.

17.50 Outline how hormones carry out 'control at a distance'.

17.7.2 Nervous control

The second coordinating system, found in most animals, is the nervous system. It links receptors, which are areas for detecting stimuli, with effectors—areas associated with bringing about a response. The nervous system is composed of cells called **neurons** (singular *neuron*) which are specialised to convey information in the form of nerve impulses. Each neuron is composed of a cell body (containing the nucleus) from which extend fibres (either axons or dendrites). The structure of a mammalian neuron is illustrated in Figure 18.5 on page 464. Messages are sent along the nerve fibres as electro-chemical changes of the cell membrane.

Because there is direct linkage, via the nerve cells, between the receptor and effector, the response time is very fast after detection of a stimulus.

The most primitive nervous organisation is found in cnidaria. The neurons are linked together by their axons and form a nerve net which makes contact with receptor cells and musculo-epithelial cells. A nerve net allows impulses to spread out in all directions from the point of stimulus. Although relatively slow, this mechanism is adequate for a small, fairly inactive animal like *Hydra*.

Two trends can be discerned in more advanced animals. Neurons have become assembled into tracts (usually longitudinally) and nerve cell bodies are congregated into **ganglia** (singular *ganglion*). Tracts are generally produced by longer axons. This speeds up the transmission of impulses because there are fewer **synapses** (gaps between neurons) to cross. Synapses in cnidarians allow nerve impulses to pass in either direction along the axon, but with the development of tracts, nerve impulses could pass across synapses in one direction only. The larger, more active cnidarians have developed some through-conduction tracts which allow the mediation of responses where rapid conduction is important—for example, the defensive shortening of the column and withdrawal of the tentacles in the sea anemone.

The development of ganglia made possible the gathering of information from different receptors and the coordination of responses by different effectors.

In association with bilateral symmetry, the annelids, many arthropods and vertebrates have evolved a double or single longitudinal tract or nerve cord which ensures rapid communication between the two ends of the body. Since the front end of the body in these animals is the first to encounter the 'new' environment, receptors became concentrated in this area. In turn this led to an increased number and size of ganglia in the anterior end to deal with the sensory input and transmit the required information to the effectors. The overall result was an increase in cephalisation—development of a head.

The aggregation of neurons in the head of invertebrates, forming structures referred to as the cerebral ganglia, is the precursor of the brain of vertebrates. The cerebral ganglia are chiefly concerned with relaying information from the receptors to the effectors via the nerve cord. In the higher animals the brain takes over more and more directive functions. This reaches a pinnacle in the mammals, where the brain exerts control over much of the animal's behaviour.

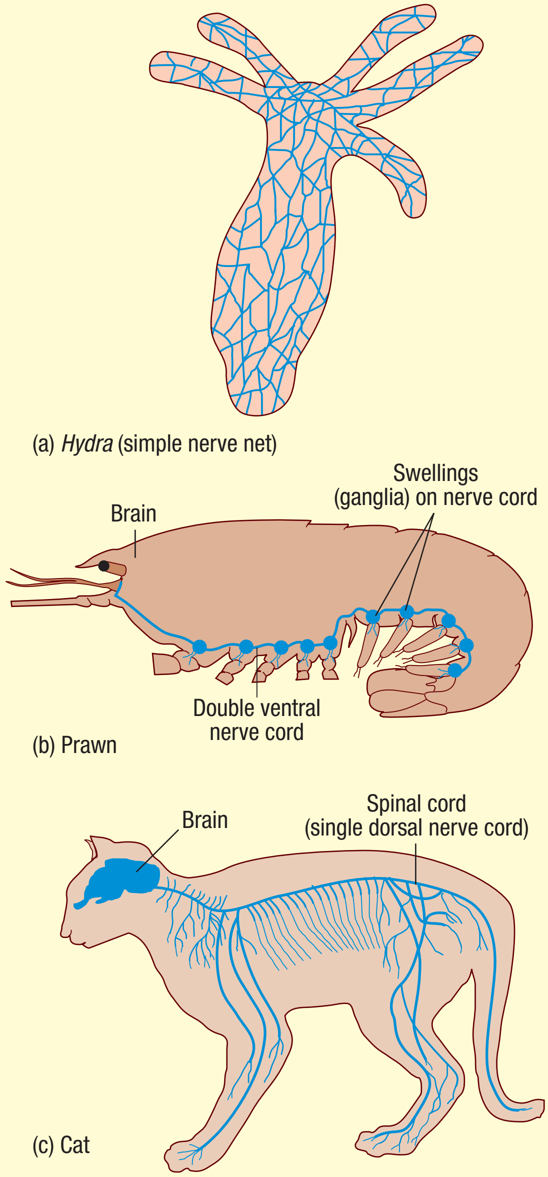


Figure 17.28 Nervous systems of: (a) *Hydra*; (b) a prawn; and (c) a cat

SUMMARY

The nervous system provides the fastest means of communication within the body. In most animals the nervous system consists of cells called neurons connected in longitudinal tracts. The cell bodies of these neurons tend to be concentrated together as ganglia in the head end of the animal. The more highly developed the animal, the larger the cerebral ganglia and thus development of a brain and thus coordination between parts of the body.

Review questions

17.51 Explain why the nervous system provides a faster communication pathway than that of the hormonal system.

17.52 The coordination achieved by the nervous system, like the hormonal system, is basically chemical. Explain why this is the case.

17.53 From the diagrams in Figure 17.28, compare the nervous systems of *Hydra*, a prawn and a cat.

EXTENDING YOUR IDEAS

1. Digestion of chunks of food is either within a food vacuole or extracellular. Give possible reasons for this phenomenon. UB
2. 'Digestion of food within the vertebrate alimentary canal can be likened to the decomposition by organisms such as fungi, in that digestion effectively takes place in the external environment of the organism.' UB
   (a) Do you agree with this statement? Explain your answer.
   (b) Compare and contrast (in general terms) the digestive processes of a decomposer and a vertebrate.
3. Young kangaroos, as they begin to eat grass, can be observed eating adult faecal pellets. Suggest a reason for this. UB
4. Ripe fruits are composed primarily of simple sugars. Some mammals feed almost exclusively on such fruits. Suggest the type of dentition, tongue and alimentary canal such animals might have. UB
5. Birds do not have teeth and yet different species are adapted to a range of food types. Draw and explain the structure of the beak of a bird adapted to a: UB
   (a) seed-eating diet (e.g. finch)
   (b) carnivorous diet (e.g. hawk)
   (c) nectar diet (e.g. honeyeater).
6. Observations of the Tamar wallaby on cold mornings revealed that, during its bounding locomotion, small 'puffs' of condensed air were ejected from the nostrils as the wallaby brought the hind limbs forward, but not when they were extended. Similar observations were made on racehorses. The 'puffs' were seen when a horse's back was flexed, with the hind limbs in the forward position. (See Figure 17.29.) UB
   (a) What causes the 'puffs' of condensed air?
   (b) Suggest a hypothesis to explain these observations.
   (c) Suggest how this mechanism may help quadrupeds to travel large distances at speed.
7. In fish, oxygen is transported in the blood in the form of oxyhaemoglobin. The table below shows the percentage saturation of blood with oxygen of a bony fish after equilibrating with oxygen at different partial pressures in the environment. The experiment was carried out at two different partial pressures of carbon dioxide. IB

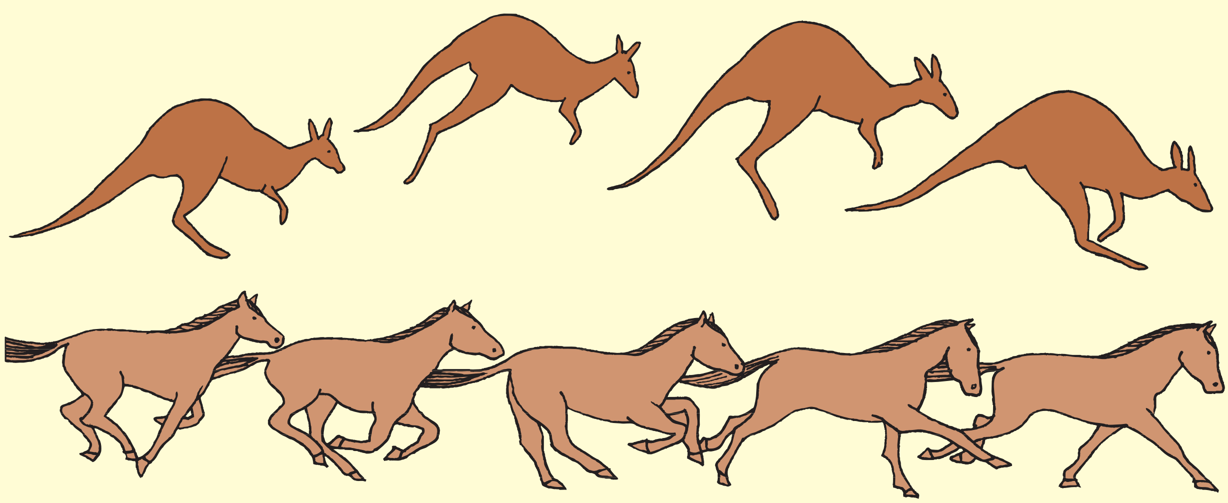


Figure 17.29

Percentage saturation with oxygen of blood of a bony fish at different partial pressures of oxygen and carbon dioxide		
Partial pressure of oxygen (Pa)*	**Partial pressure of carbon dioxide at 500 Pa**	**Partial pressure of carbon dioxide at 2600 Pa**
500	30	5
1000	70	13
2000	90	24
3000	96	33
4000	98	41
5000	99	48
7000	100	60
9000	100	69
11000	100	76
13000	100	81

*A pascal (Pa) is a unit of pressure. A pressure of 100 000 Pa is approximately equal to atmospheric pressure (760 mmHg).

(a) Calculate the difference in percentage saturation of blood at the two different partial pressures of carbon dioxide, and at an oxygen partial pressure of 5500 Pa. Show your working.

(b) Explain how changes in the oxygen content of the blood at different partial pressures of carbon dioxide are important in the release of oxygen to the tissues of the fish.

(c) What information do experiments of this type give about the environmental conditions in which fish would maintain a high level of growth as required in commercial fish farming?

8. EBI Hiccups are a sudden contraction of the muscles used by mammals to breathe in. Just after the muscles start to move, the glottis shuts off the windpipe and this produces the 'hic' sound. Ultrasounds of babies in the womb show that they start hiccuping after two months, before any breathing movements appear.

Primitive air breathers that still possess gills (e.g. lungfish, gar and many amphibians in the later tadpole stage) push water across their gills by squeezing their mouth cavities while closing the glottis to stop water getting into the lungs. This reflex is inhibited when the lungs are inflated.

It has been suggested that the brain circuitry controlling gill ventilation in these ancient ancestors has been retained in eutherian mammals.

Suggest a possible reason for the retention of this behaviour that could assist in the development of eutherian mammals.

9. UB Sea birds such as the herring gull secrete salts twice as concentrated as in sea water from nasal glands situated on top of their heads; and marine reptiles such as turtles secrete salts from glands close to their eyes. Explain why these mechanisms would be necessary.

10. UB When a tadpole undergoes metamorphosis to a frog, there are quite obvious structural changes. The changes in function are less obvious. For example, the tadpole excretes its nitrogenous waste as ammonia, whereas the frog excretes urea.

(a) Plot a graph of the following data:

Age of tadpole or frog (days)	Ammonia (percentage of total excretory material)
50	92
55	88
65	84
75	83
90	68
95	20
100	13
110	12

(b) The change from excreting mainly ammonia to excreting mainly urea occurs when the frog starts to live on dry land. Between which days do you think the animal leaves the water?

(c) Ammonia is very soluble and toxic. Suggest reasons for the fact that it is an excretory product of tadpoles but not of frogs.

11. UB The mud wasp *Abispa* builds large mud nests, particularly inside homes in Queensland. The nest is composed of separate cells. In each cell of the nest the female places paralysed spiders. She lays eggs on these then seals the cell with a thick coating of clay. When the eggs hatch, the larvae have a ready supply of 'fresh' food from which to obtain the necessary requirements for metamorphosis.

(a) Why is paralysis of the prey a better option than killing it?

(b) Suggest how the wasp brings about the paralysis of the food supply.

12. EBI Spiders display some bizarre mating behaviours. Female spiders live alone. Many build webs or use web material in burrows that are used to capture prey. It is not surprising, therefore, that the presence of a male would trigger killing and devouring behaviour by the female. Many species of male spiders, therefore, have developed strategies to prevent being eaten. The males are invariably light and highly mobile, allowing the male to move rapidly to the female and insert the sperm-containing package (spermatophore) into the female before being detected. Some species even bring food to distract the female while undertaking this hazardous process.

Male *Argiope aurantia* (an orb spider), however, spontaneously die in the act of copulation. A pair of anterior appendages, the pedipalps, of the male is modified for reproduction. Each pedipalp in this species swells after it has been inserted with a spermatophore into one of a pair of genital openings in the female. Once the second pedipalp is inserted, the male dies. If any competing males are present, they attempt to dislodge the dead lover by biting the legs and pulling at him. They are invariably unsuccessful in their efforts. The original male acts as a chastity belt.

This behaviour is most likely to have adaptive significance for the species. Discuss the implications of the behaviour of the male orb spider to the long-term success of the species.

13. UB Predict, with reasons, the types of sensory organs for detecting external stimuli that would be predominant in:
(a) an eagle
(b) a nocturnal snake.

14. UB Animals with different niches often have different sensory receptors. Suggest, with reasons, what receptors would be most dominant in a:
(a) leech specialised to parasitise mammals
(b) platypus
(c) bat.

18 THE HUMAN BODY

Human beings are mammals that belong to the phylum Chordata, sub-phylum Vertebrata. Like all living organisms, the human species must carry out life functions to survive. *Homo sapiens* is a generalist with an ability to modify the environment and thus to survive in a wide variety of habitats. Apart from adaptations, primarily to the musculo-skeletal system, associated with an upright stance, the structure and function of the human body is typical of a general eutherian mammal. Although this section will focus on the human species, mention will also be made of some other mammals, and their specific adaptations to their environment.

The division of labour is very high in the mammalian body. Specialised systems (comprising tissues and organs) are responsible for specific functions. These functions, however, need to be co-ordinated for the organism to survive. Malfunction in any part—tissue, organ or system—can lead to malfunction of the organism as a whole.

18.1 COORDINATION AND CONTROL

Both the internal and external environments of an organism are constantly changing. The abiotic and biotic conditions surrounding an individual can vary from moment to moment. As cells undergo metabolic reactions, the concentrations of cellular chemicals change. These changes impact on the individual and may be detrimental to its survival. But organisms do survive all but the most drastic internal and external changes. This is achieved by a variety of anatomical, physiological and behavioural adaptations. **Homeostasis** is the term used to describe a constant internal environment within a living organism. Mechanisms that maintain homeostasis provide the organism with some degree of independence from its environment. Mammals are among the most successful of all animals since their homeostatic mechanisms are such that they are able to maintain relatively constant levels of activity despite fluctuations in environmental conditions. The basic components of any control system are illustrated in Figure 18.1.

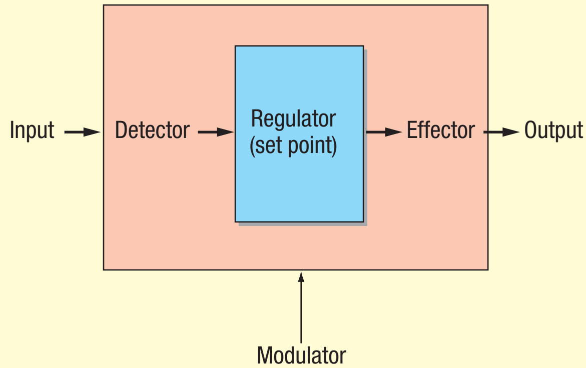


Figure 18.1 Basic components of a control system

The efficiency of the control system is measured in terms of:

- the displacement from the optimal level or set point
- the speed at which the level is restored.

Fluctuations from the set point activate the control system, which returns the particular parameter towards its optimal level. The linkage of all components of the control system allows the output to be regulated in terms of the input. **Feedback** occurs.

There are two types of feedback: positive, in which the same response will continue, and negative, in which the response is reversed or negated. Most, if not all, vertebrate homeostatic control mechanisms display negative feedback. They are self-adjusting because fluctuations in the feature being regulated trigger the appropriate corrective mechanism. Oscillation about the normal occurs because the mechanism responds only to a change in the parameter and the response causes an 'overshooting' of the set point.

This control system is activated by hormones or the nervous system or a combination of both in mammals (see Figure 18.2 on page 460).

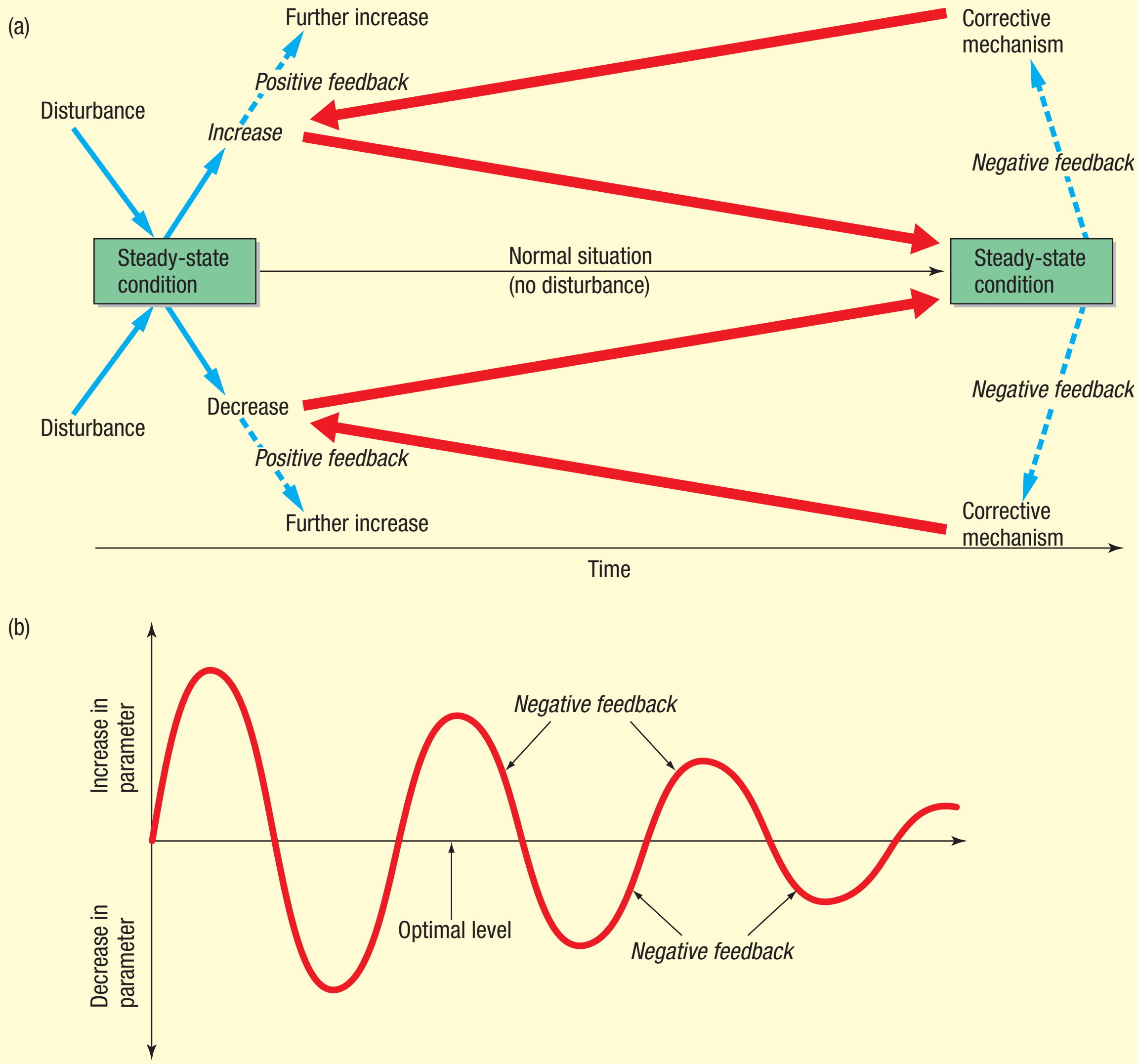


Figure 18.2 Homeostatic control mechanism shown (a) diagrammatically and (b) graphically

18.1.1 Hormones

Hormones, or chemical coordinators, are produced in ductless **endocrine glands** which pass their secretions directly into the blood vessels that pass through them. In mammals, the endocrine and nervous systems function in a coordinated fashion to maintain homeostasis. It is believed that these two systems originated and developed side by side as the increasing size and complexity of organisms made intercellular communication more important.

Figure 18.3 shows the location of the main human endocrine glands. In spite of their physical separation from one another, endocrine organs do not work in isolation. Many hormones interact with each other to bring about a particular response.

The stimuli controlling the release of any particular hormone are:

- the presence of a specific metabolite in the blood
- the presence of another hormone in the blood
- stimulation by the autonomic nervous system.

Each hormone will bring about an effect only on specific body cells. The target cells have recognition sites for specific hormones. There are several ways a hormone can influence a target cell. It may:

- change the permeability of the membrane to particular chemicals
- influence enzymes located in the membrane
- influence cell organelles
- activate genes to bring about specific protein production.

It takes time for a stimulus to result in the release of a specific hormone, for the hormone to reach the target cells and for these to respond. Similarly, once further release of a hormone is inhibited, it will be

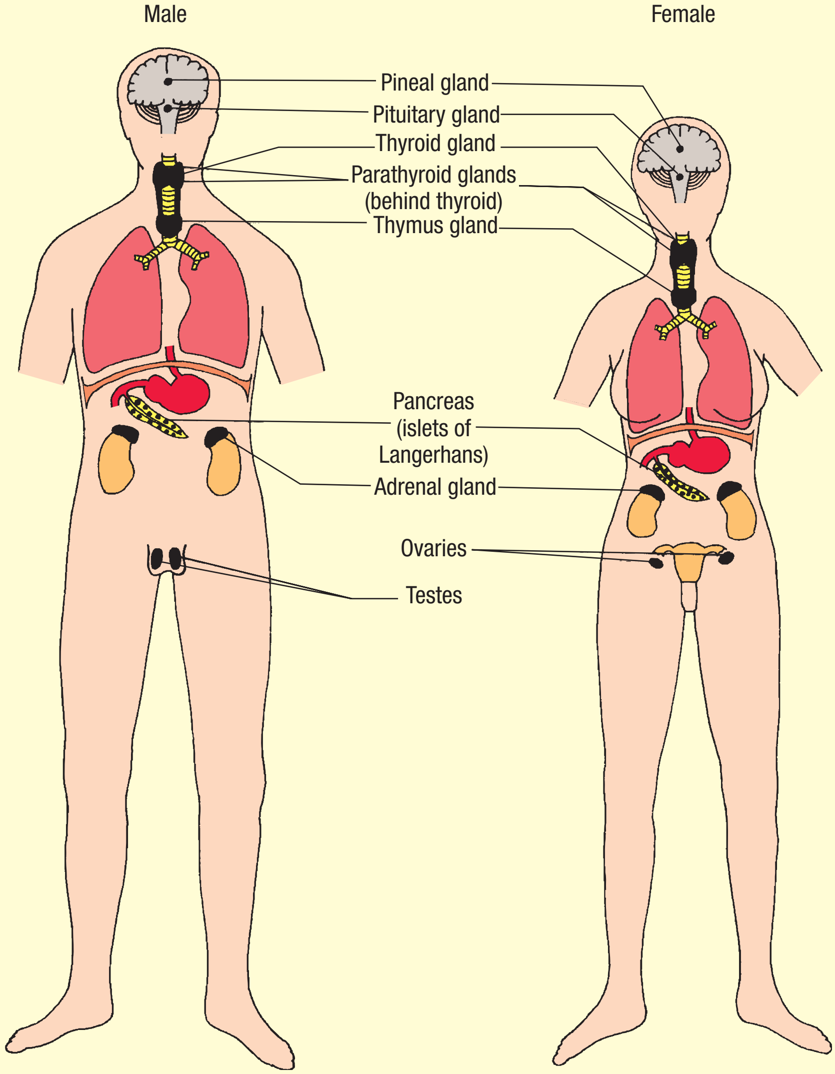


Figure 18.3 Position of the main human endocrine organs

some time before all the circulating hormone is attached to target cells. Therefore hormonal control is slow-acting but long-lasting.

The hypothalamus, a section of the forebrain of vertebrates, plays a dominant role in hormone release. It collects information from other parts of the brain, as well as monitoring levels of hormones and other chemicals in the blood vessels passing through it. Information so generated is passed to the pituitary gland, which is directly below and adjoining it, by nervous conduction or the release of neurohormones.

Table 18.1 The major human endocrine glands, the hormones they produce and their functions

Endocrine gland	Hormones	Major function
Hypothalamus	Releasing and release-inhibiting hormones	Control release of hormones from adenohypophysis (anterior pituitary)
Hypothalamus via neurohypophysis (posterior pituitary)	Oxytocin	Stimulates release of milk and uterine contractions
	Anti-diuretic hormone	Stimulates reabsorption of water in kidney

Table 18.1 (*continued*)

Endocrine gland	Hormones	Major function
Adenohypophysis	Adrenocorticotropic hormone (ACTH)	Stimulates adrenal cortex
(anterior pituitary)	Follicle-stimulating hormone (FSH)	Stimulates development of ovarian follicles and seminiferous tubules
	Luteinising hormone (LH)	Stimulates ovulation and conversion of empty follicle into corpus luteum; also stimulates progesterone and testosterone production
	Melanocyte-stimulating hormone (MSH)	Stimulates dispersion of pigment (melanin) in the skin of amphibians: stimulates melanin production in humans
	Prolactin	Maintains lactation after pregnancy; maintains secretion of progesterone during pregnancy
	Thyroid-stimulating hormone (TSH)	Stimulates thyroid gland
	Growth hormone	Promotes growth
Thyroid	Thyroxine and tri-iodothyronine	Increase metabolic rate by stimulating cellular respiration; play an important role in growth, tissue development and differentiation
	Calcitonin	Inhibits excessive rise in blood calcium by suppressing removal of calcium from bone
Parathyroid	Parathormone	Acts in opposition to calcitonin—brings about removal of calcium from bone; and increases reabsorption of calcium in kidney, thus raising blood calcium level
Adrenal cortex	Glucocorticoids, e.g. cortisone	Regulate carbohydrate metabolism
	Mineralosteroids, e.g. aldosterone	Regulate salt and water metabolism
Adrenal medulla	Adrenalin and noradrenalin	Prepare animal to meet emergency conditions, e.g. fight, flight or shock, by increasing heart rate and blood supply to skeletal muscles, lungs and liver, and raising the blood sugar level
Pancreas	Glucagon	Increases blood sugar level by converting glycogen to glucose
	Insulin	Decreases blood sugar level by stimulating the formation of glycogen
Glands in stomach lining	Gastrin	Maintains flow of gastric juice
Glands in duodenum lining	Secretin	Stimulates secretion of intestinal juices
	Pancreozymin	Stimulates secretion of pancreatic juice
	Cholecystokinin	Stimulates release of bile from gall bladder
Ovary	Oestrogens	Initiate and maintain female secondary sexual characteristics; initiate thickening of uterus lining; and controls FSH & LH secretions
	Progesterone	Maintains thickening of uterus lining; inhibits FSH and LH
Testis	Testosterone	Initiates and maintains male secondary sexual characteristics

The pituitary: the master gland

The pituitary gland is formed from two tissues: a glandular portion and a neural portion. The adenohypophysis or anterior lobe consists of glandular tissue, and the neurohypophysis or posterior lobe is the neural portion.

The adenohypophysis produces seven hormones. One promotes growth, one influences pigmentation and the others, the **tropic hormones**, stimulate other endocrine glands. The pituitary gland exerts its influence over other parts of the endocrine system through these tropic hormones. The production of the hormones by the adenohypophysis is controlled by the hypothalamus.

Hormones produced by the nerve cells in the hypothalamus act as either releasing hormones or release-inhibiting hormones to the adenohypophysis. Some of the adenohypophysis hormones—for example, growth hormone and prolactin—respond to the relative proportions of releasing and release-inhibiting hormones. Others respond only to releasing hormone.

The hypothalamus also produces the hormones antidiuretic hormone (ADH) and oxytocin, which are transported to, and stored in, the neurohypophysis. The release of these hormones is triggered by nervous stimulation from the hypothalamus.

Due to the multiplicity of hormones released either directly or indirectly by the pituitary gland, it has been termed the **master gland** of the body; and the hypothalamus has been termed the **control centre**.

Not all endocrine glands are under the sole control of the hypothalamus and pituitary gland. Some are self-regulating, as they respond directly to changes of metabolites in the blood. The secretion of insulin and glucagon from the pancreas, for example, are responses to blood sugar levels. Other organs, such as the adrenal cortex, are under direct nervous control.

SUMMARY

Animal hormones are secreted by special ductless glands (endocrine glands) into the bloodstream. The main hormones and their actions are summarised in Table 18.1. Different hormones may interact with each other in a coordinated manner by feedback mechanisms. The whole endocrine system is under the control of the hypothalamus.

When a hormone reaches a target cell it may exert its effect at the level of the cell membrane, enzymes located in the cell membrane, cellular organelles or genes. Factors which control the release of hormones are:

- presence of a specific substance in the blood (e.g. glucose stimulates the release of insulin)
- presence of another hormone in the blood (e.g. thyroid stimulating hormone—TSH—stimulates the release of thyroxin)
- stimulation by the autonomic nervous system.

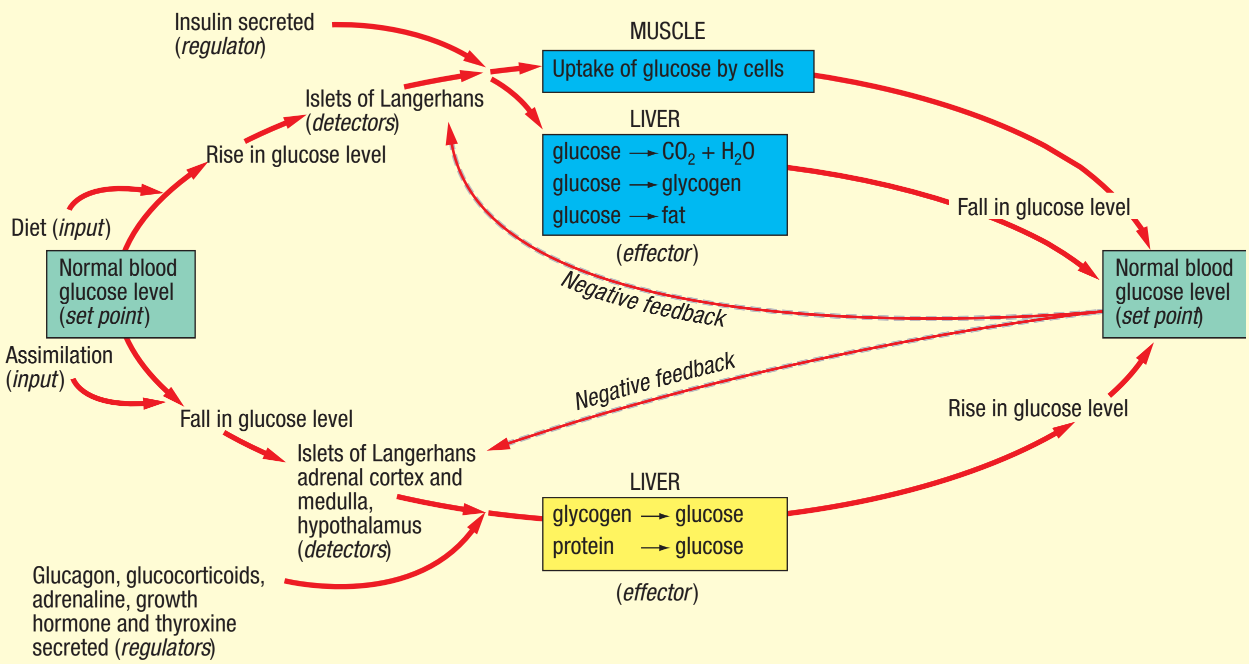


Figure 18.4 Summary of the control of the pancreatic hormones

Review questions

18.1 Homeostatic control is achieved through feedback mechanisms. Using examples:

(a) explain what a feedback system is

(b) distinguish between a positive and a negative feedback system.

18.2 Why is the hypothalamus referred to as the control centre and the pituitary as the master gland?

18.3 Using one example, show how the pituitary can act to control the production and/or secretion of another hormone.

18.4 Human hormones are generally proteins and too large to enter cells. How do they exert their control?

18.1.2 Nervous control

Structure of the nerve cell

The second coordinating system of humans is the nervous system. It links receptors, which are areas for detecting stimuli, with effectors—areas associated with bringing about a response. The nervous system is composed of cells called **neurons** (singular *neuron*) which are specialised to convey information in the form of nerve impulses. Although there are different types of neurons, each adapted for a particular function, they all share certain features. The nucleus is contained in an expanded portion of the cytoplasm called the **cell body**, from which a number of thin cytoplasmic fibres extend. Two main types of fibres can be distinguished, the **axons** and **dendrites**. Axons are usually long and rarely branched, except at their termination. Dendrites are usually shorter and much-branched. Neurons of primitive invertebrates usually have several axons: they are **multipolar**. Those of higher invertebrates and vertebrates have one axon and are therefore **unipolar**.

The cell body is concerned with controlling and maintaining the cell and its activities. With the dendrites, it serves as the main receiving area for the input of impulses from other neurons. The main pathway for the conduction of impulses away from the cell body is the axon. In most animals, the axons

Electron micrograph of a neuron

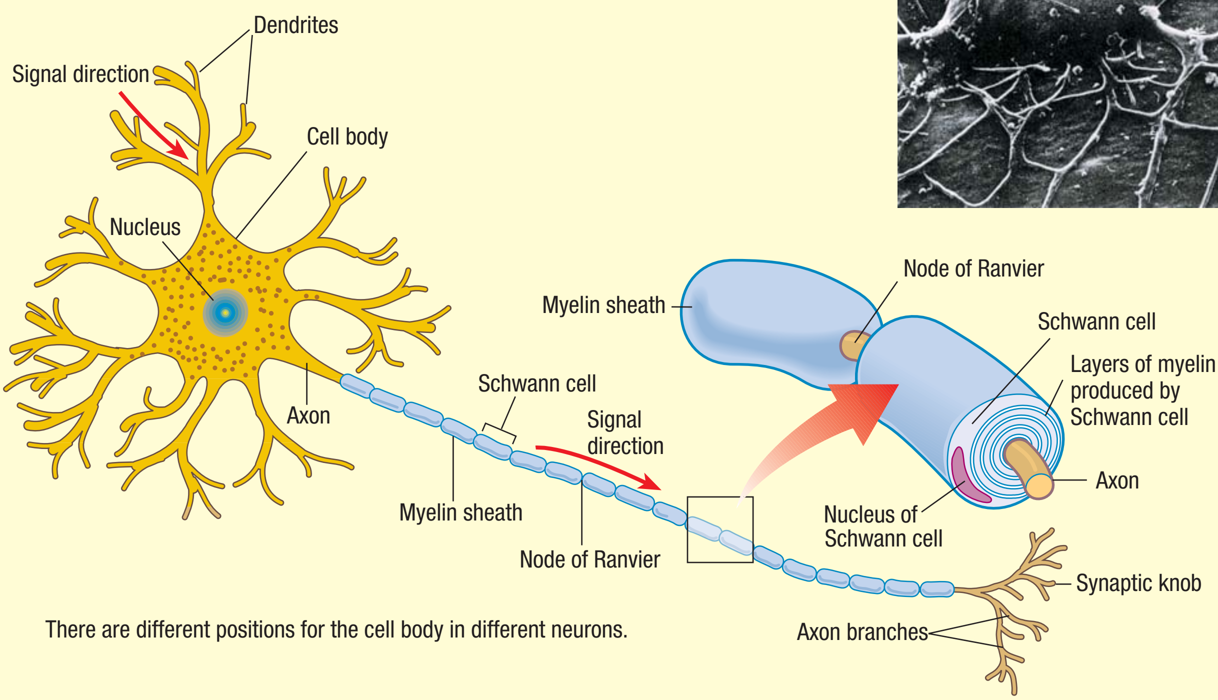


Figure 18.5 Structure of the generalised vertebrate neuron

are covered with special non-nervous cells, **Schwann cells**, which are wrapped so tightly that there is no cytoplasm between the layers of membrane. The sheath so formed is rich in lipids and is termed the myelin sheath. Between adjacent Schwann cells there is a gap where the axon is exposed and this is termed the **node of Ranvier**.

Those neurons associated with stimuli are termed **sensory neurons**, whereas **motor neurons** bring about a response. **Association neurons** link sensory and motor neurons.

Case study 18.1: Multiple sclerosis

Multiple sclerosis is a common disease which affects women and men in the ratio of 3:2. The actual cause is unknown, although it has been suggested that diet, lifestyle and physical environment may be contributory factors. The disease is more prevalent in temperate than in tropical climates. Symptoms include weakness of the limbs, 'pins and needles' and numbness, blurring of vision and pain in the eyes.

These symptoms result from gradual degradation of the myelin sheath in nerve axons. The areas of bare axons, known as plaques, most commonly occur in the optic nerve, cerebellum, neck region of the spinal cord, and in areas surrounding the brain cavity or vesicles. These areas of the central nervous system are directly concerned with either vision or motor activities. Nerve impulses cannot pass across the plaques. Input and coordination of these areas of the body is therefore restricted.

Although the symptoms of multiple sclerosis can be alleviated by drugs such as steroids and ACTH, there is no known cure.

Nerve impulse conduction

The conduction of a nerve impulse along a neuron is accompanied by both chemical and electrical changes along the neuron membrane.

When at rest, the neuron membrane is **polarised**. The outside of the membrane is positively charged with respect to the inside of the membrane. Polarisation results from sodium ions (Na^+) being actively pumped out of the neuron at the membrane so that there are more positive ions outside than inside. The active removal of the sodium ions against a concentration gradient, possibly by a carrier molecule, involves the expenditure of energy and is called a **sodium pump** mechanism. Sodium cannot diffuse back into the neuron because the membrane is relatively impermeable to it. Potassium ions (K^+), however, are able to move through the cell membrane. There is therefore a flow of potassium ions from the outside of the membrane to the inside, counteracting the outward movement of sodium ions. This results in an unequal distribution of potassium ions on either side of the cell membrane. Large, negatively charged organic molecules in the cytoplasm maintain an overall negative charge on the inside of the membrane. This polarisation creates an electrical potential difference between the two sides of the membrane which in neurons ranges between 30 and 100 millivolts (mV). Because this potential difference is characteristic of neurons at rest, it is called the **resting potential**.

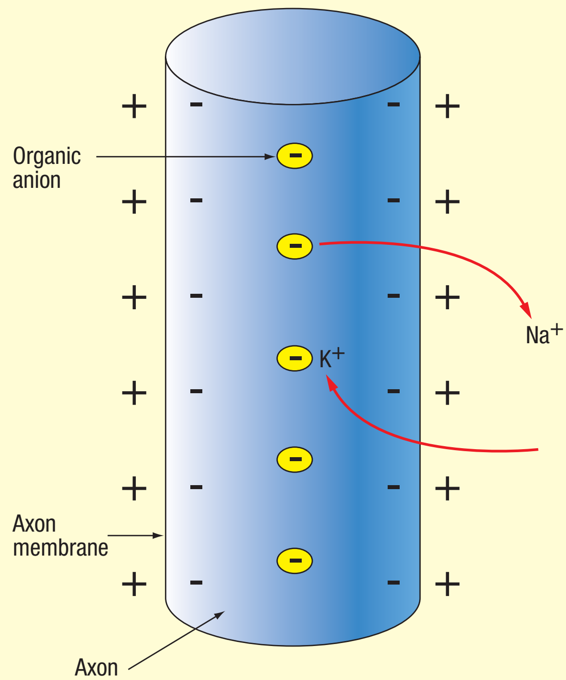


Figure 18.6 The resting potential of a section of axon

When a nerve impulse passes, the resting potential is momentarily broken down or **depolarised**. This is caused by breakdown of the sodium pump. Sodium ions rush into the neuron along a concentration gradient. At first this depolarises the membrane but, as further sodium ions rush in, the polarity across the membrane becomes reversed. The change in polarity is referred to as the **action potential**.

For about 5 milliseconds after the onset of sodium inflow, the membrane becomes impermeable to potassium ions, but then there is an outflow of potassium ions along their concentration gradient to oppose the changes in membrane potential. This initiates the restoration of the resting potential.

The **recovery period** is completed when the membrane once again becomes impermeable to sodium ions. The sodium pump is reactivated and sodium ions are pumped out of the neuron while potassium ions re-enter.

Depolarisation at one segment of the neuron membranes initiates depolarisation of the next part of the membrane. A nerve impulse can be thought of as a wave of self-propagating depolarisations passing along the membrane.

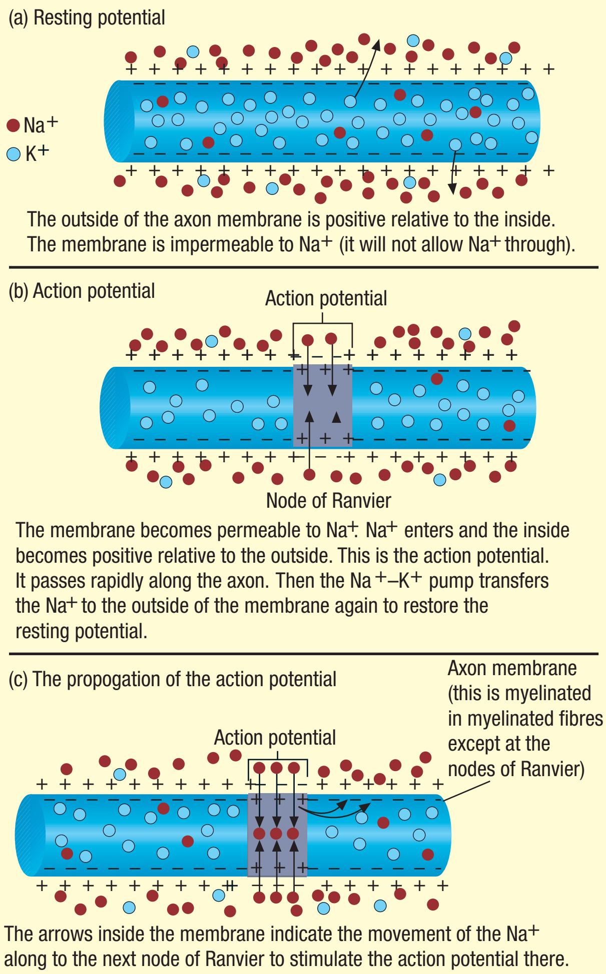


Figure 18.7 Passage of a nerve impulse

To produce an action potential, the stimulus must be of a minimum strength called the **threshold stimulus**. Any increase in stimulus over this threshold level will not increase the magnitude of the action potential, although it can increase the frequency at which the action potential occurs. Because the magnitude of the action potential is the same regardless of the strength of the stimulus above the threshold, this is called an **all-or-nothing response**.

Once an action potential has been initiated, a period of time called the **refactory period** must elapse before another response can be elicited. This period corresponds to the time taken for the membrane to restore its resting potential. An action potential corresponds to the changes in the membrane associated with depolarisation. If a membrane is already depolarised, it cannot become depolarised!

Conduction velocity varies according to the type of neuron and the diameter of the axon. The larger the diameter of the axon, the faster will be the rate of conduction. The myelin sheath also increases the rate of conduction, since action potentials are generated only at the nodes of Ranvier and not along the entire length of the axon. The rate at which a nerve impulse can travel ensures that the response to a stimulus is much more rapid than that elicited by hormones. The nerve impulse can also be rapidly inhibited. Nervous control is rapid but of short duration.

Junctions between neurons

Some means of transmitting information from one neuron to another is essential. The zone of interaction between two neurons is termed a **synapse**. The narrow physical space separating the neuron is the **synaptic cleft**.

Synapses occur between axons and dendrites, between axons and cell bodies, or between axons and effectors such as muscles. The output area of the

Table 18.2 Events within the neuron membrane with passage of the impulse

State of membrane	Type of potential	Polarisation	Ionic movement	Internal potential	External potential
resting	resting	polarised	stable, differential ion concentration maintained	negative	positive
active	action	depolarised	increased permeability to sodium and potasssium ions	positive	negative
recovering	resting	repolarising	almost stable, differential ion concentration being restored	negative	positive

neuron—the axon end that passes on information—is called the **pre-synaptic element**. The part that receives information—the dendrite, cell body or effector—is the **post-synaptic element**. Usually the pre-synaptic area forms a swelling which is termed the **synaptic knob**. Since some neurons, such as those in the brain, have many branched dendrites, they may make contact with a large number of other neurons.

Some synapses have a very narrow cleft. This is seen in some neurons in the brain. The action potential at the pre-synaptic area can directly stimulate an action potential in the post-synaptic area. There is electrical transmission across the synapse.

Most synapses, however, have a wider cleft across which the direct passage of the action potential is not possible. In this case the synaptic knob contains numerous synaptic vesicles which contain a **chemical transmitter substance**. When the action potential arrives at the synaptic knob, it causes the vesicles to move to the pre-synaptic membrane and release the chemical transmitter into the cleft. The transmitter then diffuses across the cleft to the post-synaptic membrane where it combines with special receptor sites. This combination is believed to alter the permeability of the membrane, and bring about its depolarisation. Because the receptor sites occur on only one side of the synaptic cleft, chemically transmitting synapses impose a one-way direction on the passage of nerve impulses through the nervous system.

Many different substances function as synaptic transmitters. The best known transmitters are **acetylcholine** (ACh) and **noradrenalin**. Once depolarisation of the post-synaptic membrane has been achieved, enzymes in the cleft break down the transmitter. This frees the receptor sites to receive further emission of transmitters when another action potential arrives at the synaptic knob. Repeated impulses arriving at the synapse can lead to the depletion of transmitters in the vesicles. This condition is known as **synaptic fatigue**. No more impulses can cross the synapse until the supply has been replenished.

A **neuromuscular junction** is a synapse between a neuron and a special thickened and folded part of the muscle fibre membrane, called an **end plate**. The chemical transmitter in this case is always acetylcholine. It is released from the axon terminal of the neuron, causing depolarisation of the end plate and bringing about muscle contraction.

Synapses can be excitatory and bring about depolarisation of the joining element. They can also be inhibitory, in which case the receptor–transmitter combination causes an increase in negativity of the inside of the post-synaptic membrane. This

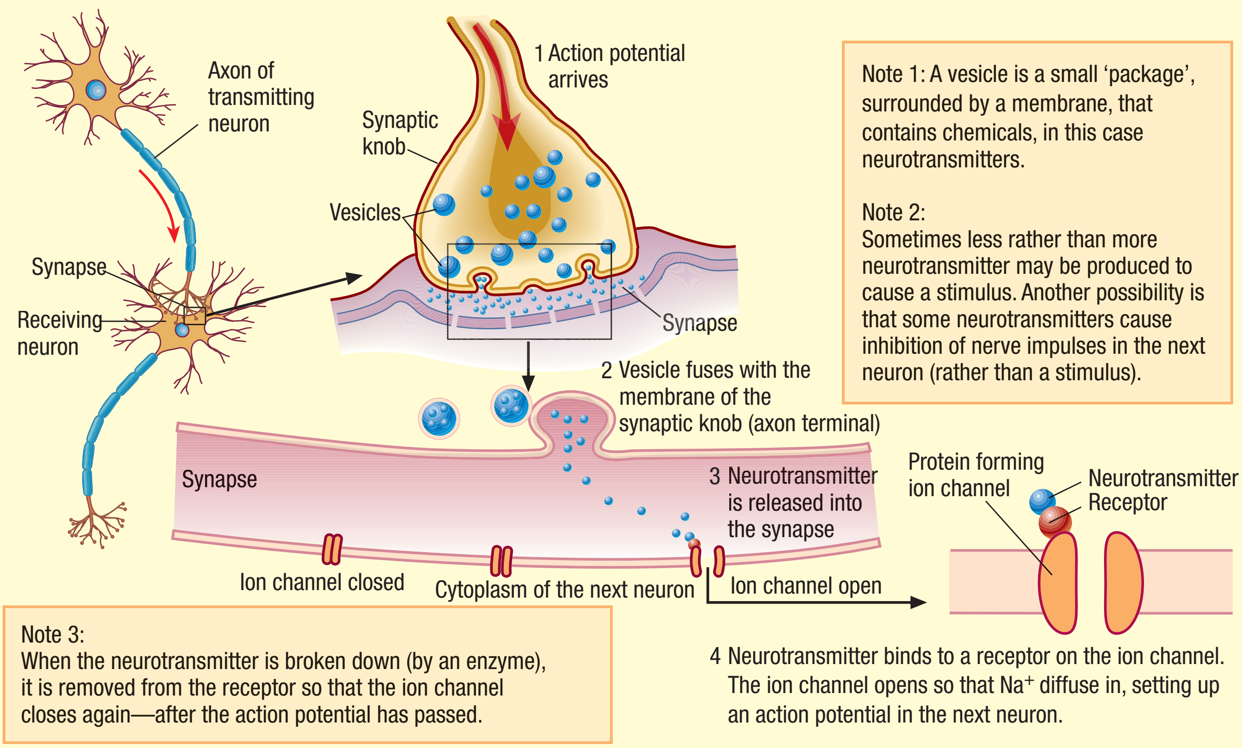


Figure 18.8 General features of a chemically transmitted synapse

hyperpolarisation makes it more difficult for subsequent depolarisation. Inhibitory synapses therefore act as 'brakes' on the post-synaptic cell.

Many drugs and poisons exert their effects by interfering with the synaptic mechanism. They may:

- prevent the release of transmitter substance (e.g. botulism)
- prevent the transmitter from combining with the receptor (e.g. curare, which competes with ACh for the receptor sites at neuromuscular junctions and so results in muscular paralysis)
- inactivate the enzyme that breaks down the transmitter (e.g. organophosphate poisons). Prolonged end-plate stimulation and subsequent uncontrollable muscular spasms result.

Synapses do not merely transmit nerve impulses from one cell to another. They can filter out weak stimuli, by not generating an action potential in the post-synaptic membrane unless a particular frequency is reached. Most synapses enable information from different sources to interact. Sorting out of nerve impulses can be achieved by information from one source acting as an inhibitor to information from other sources.

Organisation of the human nervous system

The two parts of the nervous system are:

- **central nervous system** (CNS)—brain and spinal cord
- **peripheral nervous system**—cranial and spinal nerves.

In humans there are thirty-one pairs of **spinal nerves**, one per body segment. Each **nerve** carries fibres (axons and dendrites) to and from all parts of the body except the head region. It has two separate connections with the spinal cord: a dorsal and ventral root. At the dorsal root, sensory fibres enter the spinal cord, whereas motor fibres leave at the ventral root. Each of these nerves divides into a number of branches. For example, a dorsal branch innervates the skin and muscles of the back, and a ventral branch innervates the skin and muscles of the ventral part of the body. The cell bodies of sensory neurons are found just outside the spinal cord in a swelling (**ganglion**) that connects the sensory nerve to the spinal cord. The cell bodies of motor neurons are inside the spinal cord.

There are twelve pairs of **cranial nerves** in the human body which arise from the ventral surface of the brain. All, except the vagus nerve, are involved in behaviours associated with the head only. Some of these nerves, such as the optic nerve from the eye, are sensory nerves. Others—for example, the hypoglossal nerve to the tongue and neck muscles—are motor only. Some nerves contain both sensory and motor fibres. The facial nerve inputs information from the tongue and palate and also sends messages to the salivary glands and facial muscles.

There are two major divisions of the peripheral nervous system: the **somatic** and the **visceral** nervous system. The somatic nervous system is concerned with the outer body tube (skin, skeletal muscle and associated organs). The visceral nervous system is concerned with the inner body tube and organs. Both of these divisions contain sensory and motor neurons. The motor area of the visceral nervous system is also called the **autonomic nervous system** since it is generally not under conscious control of the higher centres of the brain. These motor neurons are part of either the **sympathetic** or **parasympathetic** system. In these systems impulses pass from the CNS to the effector via two motor neurons. Ganglia form where the two motor neurons synapse.

In the parasympathetic system:

- the transmitter is acetylcholine
- the ganglia are situated on or near the effector
- the post-ganglionic fibres are short.

In the sympathetic system:

- the transmitter is noradrenalin
- the ganglia lie close to the spinal cord
- the post-ganglionic fibres are relatively long.

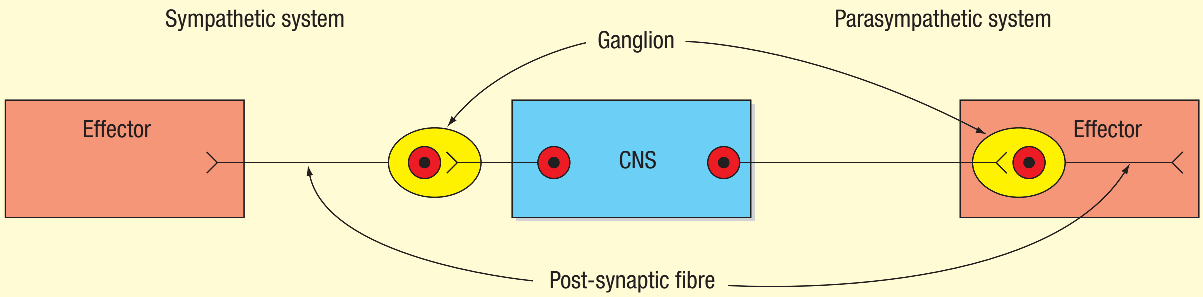


Figure 18.9 Position of the autonomic ganglia

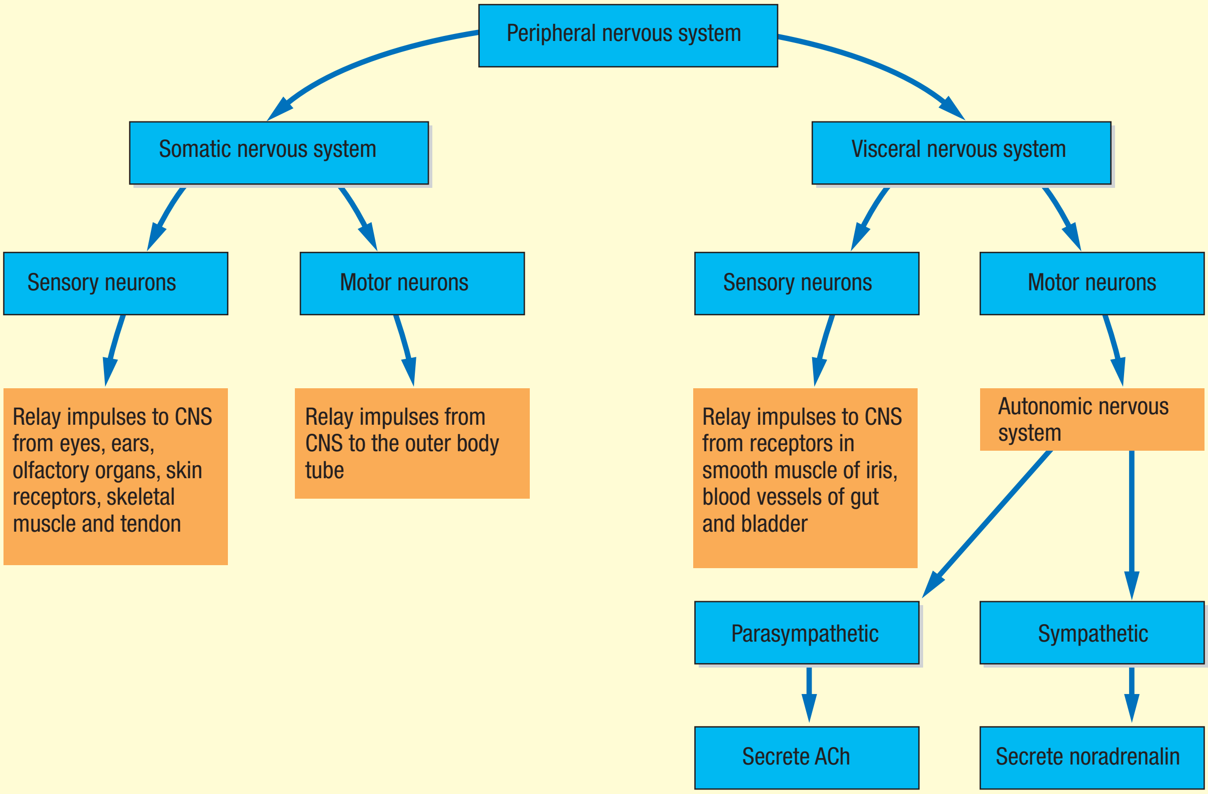


Figure 18.10 Divisions of the peripheral nervous system

Table 18.3 Summary of the responses evoked by the autonomic nervous system

Sympathetic	Parasympathetic
Dilates pupil	Constricts pupil Stimulates tear gland
Suppresses secretion from salivary gland	Simulates secretion from salivary gland
Contracts hair erector muscles	
Dilates bronchioles	Constricts bronchioles
Slows peristalsis	Accelerates peristalsis
Accelerates heart	Slows heart
Constricts arteries	Dilates arteries
Contracts anal and bladder sphincters	Relaxes anal and bladder sphincters
Controls vasodilation	Controls vasoconstriction
Increases sweat secretion	
Causes secretion of adrenalin	

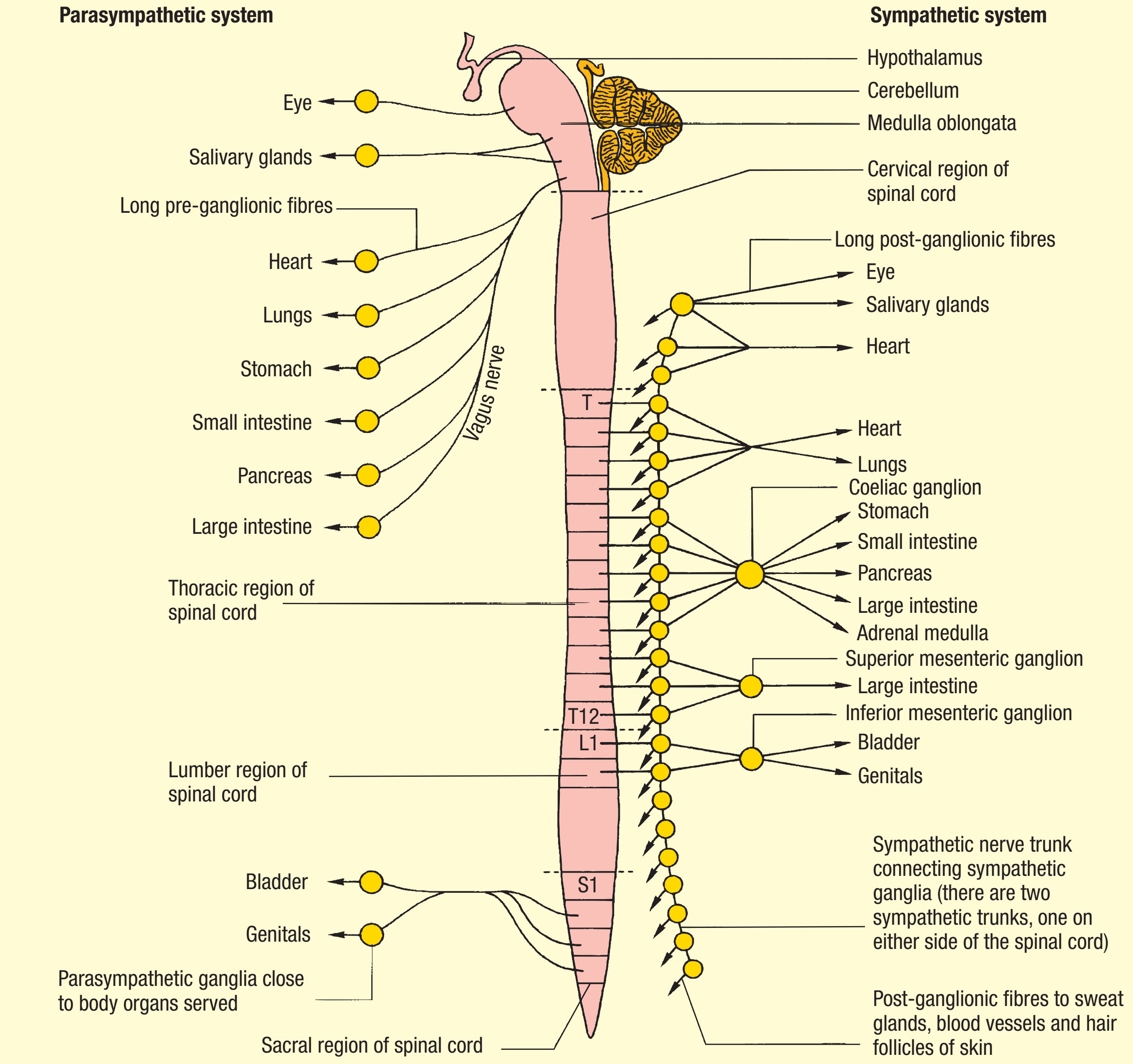


Figure 18.11 The human autonomic nervous system

Case study 18.2: Stress

Amazing feats of bravery and strength have been recorded in cases of severe physical danger. A man lifting a truck to rescue a child trapped under a wheel, a woman running at incredible speed to seek help for an ailing person or a firefighter entering a blazing building—these are extremes of the 'fight or flight' response to stress. The evolution of this response promotes survival in the face of extreme danger to an animal. It is mediated by the nervous and endocrine systems. Once the danger is past, the body's systems return to normal.

Stress can result from any disturbance of the body's physiological systems, and the trigger may be internal or external. The degree of response depends on the situation causing the stress, and the physical and mental condition of the individual. Thus a person's first experience of public speaking may be accompanied by feelings of nausea, sweating, dry mouth and hyperventilation. After many such appearances, mild 'butterflies' may be the only significant change.

In short-term stress situations, the stimulus initiating the response is transmitted to the hypothalamus. Sympathetic nerves mobilise the major organs and systems for action. Heart rate increases and blood is directed away from internal organs to the muscles. These and related actions are immediate. The adrenal medulla is also stimulated to secrete adrenalin and noradrenalin which supplement the sympathetic nerve transmitter substance. The body is now ready to 'fight' or rapidly retreat ('flight').

Most stress, however, is prolonged and part of the lifestyle of modern societies. Studying for exams, death of a loved one, crowded living conditions, loneliness or financial concerns all result in long-term stress. Continued release of adrenalin, often associated with growth of the adrenal medulla, results in irritability, inability to sleep, lack of appetite and restlessness.

Research has indicated that long-term stress is often associated with increased susceptibility to infections. The adrenal cortex is stimulated to secrete more cortisol. Cortisol initiates the breakdown of proteins to amino acids, which are converted either to glucose or the respiratory enzymes. It also suppresses inflammation and inhibits the immune response.

The brain

The CNS develops in chordates from a hollow, dorsal neural tube that extends the length of the body. The anterior end of the tube swells to form the brain and the rest develops into the spinal cord. The hollow centre persists in the adult as spaces or ventricles in the brain and the central canal of the spinal cord. These spaces are filled with **cerebrospinal fluid** which distributes nutrients and oxygen to the nervous tissue.

The **spinal cord** is surrounded and protected by the vertebral column. It is composed of outer **white matter** and inner **grey matter**. The grey matter contains cell bodies and non-myelinated fibres, whereas the white matter consists of myelinated fibres. The two main functions of the spinal cord are to connect the spinal nerves to the brain and to act as a coordination centre for reflex actions.

The **brain** of all vertebrates, enclosed within a protective cranium, consists of a forebrain, midbrain and hindbrain. The extent of the development of each of these areas varies in the different classes of vertebrates, having maximum development in the higher mammals.

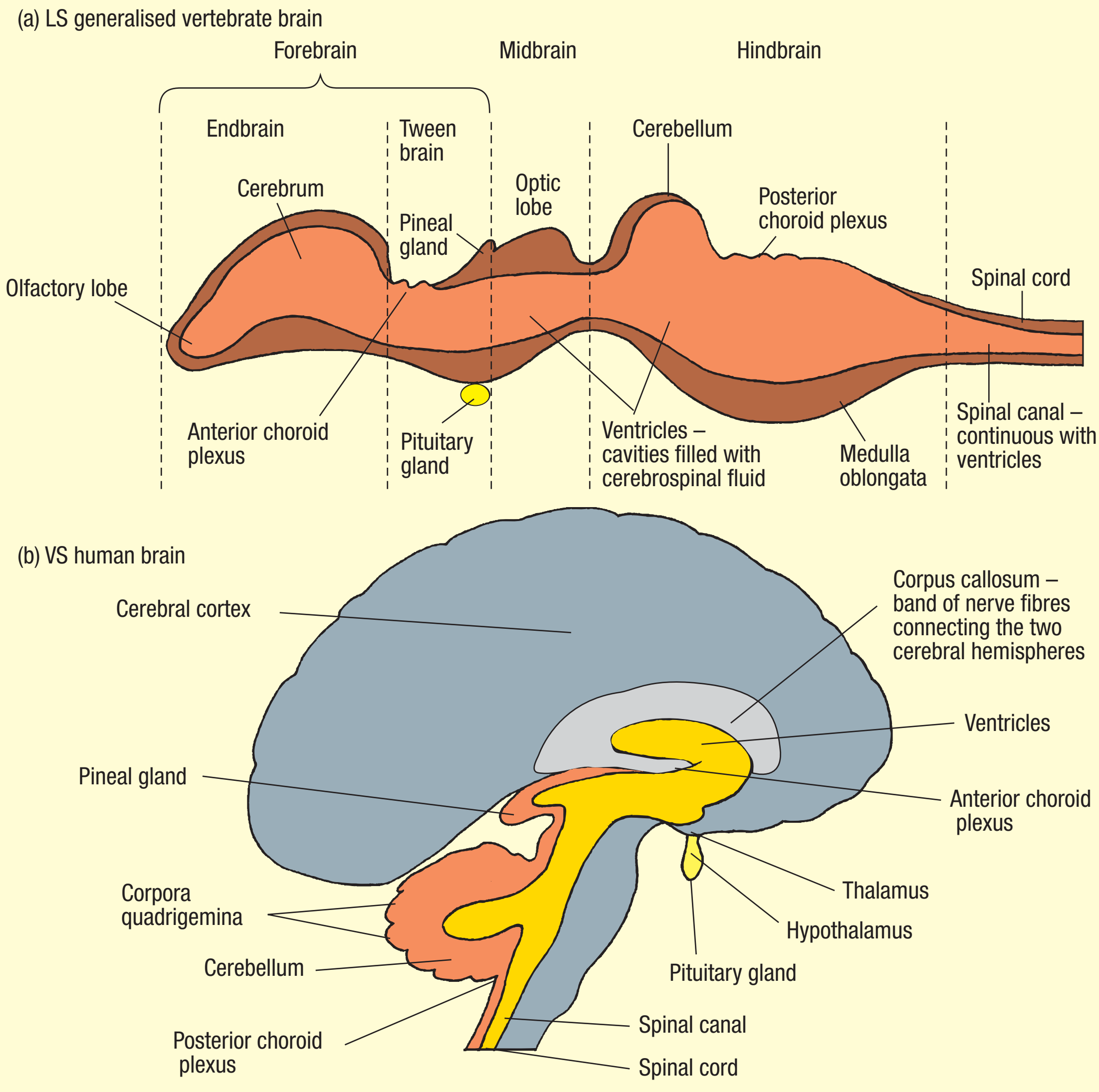


Figure 18.12 Sections through vertebrate brains

Like the spinal cord, the brain is composed of white matter and grey matter. Areas of grey matter form centres for cell bodies concerned with specific sensory and motor impulses, such as the respiratory centre in the hindbrain. The white matter consists of tracts of fibres which link various parts of the brain together and with the receptors and effectors.

The human cortex shows division of labour between the left and right sides. The left hemisphere functions mainly in thought centres associated with speech, logic, writing and arithmetic. The right is involved in the creative activities of spatial, artistic and symbolic thought processes. The two sides of the cerebrum are linked by a bridge of tissue, the corpus callosum, through which impulses are passed in both directions.

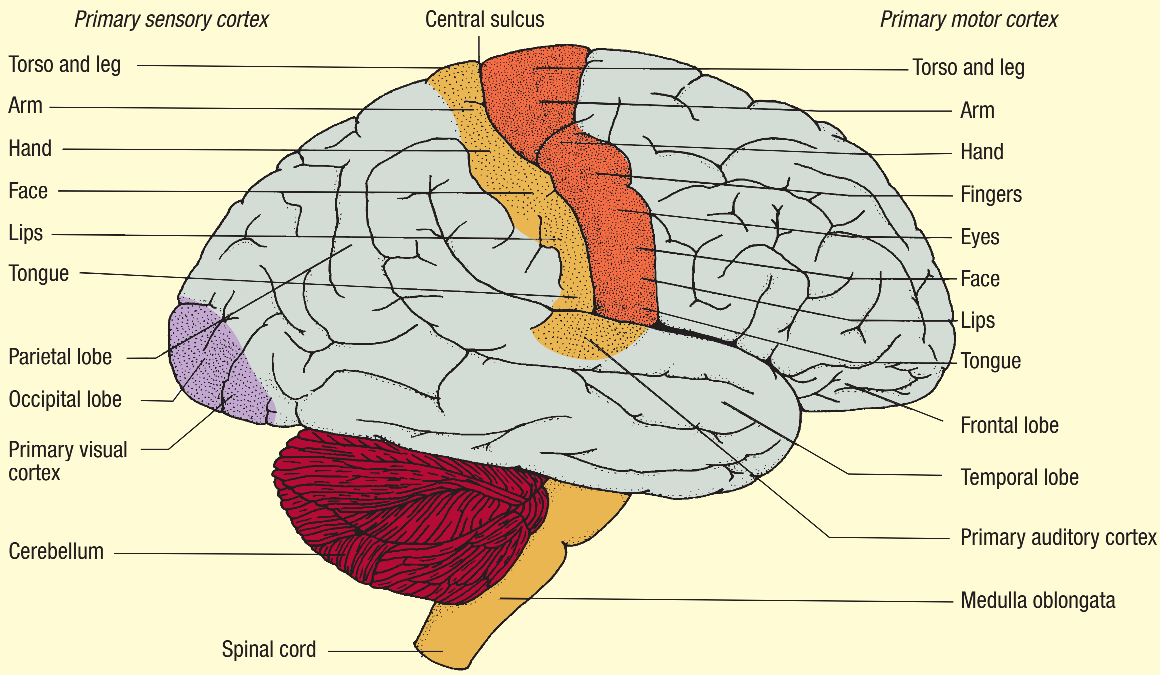


Figure 18.13 The human brain, showing locations of functions

Table 18.4 Major functions of the mammalian brain

Section	Area	Functions
Hindbrain	Medulla oblongata	Controls heartbeat, blood pressure, respiration rate, swallowing, salivation, vomiting, sneezing and coughing
	Cerebellum	Controls posture, equilibrium and fine adjustments of movement
Midbrain	Corpora quadrigemina	Controls eye movements and auditory reflexes
	Red nucleus	Controls movement and posture; inhibits excessive contraction of postural muscles
Forebrain:		
(a) Tweenbrain	Thalamus	Contains tracts which form the link between forebrain and spinal cord
	Hypothalamus	Controls sleep, feeding, drinking, speech, body temperature, certain emotions and osmoregulation
	Pineal body	Believed to be involved in light sensitivity
	Pituitary gland	Regulates endocrine glands; controls osmoregulation, growth, metabolism and sexual development
(b) Endbrain	Cerebrum	The outer cortex is deeply folded, thus increasing the surface area; it is the centre of integration and coordination of all but hindbrain activities via a network of neurons called the reticular formation; correlates incoming information with past experience; memory; has some direct sensory (e.g. olfactory) and motor functions

All sensory impulses entering the brain pass through the brainstem (medulla, midbrain and thalamus) before being relayed into the cortex. During passage through this region the incoming fibres divide, with one branch going directly to the cortex and the other going to the diffuse network of neurons in the brainstem called the **reticular formation**. Part of this formation acts as a sensory filter, suppressing background 'noise' and selecting only the information that is significant to relay to the cortex. This **reticular activating system** (RAS) plays an important role in arousal and conscious awareness of the cerebral cortex, and thus in learning and memory.

It appears that there are several neurotransmitters involved in the filtering mechanism of the RAS:

- 5-hydroxytryptamine (5-HT) causes drowsiness and sleep.
- Noradrenalin (NA) causes behavioural alertness. Severe depression may be related to abnormally low levels of noradrenalin at certain synapses.
- Acetylcholine (ACh) increases the level of activity of the cortical neurons.
- Dopamine is a transmitter for a few neurons involved in motor activity. Low levels of dopamine in certain areas of the brain have been associated with Parkinson's disease. People with this condition typically suffer from muscular tremors and weakness.
- Serotonin is found in regions of the brain associated with arousal and attention. Sleep is brought on by high levels of serotonin.
- Gamma-aminobutyric acid (GABA) is the major inhibitory transmitter in the central nervous system. A genetic disease, Huntington's disease, causes a progressive destruction of brain cells which results in death after about 10 years from the onset of the symptoms. One of the features of the disease is the loss of GABA synapses.

Case study 18.3: The effect of drugs on brain activity

Certain drugs can cause changes in brain activity due to interference with the transmitters. Amphetamines are noradrenalin mimics and thus increase arousal. They are antidepressants which are used clinically to elevate mood, increase alertness and reduce fatigue. By stimulating RAS noradrenalin secretion, the activity of the cortex is enhanced. These drugs also act directly on the hypothalamus to suppress the food drive and increase body temperature. Amphetamine abuse can lead to hallucination resulting from lack of sleep, and this can develop into schizophrenia (an inability to distinguish the real from the imaginary). Cocaine, ecstacy, caffeine and nicotine also have these mimic properties.

Alcohol, barbiturates, marijuana and LSD have been found to interfere with information transfer from short-term to long-term memory, possibly through blocking ACh in the reticular formation. Thus these drugs inhibit learning. Many tranquillisers block dopamine receptors. LSD interferes with the normal action of serotonin in the brain.

The hallucinogenic drugs, such as LSD, mescaline and psilocin, all bear a chemical resemblance to 5-HT and probably act by antagonising the action of this neurotransmitter, thereby causing diffuse brain activity.

Nerve pathways

Most behaviour is brought about by the passage of impulses from a receptor to the CNS and then on to an effector. Three main types of neurons are involved in this process: sensory, association and motor neurons.

Sensory neurons

The dendrites of sensory neurons tend to be very long and are myelinated. The cell body is found in the ganglion adjacent to the CNS (the dorsal root ganglion). The axons are short and end in the CNS.

Association neurons

Association neurons are found only within the CNS. They function in linking sensory and motor neurons or different parts of the CNS. These neurons may form longitudinal tracts running the length of the spinal cord and into the brain.

Motor neurons

The dendrites of motor neurons are short and non-myelinated. The cell body is within the CNS and the myelinated axon exits the CNS via the ventral root to run to the effector organ.

The simplest nerve pathways are **reflex arcs** which are responsible for bringing about reflex actions such as the knee jerk. Such actions are unlearned, automatic responses to a stimulus. The reflex arc may involve only a sensory and motor neuron which make a synaptic contact within the CNS, although usually an association neuron is also involved.

Most behaviours, however, are more complex than this and often involve many individual responses. These responses are coordinated in the brain via impulses conducted by association neurons running in ascending and descending tracts in the white (myelinated) matter of the spinal cord.

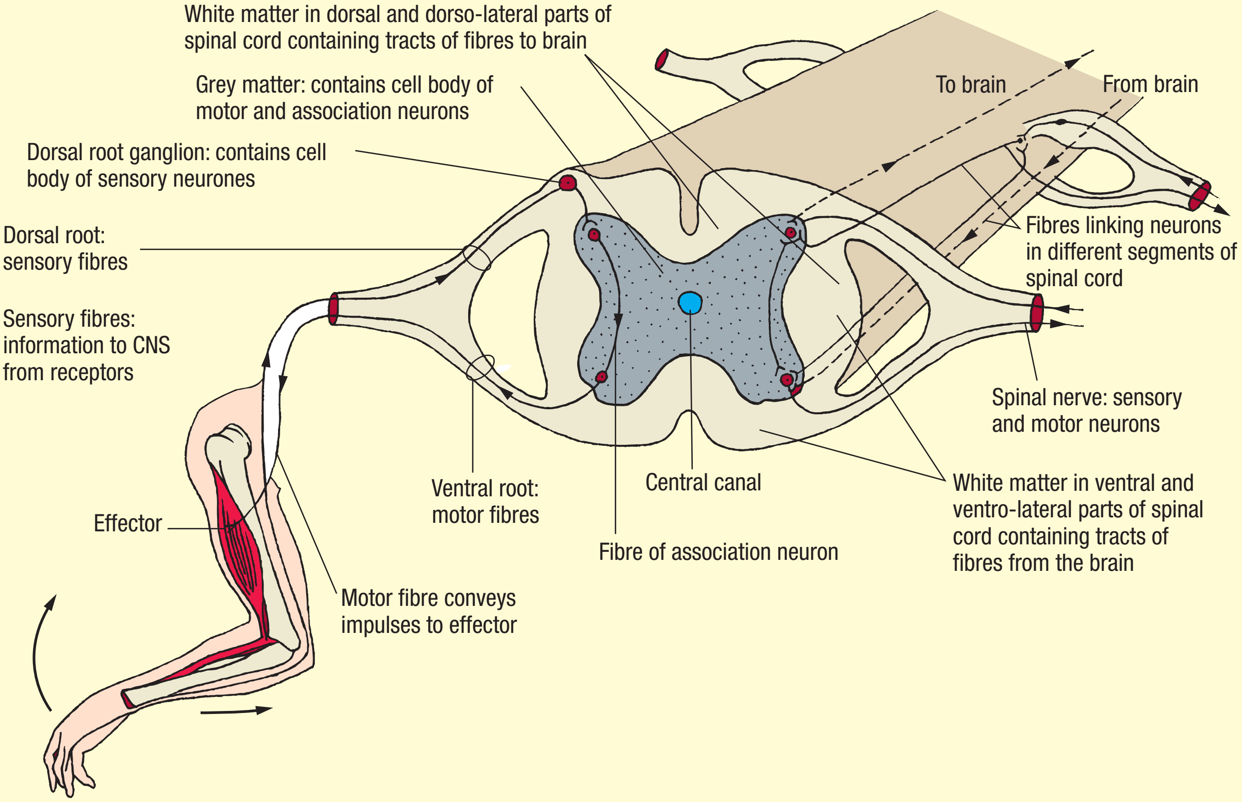


Figure 18.14 A portion of the human spinal cord showing possible nerve pathways

SUMMARY

The nervous system provides the fastest means of communication within the body. In mammals the nervous system consists of neurons concentrated in a central nervous system (CNS) and peripheral nerves.

Neurons possess a cell body from which arise a variable number of dendrites with one or more axons. The axon generally has a myelin sheath.

Nerve cells are classified as sensory, association or motor.

At rest, the inside of the neuron membrane is negative with respect to the outside. During the passage of a nerve impulse, this situation is momentarily reversed.

For a period of time after the passage of an impulse, no further impulse can pass (refractory period). Once the membrane is repolarised, a new impulse can be generated. The size of an action potential is independent of the strength of the stimulus.

Adjacent nerve cells are connected by synapses. The impulse passes from one neuron to the next via a transmitter substance which depolarises the membrane of the next neuron. The transmitter substance is subsequently broken down to prevent continuous stimulation. The nerve–muscle junction acts in a similar manner.

Nerve cells are frequently organised into reflex arcs which involve receptor, sensory, association and motor neurons and an effector.

The vertebrate CNS consists of the brain and spinal cord. The brain is subdivided into forebrain, midbrain and hindbrain.

The peripheral nerves are divided into spinal and cranial nerves. They may be associated with the outer body tube (somatic) or inner body tube (visceral). Visceral motor neurons constitute the autonomic nervous system and, depending on their transmitter substance, form the sympathetic or parasympathetic system. The actions of each are antagonistic.

Review questions

18.5 Draw and label a neuron.

18.6 Explain how a nerve impulse is transmitted along an axon. In your answer, use the following terms: polarised, depolarised, action potential, sodium pump, resting potential, recovery period.

?

18.7 What does it mean that nerve conduction is an all-or-nothing response?

18.8 How does a chemical synapse bring about one-way nerve conduction?

18.9 List all the divisions of the vertebrate nervous system.

18.10 Replace each of the words in bold in the sentence below with one of the following terms: stimulus, receptor, central nervous system, effector, impulse.

*The student's **salivary glands** produced saliva when the **sound** of the bell entered her ear and the **message** reached her **brain**.*

18.11 Name the part of the CNS that controls:

(a) thinking

(b) body reflexes

(c) balance and coordination

(d) heart rate and breathing.

18.12 Distinguish between sensory, motor and association neurons.

18.13 What is a reflex arc? Draw and label the structures involved.

18.1.3 Perception of stimuli

Information about the environment is carried to the CNS by sensory neurons. These neurons are triggered by a stimulus. The energy of the stimulus is converted to the energy of an action potential in the sense organ.

There are many different types of stimuli. Temperature, pressure, humidity, light, vibrations and chemical stimuli each possess a different type of energy which must be translated to the nerve impulse. Sense organs are therefore specialised to respond to a particular stimulus. In all cases, the more intense the stimulus, the greater is the frequency of action potentials.

The types of environmental clues to which an animal responds are ultimately related to the significance of the clue to its survival. Different animals have different niches. Thus they will respond to different types of stimuli. Many bats and dolphins, for example, emit and can hear reflected ultrasounds which cannot be detected by other animals. Dogs use smell in both intraspecific communication and hunting. Their olfactory organs are therefore particularly sensitive.

Different sensory neurons transmit information to different parts of the brain. In many cases, several different types of sense organs are stimulated simultaneously. The interpretation of the information involves communication between the different centres in the brain. Past experiences (memory) may also be a significant factor in the animal's response to a particular situation.

Sensory receptors are found throughout the body. Those involved in detecting the external environment are found in the skin (pain, touch and temperature receptors), the mouth (taste receptors) and the head (light, sound). Other receptors are internal. Thus stretch receptors are found in the lungs and muscles, in the carotid and aortic bodies for detecting blood pH, and receptors that measure distension and pH are in various parts of the intestine.

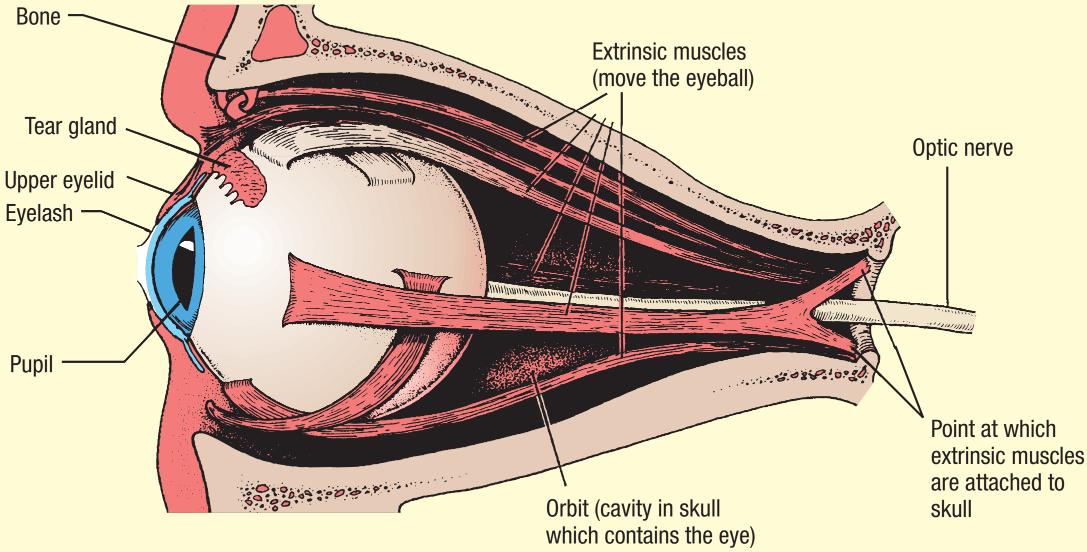
Sensory cells tend to be grouped together in such a way as to maximise the reception of a stimulus. Many have accessory tissues to magnify, select or filter particular stimuli.

The human eye provides a good example of grouped sensory tissue. Vision of a particular object is aided by a **lens** mounted on muscles which change its shape according to the distance from the object. Light reflecting from an object passes through a protective **cornea** and into the **pupil** to the lens. The pupil is surrounded by a coloured **iris** which expands and contracts in different light intensities. This is controlled by the autonomic nervous system. In bright light the pupil diameter is small, whereas in dim light it is large. Light passing through the lens forms an image on a special layer of tissue, the **retina**, at the back of the eye.

Light-sensitive cells, **photoreceptors**, in the retina change light energy to the energy of the action potential. Each is connected to a nerve fibre. All of the nerve fibres from the retina form the optic nerve, which carries information to the optic centres of the brain. The number and position of the photoreceptor fibres stimulated determine what is seen.

There are two types of photoreceptors in the human eye. The **rods** are extremely sensitive to low light intensities. The more numerous **cones** are concentrated into a central area called the **fovea**. There are three types of cone cells, each with different pigment systems (red, blue and green), which are stimulated by different frequencies of light. Colour vision is thus detected.

(a) Structures attached to the eyeball



(b) Section through the eye

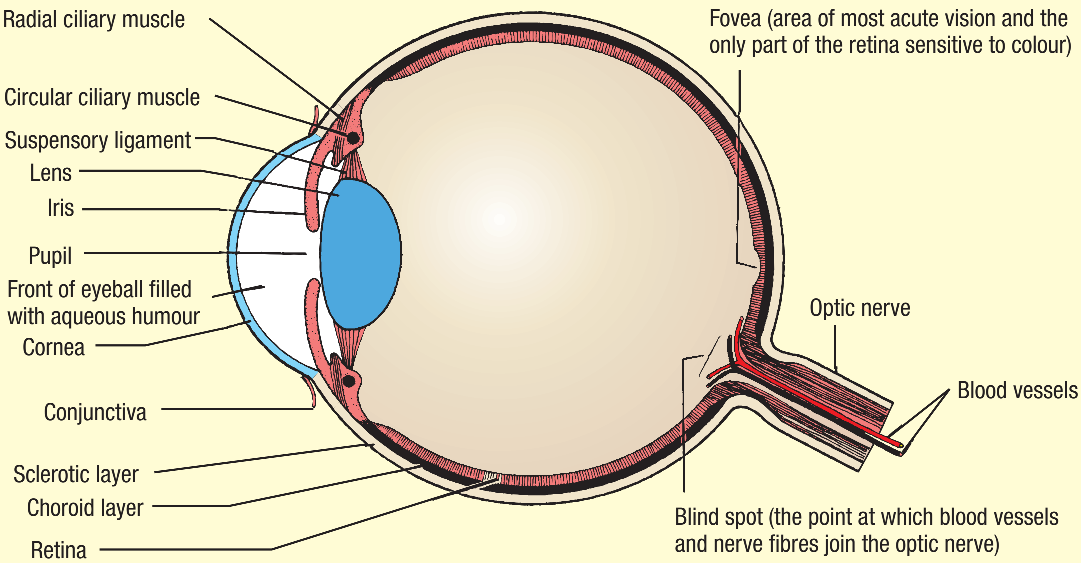


Figure 18.15 Structure of the human eye

Case study 18.4: Hearing and causes of impairment

The ear consists of four main parts: the external, middle and internal ear, and the central auditory pathways. The external ear has an **auricle** or pinna which channels sound into the **external auditory canal**. The sound waves cause vibrations of the **tympanic membrane** (drum), which separates the external and middle ear. The vibrations mirror those of the frequencies of the sound energy. These vibrations are transmitted through three bones of the middle ear—from the **malleus** (hammer), via the **incus** (anvil) to the **stapes** (stirrup)—on to an opening of the inner ear called the 'oval window'. The vibrations are transferred to the fluid of the spiral **cochlea**, to its centre, the **organ of Corti**. Within this organ are the sensory cells, each with a small tuft of hairs. Each cell is specialised to respond to a particular pitch or frequency of sound as it is transmitted to the hairs. The transformed sound energy is transmitted to the auditory centres of the brain by the auditory nerve. Since the ear is stimulated by the movement of air particles, it is classified as a mechanoreceptor.

The organ of balance is found just above the cochlea. It consists of a **sacculus** and **utriculus**, which register changes in the head position, and three semicircular canals. These canals sit in three planes at right angles to each other. They detect changes of overall body movement in all directions. The brain

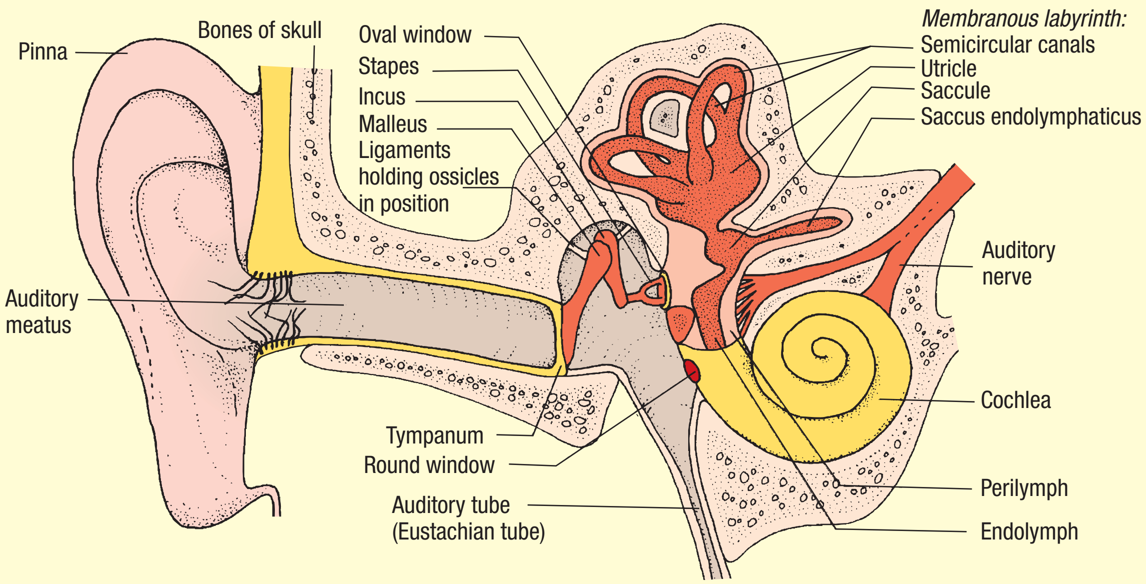


Figure 18.16 Structure of the human ear

coordinates input from the eyes, the organ of balance and muscles to maintain body balance. When one of these systems is malfunctioning, dizziness may result.

The range of human hearing is between sixteen vibrations per second (16 Hz) and 20 000 vibrations per second (20 kHz). Hearing loss is often associated with age, but may also be caused by damage resulting from loud noise or a blow. Hearing loss usually occurs first in the higher sound frequencies.

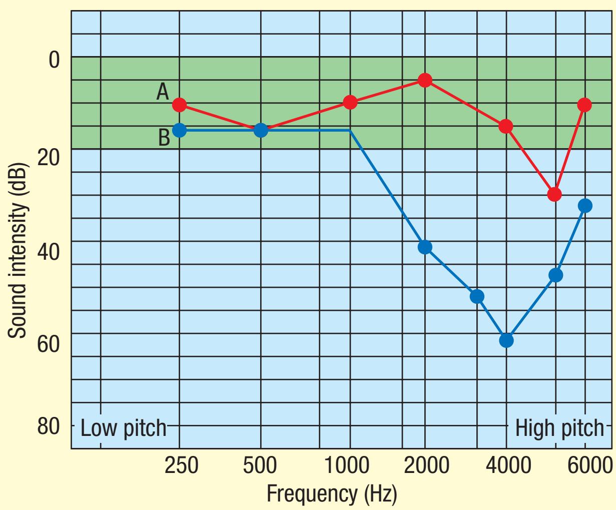


Figure 18.17 An audiogram showing the lowest intensities of sound (measured in decibels) at various frequencies that the human ear can perceive. The dark band indicates the normal hearing range. Curve A shows a slight hearing loss between 4000 and 6000 Hz; curve B shows severe hearing loss.

Both long-lasting intense noise and impulse sounds such as a loud bang can cause hearing damage, by destroying the hairs of the sensory cells. In many cases these hairs cannot be restored. The extent of the hearing loss is determined by the number of hairs destroyed.

The most common causes of hearing loss from impulse sounds ('acoustic trauma') are sledge blows against metal, gunshots and fireworks. In these cases, permanent hearing loss may be instantaneous.

Most hearing damage, however, occurs as a result of long-term exposure to noise. The higher the pitch, the clearer the tone and the greater the intensity, the more damage is inflicted. Frequent exposure to loud disco music, rock concerts and blasts through walkman earpieces all contribute to significant hearing loss and/or ringing in the ears. Loss of hearing is generally gradual, and may not be noticed at first.

Blows to the skull, particularly below and behind the ear, can also cause hearing loss. A hard blow may cause concussion of the inner ear and destruction of sensory cell hairs. The incus and stapes of the middle ear can also be dislocated. A fracture of the skull in this area may cause instantaneous, total deafness which is permanent.

Loud noise in conjunction with vibrations has an additive effect. Commercial fishermen often have hearing loss. They stay out in their boats for days and are subjected to the compounding effects of engine noise, boat vibrations, exhaust, waves and wind.

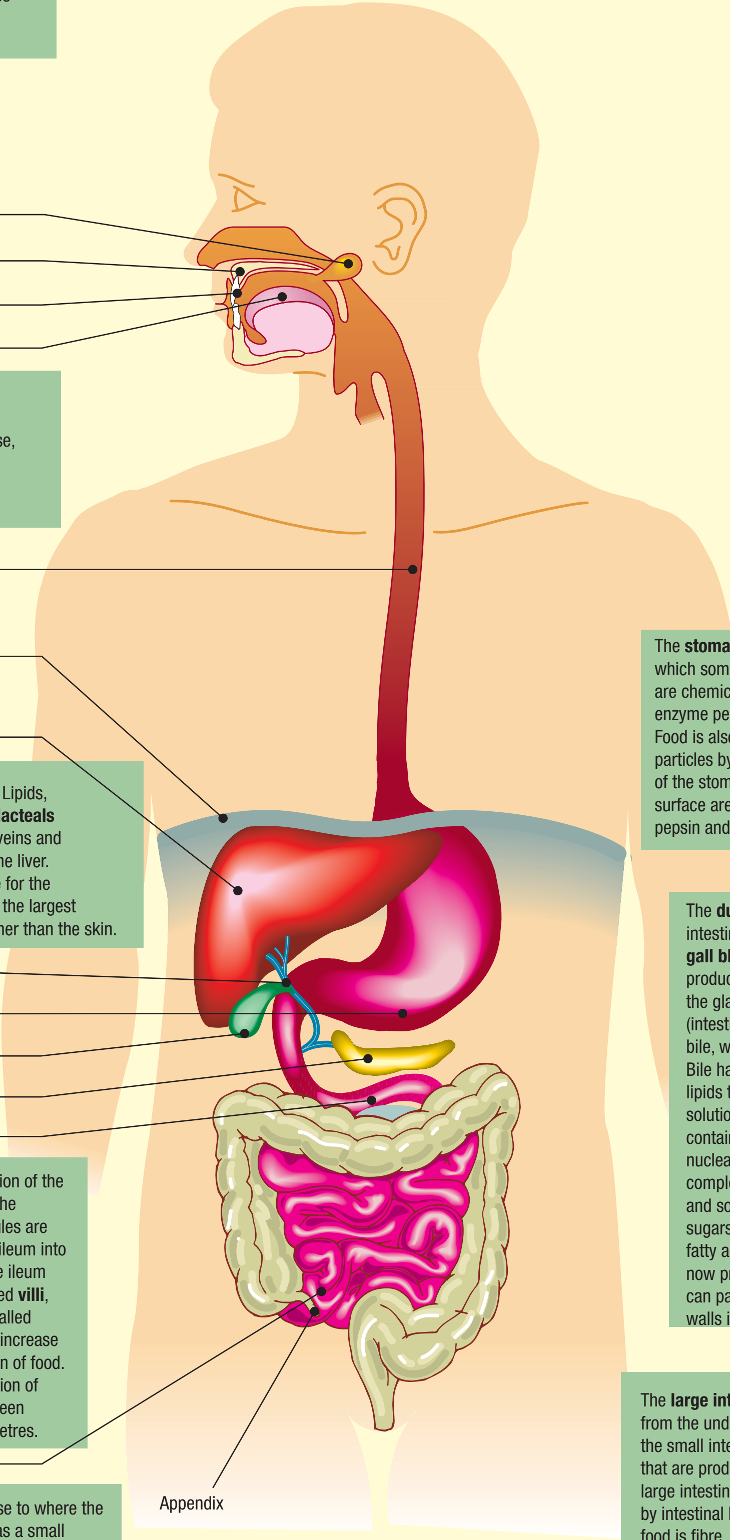
In the **mouth** food is digested both mechanically (physically) and chemically. Biting, chewing and grinding by the teeth increases the food surface area for the action of the digestive enzymes.

The **tongue** mixes the food with saliva and forms it into a ball called a bolus.

Salivary glands secrete (produce and release) saliva into the mouth. Saliva contains amylase, which breaks down complex carbohydrates (polysaccharides) into the disaccharide maltose.

Digested food travels to the liver. Lipids, fatty acids and glycerol travel in **lacteals** (lymph vessels), which join with veins and so enter the blood and move to the liver. The liver is the processing centre for the body's nutrients and wastes. It is the largest organ in the mammalian body other than the skin.

The **ileum** is the coiled, long section of the small intestine and follows from the duodenum. Digested food molecules are absorbed across the walls of the ileum into blood capillaries. The walls of the ileum are arranged into projections called **villi**, which contain more projections called **microvilli**. The villi and microvilli increase the surface area for the absorption of food. The total surface area for absorption of nutrients by the human villi has been estimated at over 4000 square metres.



The **oesophagus** is a muscular tube down which food passes to the stomach.

The **stomach** is a J-shaped sac in which some of the proteins in the food are chemically digested by the protease enzyme pepsin activated by hydrochloric acid. Food is also physically broken down into fine particles by contractions of the muscles of the stomach walls. This increases the surface area of the food for contact with pepsin and the enzymes in the intestine.

The **duodenum** (first part of the small intestine) receives secretions from the **gall bladder** and the **pancreas** and also produces its own digestive enzymes from the glands in the walls of the intestine (intestinal juice). The gall bladder stores bile, which is produced by the liver. Bile has a detergent action, enabling the lipids to mix with the aqueous (water) solution in the intestine. Pancreatic juice contains proteases, amylases and nucleases, which break down proteins, complex carbohydrates, nucleic acids and some lipids into amino acids, sugars, phosphates, nitrogen bases, fatty acids and glycerol. The food is now present as small molecules, which can pass across the intestinal walls into the blood.

The **large intestine** (colon) absorbs water from the undigested food that passes from the small intestine. It also absorbs vitamins that are produced by bacteria living in the large intestine; for example, vitamin K is made by intestinal bacteria. Most of the undigested food is fibre. Fibre consists mainly of cellulose from plant cell walls. The presence of fibre in the diet is necessary, as it helps waste products to retain some water and move through the large intestine faster.

The **caecum** is a blind pocket close to where the large and small intestine join. It has a small projection called the **appendix**. The caecum and the appendix have no special function in the human digestive system but they are important in herbivores.

The **rectum** stores waste products of digestion (faeces), which are passed out through the **anus**.

Figure 18.18 The human digestive system

SUMMARY

Sensory receptors are cells or groups of cells that convert the energy of environmental stimuli to action potentials in sensory neurons. This information is transmitted to specific centres in the brain which register the incoming information and coordinate appropriate responses.

Different types of sensory organs are specialised to detect, and often amplify, the various forms of stimuli. Receptors are classified according to the type of stimulus they detect.

Review questions

18.14 How do sensory receptors function?

18.15 What is the function of the iris of the eye?

18.16 What functions do the rods and cones perform in the retina of the eye?

18.17 Describe what happens from the time light hits an object to the time a person 'sees' the object.

18.18 Explain why the ear is classified as a mechanoreceptor.

18.2 Digestion

Humans feed on large chunks of solid organic material derived from plant and animal organisms. Like other chunk feeders, they must have the means to:

- obtain and ingest food
- digest the food
- absorb the digested molecules and transport them to the cells for assimilation
- egest undigested food.

18.2.1 General structure of the digestive system

The digestive system of humans consists of an alimentary canal and associated organs. Throughout the length of the alimentary canal, each part is modified for a specific function. Other organs, such as the liver and pancreas, are linked with it. The overall structure of the digestive system, and the functions performed at each specialised part, are summarised in Figure 18.18.

In the abdominal region there are thin membranes, through which blood and lymph vessels run, connecting the alimentary canal to the body wall. The membranes also hold the loops of the alimentary canal together.

The inner layer of the alimentary tract differs along its length, reflecting its function at any particular point. The general structure is consistent, however, and consists of four basic layers:

- The outer layer is connective tissue, and is continuous with the thin supporting membranes.
- Inside the connective tissue is an external muscle layer, usually consisting of an outer layer of longitudinally oriented cells and an inner circular layer. These are smooth (involuntary) muscle cells. The muscles are not consciously controlled, and are responsible for peristalsis.
- Inside that is another zone of connective tissue with a high proportion of strong fibres. Within this layer are the major blood and lymphatic vessels, nerves and stretch receptors.
- The inner layer consists of more smooth muscle fibres and loose connective tissue which supports the lining or epithelium. All glands of the alimentary tract are derived from this epithelium.

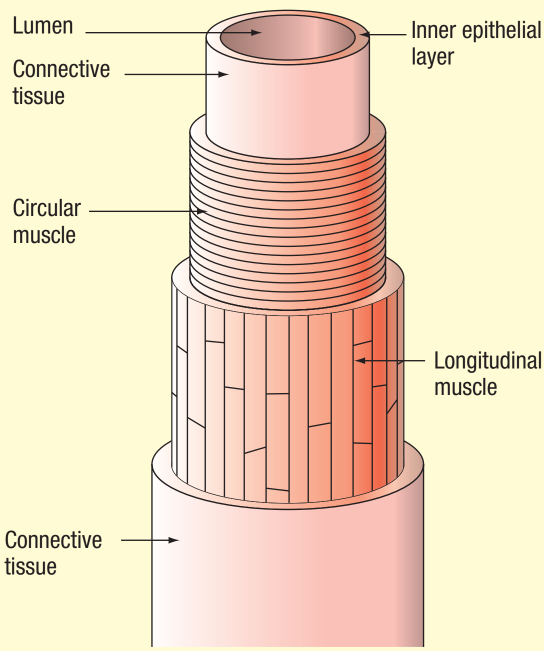


Figure 18.19 Section of the alimentary canal showing the general structure of the wall

18.2.2 Structure and function of the buccal cavity

Humans use their hands, and tools, to obtain food. The food is ingested through the mouth into the **buccal cavity**, where digestion begins. The buccal cavity is bound by the palate and upper jaw dorsally, by the lower jaw and soft tissues ventrally and soft tissues laterally. The upper jaw is fused to the rest of the skull but the lower jaw is movable. It is attached to the skull by the ligaments of the comparatively loose posterior hinge joint. Muscles between the lower jaw and the skull allow some freedom of movement: in the human, the lower jaw can move both sideways and up-and-down. Teeth project from the margins of both upper and lower jaws. A muscular tongue is attached at the posterior, ventral surface of the buccal cavity.

The inner portion of a tooth consists of a bone-like substance called **dentine**, surrounding a core of **pulp** which contains nerves and blood vessels. Each tooth is set in a socket in the jawbone and consists of a **crown**, a **neck** and a **root**. The crown is the biting surface and is covered with a hard material called **enamel**. The neck is surrounded by gum and the root is embedded in bone. The root is covered with cement—another bone-like material. **Peridontal fibres** attach the cement to the jaw. The fibres allow a small amount of movement of the teeth during chewing, thus preventing them from snapping off when hard food is eaten.

Humans have four types of teeth. At the front are the **incisors**, which are typically chisel-shaped and are used to cut food into manageable pieces. They are also used for nibbling actions such as taking corn off a cob or flesh from a bone. Next to these are two **canines**, one at either side of the incisors of each jaw. Although very prominent in carnivores, these are reduced in size in humans, but they still display the characteristic pointed shape. At the back are the cheek teeth, the **premolars** and **molars**, which have projections on their surface called **cusps**. These teeth are used to crush food.

The surface of the buccal cavity, apart from the teeth, is covered in epithelium. Some of the epithelial cells on the tongue are specialised for tasting the food. Other specialised cells form the **salivary glands**, secretions from which keep the surface moist.

The smell of food, or the ingestion of it, causes the salivary glands to produce copious secretions of **saliva**. This is a neutral to slightly alkaline fluid containing mucus and a digestive enzyme, **amylase**. By movements of the lower jaw, the teeth cut and crush the food into small pieces. These are lubricated and moistened by the salivary mucus. The smaller pieces of food can be acted upon by amylase, which starts the breakdown of complex carbohydrates to the disaccharide maltose. The short length of time the food spends in the mouth is probably inadequate for the full breakdown to monosaccharides.

The muscular tongue manipulates the food during chewing. By pushing the food against the roof of the mouth it forms a mass, the **bolus**, ready for swallowing. The tongue then pushes the bolus backwards through the pharynx into the oesophagus. The **pharynx** is a short area behind the buccal cavity, through which both food and air pass to their respective canals.

Swallowing involves a complex set of reflexes during which a flap of tissue called the **epiglottis** blocks off the opening to the windpipe (the **glottis**) and ensures that the food enters the oesophagus.

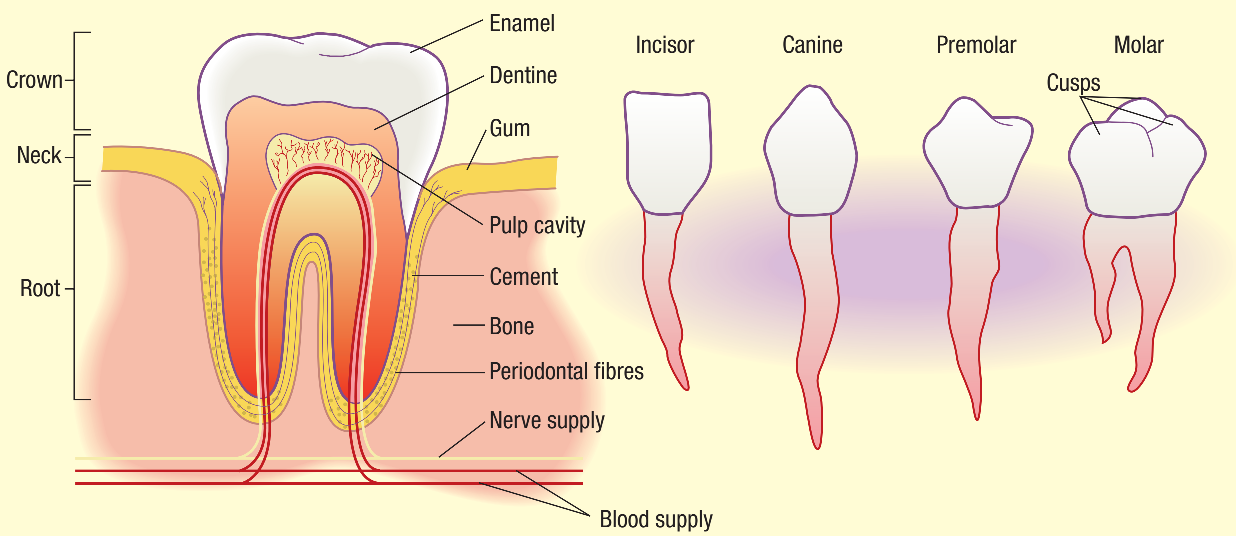


Figure 18.20 Human tooth structure and types

18.2.3 Structure and function of the oesophagus

The **oesophagus** is a long tube running downwards through the throat, thorax and diaphragm to connect with the stomach, which is in the upper portion of the abdominal cavity. Its only function is to transport the bolus to the stomach by peristalsis (see Figure 17.4 on page 424). Although the food bolus is lubricated and the pieces are relatively small, sharp or rough edges still exist which could damage the lining of the oesophagus. The epithelium in this region of the alimentary canal provides a very smooth surface which is constantly being replaced to minimise damage to the underlying tissues.

18.2.4 Structure and function of the stomach

A special ring of muscle, the **cardiac sphincter**, separates the oesophagus from the stomach. When contracted, this closes the entrance to the stomach and prevents backflow of stomach contents into the oesophagus. Peristaltic contractions of the lower oesophagus cause this sphincter to open.

The **stomach** is a large muscular sac, located slightly to the left side below the lower ribs. The posterior end of the stomach is also guarded by a muscular ring, the **pyloric sphincter**, which prevents food leaving it at random. The stomach functions as a storage organ and as a digestive organ. Its storage function makes it possible for feeding to take place intermittently. The stomach has an additional layer of oblique muscles. The three differently oriented muscle layers afford a large range of movements to the stomach wall which churn the food, mixing and breaking it up (physical digestion).

The inner layers of the stomach wall have longitudinal folds which flatten out when the stomach is distended with food. The lining contains several different types of glands, some of which secrete mucus, which protects the stomach lining from the actions of enzymes. Other glands secrete gastric juice, a mixture of hydrochloric acid and several enzymes. These gastric glands are situated at the base of folds in the epithelium, and are stimulated to release **gastric juices** by food entering through the cardiac sphincter.

Each enzyme has an optimum pH at which it operates. The acid conditions of the stomach (pH 1.5–2.5) are optimum for the action of **pepsin**, the main enzyme in gastric juice. The acid also:

- kills any bacteria entering with the food and drink
- prevents further action of amylase
- breaks down the disaccharide sucrose to release glucose and fructose
- breaks down nucleoproteins to form nucleic acid and protein.

Pepsin will mediate the hydrolysis of peptide bonds between only a few specific amino acids, and therefore converts proteins only to polypeptides.

The cells of the alimentary canal are composed of a significant amount of protein, and therefore need protection from the action of the pepsin. Instead of pepsin itself, the gastric glands produce **pepsinogen**, an inactive precursor. This is activated by contact with the acid in the lumen of the stomach to form pepsin. The mucus that is secreted protects the epithelial lining from being digested once pepsin has formed. A peptic ulcer is an area of the stomach lining in which these defences have broken down and the enzymes start to 'eat' it away.

Rennin, another gastric enzyme, acts on milk proteins and causes them to clump together. Although it does not bring about their digestion, rennin is responsible for these proteins coming out of solution and being more readily available for the actions of other enzymes that do digest protein.

Some absorption of water and glucose occurs across the stomach epithelium into capillaries of the underlying connective tissue.

The actions of the stomach, both mechanical and chemical, cause the food to form a soupy mixture or **chyme**. This chyme cannot leave the stomach until it has reached the correct consistency. When this is achieved, the chyme stimulates the pyloric sphincter to release small amounts at a time into the small intestine.

18.2.5 Structure and function of the small intestine

In humans the **small intestine** is about 3 metres long and consists of a short, straight **duodenum** and a long, coiled **ileum**. A combined duct, formed by the union of the **bile duct** from the liver and the **pancreatic duct** from the pancreas, opens into the duodenum.

The inner surface has folds from which small finger-like **villi** (singular *villus*) project (Figure 18.21 on page 482). The folds help to slow down the passage of food and the villi increase the surface area for digestion and absorption. By contraction and swaying, the villi also circulate the chyme. Special cells in pits within the epithelium of the small intestine produce and secrete intestinal juice. Other epithelial glands produce mucus and an alkaline solution.

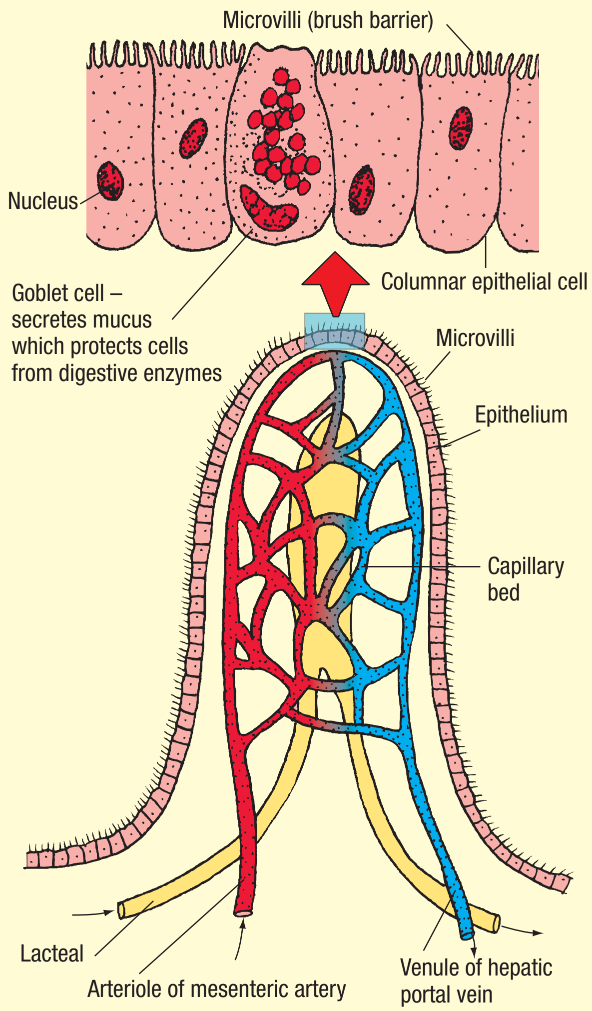


Figure 18.21 The structure of a villus

The duodenum receives fluids made by the liver, pancreas and intestinal wall.

Bile

The liver cells produce **bile** which is stored in the **gall bladder**. Bile is a yellowish-green, watery fluid of pH 8, containing bile salts, bile pigments, mucin and cholesterol. Its alkalinity helps to neutralise the acid chyme entering the duodenum. This aids the activity of the digestive enzymes from the pancreas and intestinal glands.

The bile salts help to emulsify fats. **Emulsification** breaks up the fats into small droplets which provide a larger surface area for the action of digestive enzymes. This is a form of physical digestion.

The pigments are excretory products of the breakdown of old red blood cells by the liver and are partly responsible for the colour of the egested faeces.

Cholesterol is excreted into the bile when blood cholesterol levels are high. Mucin acts as a lubricant in the intestine.

Pancreatic juice

Pancreatic juice is colourless and contains sodium bicarbonate, giving it a pH of about 8.8. It contains:

- the enzyme amylase (similar to that in saliva), which continues the conversion of starch to maltose
- the fat-digesting enzyme, **lipase**, which hydrolyses fats to glycerol and fatty acids
- **nucleases**, which digest DNA and RNA
- two enzyme precursors, **trypsinogen** and **chymotrypsinogen**, which are activated only when they encounter the enzyme **enterokinase**, produced in the intestinal juice. In their active forms, **trypsin** and **chymotrypsin** digest proteins to peptides.

Intestinal juice

The **intestinal juice** is a watery solution of pH about 8.3. It is released when food enters the small intestine. Its enzymes contain:

- a number of **peptidases** which hydrolyse polypeptides to peptides and amino acids
- enzymes which are responsible for the hydrolysis of nucleic acids
- **carbohydrases**, which convert disaccharides to monosaccharides:
  - — **sucrase** (breaks down sucrose)
  - — **maltase** (breaks down maltose)
  - — **lactase** (breaks down lactose).

The combined, simultaneous release of these secretions brings about, directly or indirectly, the digestion of carbohydrates, proteins, lipids and nucleic acids. Although at this point chemical digestion is most significant, peristaltic contractions of the small intestinal wall continue to break up the chyme and keep it mixed with enzymes.

Absorption

The bulk of absorption of digested food molecules occurs in the ileum by diffusion. The surface area is further increased in this area by hair-like extensions of the epithelial cells of the villi, called **microvilli**. As absorption proceeds, there is a rapid build-up of chemicals in epithelial cells. Monosaccharides, nucleotides and amino acids are removed from these cells into the bloodstream by the capillaries of the villi. Transport away from the cells is not always rapid enough and a concentration barrier may build up. It is only by active transport across the cell membranes that this can be overcome.

Table 18.5 Summary of the digestive secretions and their functions

Secretion	Source	Site of action and induced by	Optimum pH	Enzyme or other substances in secretion	Substrate	Products
Saliva	Salivary gland	Buccal cavity or mouth—expectation and reflex	Approx. 7.5 (neutral to slightly alkaline)	Salivary amylase (ptylin) + mucus	Amylose in cooked starch	Maltose
Gastric juices	Stomach wall or mucosa gastric glands	Stomach—reflex and hormone (gastrin)	2.0 (acidic)	Hydrochloric acid (HCl) (NB not an enzyme) + mucus	Pepsinogen	Pepsin
				Pepsin (pepsinogen)	Proteins	Peptides (polypeptides)
				Rennin (prorennin in children only)	Milk—soluble caseinogen	Insoluble curds Casein
				Lipase small amount in children only	Lipids (fats and oils)	Fatty acids and glycerol
Bile	Liver (via gall bladder)	Duodenum—reflex and hormone (cholecytokinin)	7.0–8.8 (neutral to alkaline)	Bile salts (NB not enzymes)	Fats and lipids	Fat droplets—emulsifies lipids
Pancreatic juices	Pancreas	Duodenum—hormone (secretin)	7.0–8.0 (neutral to alkaline)	Amylase + mucus	Amylose in starch	Maltose
				Trypsin (trypsinogen)	Proteins Chymotrypsinogen	Peptides Chymotrypsin
				Chymotrypsin(ogen)	Proteins and casein	Peptides
				Carboxypeptidase	Peptides	Amino acids
				Lipase	Lipids (fats and oils)	Fatty acids and glycerol
				Nucleases	Nucleic acids (DNA & RNA)	Nucleotides
Intestinal juices	Small intestinal walls or mucosa glands (crypts of Lieberkühn)	Small intestine—mechanical stimulation	8.3 (7.5–8.5) (slightly alkaline to alkaline)	Nucleotidases + mucus	Nucleotide	Nucleosides = phosphoric acid, pentose sugar and organic bases
				Amylase	Amylose in starch	Maltose
				Maltase	Maltose	Glucose
				Lactase	Lactose (milk sugar)	Glucose and galactose
				Sucrase	Sucrose	Glucose and fructose
				Lipase (small amounts)	Lipids (fats and oils)	Fatty acids and glycerol
				Enterokinase	Trypsinogen (inactive)	Trypsin (active)
				Peptidases	Peptides and dipeptides	Amino acids
Large intestine	Walls of large intestine			Mucus		

Glucose and galactose are absorbed more rapidly than the other monosaccharides. This is possibly because they undergo a chemical conversion immediately they enter the epithelial cells, ensuring the maintenance of a very steep concentration gradient. These sugars then pass by diffusion into the capillaries which drain into the **hepatic portal vein**. This blood vessel acts as a short circuit, carrying the absorbed food molecules directly to the liver.

Lipids, absorbed as small droplets, and as glycerol and fatty acids, pass into blind-ending lymphatic channels in the villi, called **lacteals**. These join together to form lymphatic vessels which enter the blood supply just before its return to the heart. Small amounts of fatty acids and glycerol may also enter the capillaries of the villi.

Absorption of vitamins, inorganic salts and water also occurs in the small intestine. This takes place by osmosis as the gut contents become hypotonic to the blood.

After three to four hours, the food in the small intestine passes through a sphincter to the large intestine.

18.2.6 Structure and function of the large intestine

The **large intestine** is about 1.5 metres long and consists of the caecum, appendix, colon, rectum and anal canal.

The **caecum** is found at the junction of the ileum and colon and has a blind ending, the **appendix**, projecting from it. The caecum is very large in some herbivores, where it and the appendix are the major sites of cellulose digestion by bacteria. In humans, however, it is much reduced in size. Appendicitis is a condition that results from inflammation of these areas if food becomes trapped in them and putrefies.

The **colon** has three regions: an ascending, a transverse and a descending limb. The colon leads to the **rectum** and on to the **anus**, where undigested food is egested. The epithelium has an almost smooth surface in the large intestine.

The main function of the large intestine is the absorption of water. About 7 litres of water enters the alimentary canal each day as a solvent for the digestive juices. Although most of this is reclaimed by absorption in the small intestine, the remainder must be removed in the colon. This results in the compaction of solid, insoluble undigested material which is referred to as **faeces**. If the lining of the colon is irritated—for example, by some sort of infection—the undigested material moves too quickly, less water than normal is reabsorbed, and diarrhoea results. If the material passes through the colon too slowly, an excess of water is removed and the result is constipation.

In addition to the waste materials secreted in the bile from the liver, excess mineral salts may be secreted into the colon from blood vessels in its walls.

Normally there is quite a large bacterial community present in the large intestine. They obtain their nourishment from undigested food. By-products of their metabolism, vitamin K and several of the B group vitamins, are absorbed through the large intestinal epithelium. This is virtually the only source of vitamin K, which is essential in the blood clotting reactions in humans. Thus there is a mutualistic relationship between these bacteria and the human organism harbouring them.

Other products of bacterial decomposition of foods, particularly those from amino acid breakdown, are responsible for the odour of the faeces. Many bacteria, both dead and alive, are eliminated with the faeces. Continuous use of oral antibiotics in the treatment of infections has the undesirable side-effect of destroying these important gut bacteria.

The movement of faeces is slow. This provides adequate time for water to be absorbed and mineral salts to be secreted before they pass into the rectum. Arrival of the faeces in the rectum stimulates egestion (defaecation). Both involuntary and voluntary muscles are involved in this process. Two sphincters surround the anus, an inner one of smooth muscle (involuntary control) and an outer one of striated muscle (voluntary control). Control of the voluntary anal sphincter muscles is one of the early learning processes in children.

Case study 18.5: The importance of dietary fibre

The diet of most modern societies has a high proportion of refined food and a low proportion of fibre. Refined foods have been processed so that much of the indigestible material has been removed. Flour, for example, has been milled from the wheat grains to remove the husks. All of the nutrients are available in a form which makes it easier to produce 'attractive' meals. Fibre, which consists mainly of indigestible cellulose from plants, is critical for the healthy functioning of the individual, however.

Individuals with a low fibre intake may experience severe constipation. Fibre levels control the rate at which matter moves through the colon. If fibre is lacking or in inadequate quantities, the faeces move through the colon at a very slow rate. This results in an excess of water being removed. The compaction of the faecal material can become so extreme that it becomes rock-like in consistency. Retention of the faeces may result, since the anal sphincter may not be able to relax adequately for egestion. Even if constipation is not this severe, movement of the hard faecal matter can damage the cells lining the lower colon and rectum. Continual damage may ultimately lead to the development of bowel cancer.

18.2.7 Assimilation

Assimilation is the incorporation of nutrients into the body. These chemicals are carried from the intestine to the liver by the hepatic portal vein. In the liver they are stored, changed or redirected to other organs.

Amino acids are needed for growth, maintenance, repair and secretion, but they cannot be stored within cells. Amino acids taken into the body in excess of immediate needs must be changed in one of three ways:

- conversion to urea for removal by the kidneys
- transfer of amino groups to carbohydrates to produce glycoproteins which are required by the body
- conversion to glucose and other carbohydrates.

One of the essential aspects of carbohydrate metabolism is the maintenance of a steady blood glucose level. This is critical for the homeostasis of the body. It ensures that all the body cells have glucose available at all times for respiration. Glucose is, however, removed from the blood in the kidneys. Any glucose in the blood greater than that required for immediate use is excreted. Regulatory mechanisms operate to prevent the loss of glucose. The correct blood glucose level is maintained by interconversion between glucose and glycogen. These reactions are controlled by the hormones **insulin** and **glucagon** which are produced by special cells in the pancreas. When glycogen storage areas are saturated, any excess glucose is converted to fat for storage in specialised areas—for example, around organs, in abdominal membranes and under the skin. All of these reactions occur in a series of steps, each of which is mediated by a specific enzyme.

18.2.8 Control of digestive secretions

The release of the various secretions involved in the digestive process occurs in response to specific stimuli. The stimulus may be the anticipation of food or its actual presence at a particular point in the alimentary canal, or it may be hormonal.

Food entering the stomach causes the release of gastric juices. The flow of these juices is maintained by a hormone, **gastrin**. The tissue which produces gastrin is found in the pyloric region of the stomach. While there is still chyme present, the glands release gastrin into the bloodstream. Gastrin stimulates the continued release of gastric juices from the cardiac region of the stomach.

Chyme entering the duodenum stimulates the release of hormones from glands in its wall. These hormones pass into the bloodstream and activate the secretion of fluids from various organs:

- **Cholecystokinin** stimulates the gall bladder to contract and send bile down the bile duct.
- **Secretin** stimulates the pancreas to release pancreatic juice into the pancreatic duct.

The physical presence of food brings about the release of intestinal juices.

As food passes any particular site, the stimulus for the release of a secretion or hormone is no longer present, with the result that further secretion is inhibited.

SUMMARY

Human digestion occurs in the alimentary canal. Different parts of the alimentary tract are specialised for different functions.

In the buccal cavity the teeth and tongue are responsible for physical digestion of food, and chemical digestion of starch by salivary amylase occurs. Mucus in the saliva moistens the food. The food ball, or bolus, is passed to the oesophagus, whose function is to transfer food through the thoracic cavity to the stomach.

The stomach can enlarge to store food. Muscular contractions continue physical digestion of food and mix the stomach contents. The folded inner lining contains glands. One type of gland secretes mucus, which protects the stomach wall from being digested. Other glands produce gastric juice, containing acid and enzyme precursors which are activated only within the cavity of the stomach. The enzyme pepsin digests proteins to polypeptides, and rennin causes milk proteins to coagulate. Absorption of water and glucose occurs.

The resultant partially digested chyme is released into the small intestine.

The duodenum is primarily involved in digestion. The lining is folded, slowing down movement of food. It has numerous small projections, or villi, which increase surface area; it also has glandular areas.

Acidic chyme in the duodenum stimulates secretions from the gall bladder, intestinal glands and pancreas. Bile from the gall bladder brings about emulsification of fats. Pancreatic juices contain enzymes and their precursors in an alkaline fluid. Both enter the duodenum through ducts. Intestinal juice secreted from glands in the duodenal wall also contains enzymes in an alkaline

medium. Other glands secrete mucus which protects the intestinal wall. Enzymes in the intestine, which operate in alkaline conditions, complete digestion of the food.

Small molecules pass by diffusion and active transport into the cells of the villi that line the ileum and on to the capillaries. These molecules are transported directly to the liver for assimilation. Most of the fat molecules are absorbed by lacteals and transferred to lymphatic vessels. Undigested food is passed into the large intestine.

In humans, the caecum and appendix do not function in digestion and have become much reduced in size. Bacterial decay of remaining food occurs in the colon. This produces vitamin K, which is important in human blood clotting, and also produces vitamins in the B group. These vitamins and water are absorbed in the colon. Excess salts are secreted by the large intestine for elimination. Compacted undigested material is passed to the rectum and finally egested through the anus as faeces.

Absorbed food is stored, changed or redirected in the liver.

Review questions

18.19 The alimentary canal has the same basic structure throughout its length, although differences are superimposed at particular sections of it in relation to specific functions.

(a) Describe the basic structure of the human alimentary canal.

(b) List differences observed in different regions of the alimentary canal and state functions associated with the differences.

18.20 Explain why protein-digesting enzymes are produced and secreted in an inactive form.

18.21 The colon is a part of the:

A. stomach.

B. small intestine.

C. oesophagus.

D. large intestine.

18.22 Which of the following components of bile juice function in digestion?

A. bile pigments

B. cholesterol

C. bile salts

D. urea

18.23 Describe features of the small intestine which make it an efficient organ for the absorption of digested food.

18.24 Describe the digestion and absorption of fats in humans.

18.25 Read the following passage carefully and then answer the questions.

Peristaltic contractions of the stomach keep the chyme moving towards the duodenum, the first loop of the small intestine. The passage of food into the duodenum is controlled by a ring of muscle situated immediately between the end of the stomach and the duodenum. The duodenum is the main site of digestion in the gut. The agents of digestion come from three sources: the liver, pancreas and wall of the intestine. The liver produces bile, a mixture of substances not all of which are concerned in digestion. The digestive components are the bile salts which emulsify fats. It must be stressed that bile salts are not enzymes. Bile is also rich in sodium bicarbonate, which neutralises acid from the stomach. The pH of the small intestine is therefore distinctly alkaline, which favours the action of the various enzymes. Some of these enzymes are constituents of the pancreatic juice which flows into the duodenum from the pancreas via the pancreatic duct. The main pancreatic enzymes are pancreatic amylase, trypsin and pancreatic lipase.

(a) What are peristaltic contractions, and what causes them?

(b) Explain the terms 'chyme' and 'emulsify'.

(c) Why are bile salts not classed as enzymes?

(d) Why are the stomach contents acidic?

(e) What is the function of pancreatic amylase?

18.26 Explain each of the following statements:

(a) It is possible to swallow food and pass it into the stomach while standing on your head.

(b) When food touches the back of the pharynx it is difficult not to swallow.

(c) If the bile duct is blocked, fat digestion is impaired.

18.27 Explain how, after removal of the stomach, people may continue to eat and digest a fairly normal diet. What difficulties would arise in such a situation?

18.28 Junket is a creamy substance formed from the separation of solids from the watery solution of milk. It is prepared by warming milk with a commercial substance called 'rennet' to a temperature of about 36°C.

(a) Suggest the active ingredient in 'rennet'.

(b) Explain the possible processes occurring in the formation of junket.

(c) Where would this type of process occur in the alimentary canal?

(d) What is the biological significance of this process?

18.3 THE ACCESSORY ORGANS OF THE ALIMENTARY CANAL

18.3.1 THE PANCREAS

The human pancreas is a cream-coloured organ, about 12 cm long, lying between the stomach and the duodenum. There are two basic types of cells in the pancreas, each of them forming glandular material. The exocrine portion of the pancreas produces pancreatic enzymes. Groups of glandular cells (**acini**; singular *acinus*) are arranged around a central duct into which the enzymes are secreted. Each group of cells is surrounded by connective tissue to form lobules. The individual ducts join up to form the pancreatic duct.

Scattered between the lobules are ductless or **endocrine** glands (**islets of Langerhans**) which produce the hormones insulin and glucagon and secrete them directly into the bloodstream for transport to their target sites.

18.3.2 THE LIVER

The liver is a very large organ, comprising approximately one-fifth of the viscera. It is found directly under the dome of the diaphragm which separates the thoracic and abdominal cavities. Contractions of this muscular sheet help move blood through the liver tissues.

The liver consists of several lobes, each of which has fine ducts through which bile can pass to the gall bladder. It is supplied with oxygenated blood from the hepatic artery and blood rich in nutrients from the hepatic portal vein. Inside the liver these blood vessels divide into a network of capillaries and open spaces called sinusoids, which rejoin as the hepatic vein. Phagocytic cells are to be found inside the sinusoids. These are involved in the destruction of old red blood cells, bacteria and any other foreign material passing through the sinusoids.

The appearance of the liver in cross-section is lobular. The liver cells within these hexagonal lobules are small with a large nucleus, and stores of fat and glycogen. They form cords radiating out from the centrally placed intralobular branch of the hepatic vein. Between these cords of cells are the sinusoids. The cells, therefore, are bathed directly in blood.

Blood passes from branches of the hepatic artery and hepatic portal vein along the ‘corners’ of the lobules and through capillaries into the sinusoids. Chemical exchange occurs between the liver cells and the blood before the blood passes into the

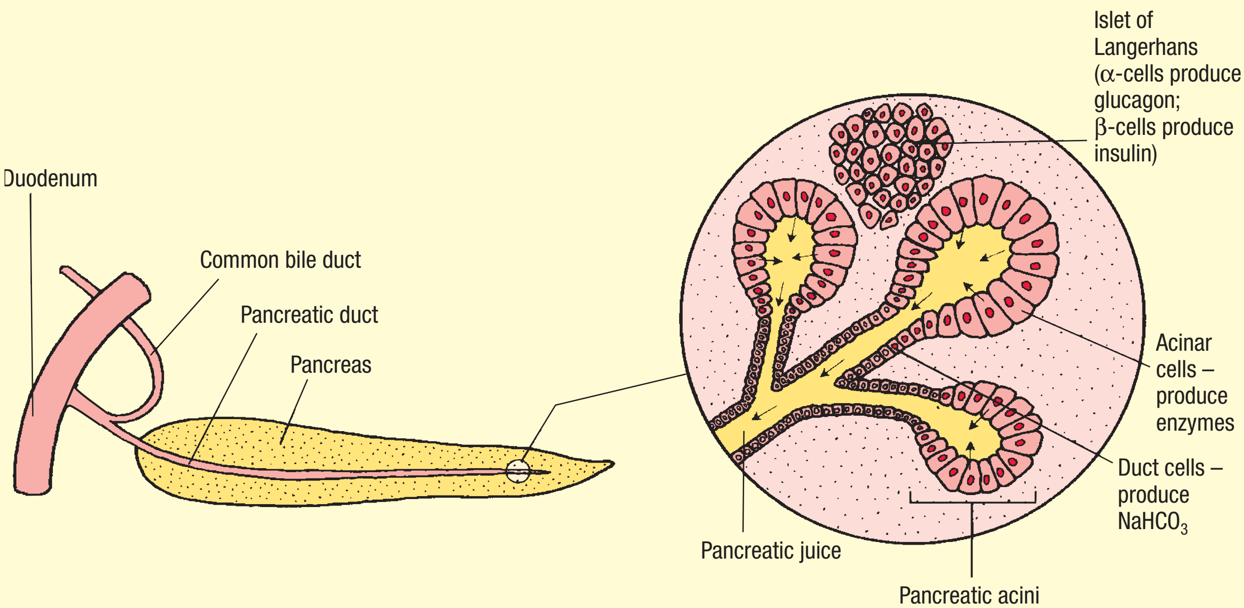
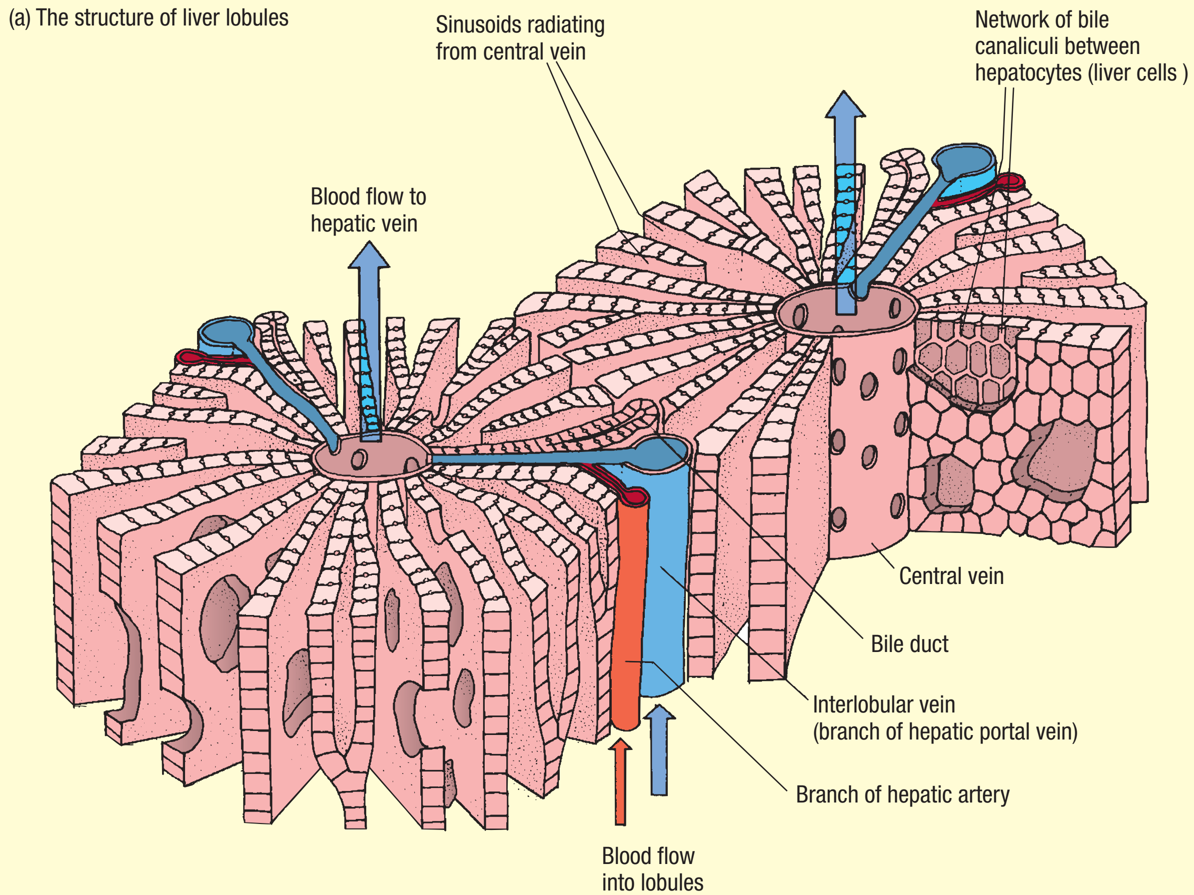


Figure 18.22 Transverse section through part of the pancreas

branch of the hepatic vein and out of the liver. Bile canaliculi run parallel with the sinusoids. The surrounding cells continually pass bile substances into them. The direction of flow of the bile is opposite to that of the blood. These canaliculi drain into ducts at the edge of each lobule which link up to enter the gall bladder.

The liver has numerous functions, many of which are involved in the metabolism of food. These include:

- the reception and storage of food substances digested in the intestine
- carbohydrate metabolism and regulation of blood sugar level
- break-down and/or conversion of excess amino acids
- fat metabolism
- secretion of bile
- storage of iron released by the break-down of old red blood cells



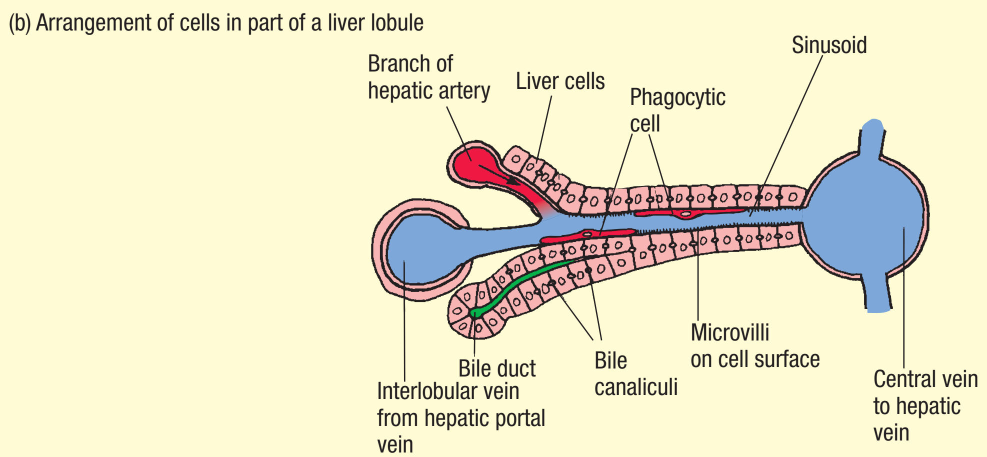


Figure 18.23 Structure of the liver lobules

- storage of vitamins A, D and B_{12}
- manufacture of plasma proteins, including those used in blood clotting—e.g. prothrombin
- production of heat as a by-product of active metabolism
- defence
- detoxification—break-down of ammonia (from amino acid) to urea; the destruction of hormones under homeostatic control; modification of drugs and alcohol prior to their excretion by the kidney.

Case study 18.6: Alcoholic beverages

Ethyl alcohol, the active component of alcoholic beverages, is a small molecule which is readily absorbed by the stomach and small intestine. This process is increased if there is no food present, particularly fats and proteins which slow down alcohol absorption. Absorption is also increased if the alcohol is mixed with carbonated fluid. Carbon dioxide stimulates movement of alcohol through the stomach, passing it rapidly to the intestine where the absorption rate is higher. Thus alcohol is rapidly absorbed into the bloodstream. The blood distributes the alcohol to the body tissues where it is slowly absorbed. Alcohol may therefore be present in the blood 18 hours after it was ingested.

Ten per cent of alcohol is removed from the body in the urine, breath and sweat. The remaining 90 per cent must undergo three chemical reactions before it is eliminated. The first stage, conversion of alcohol to acetaldehyde, occurs only in the liver. The second and third stages—acetaldehyde to acetic acid, which is then converted to carbon dioxide, water and energy—may also occur in other organs.

Alcohol exerts its effects by depressing brain activity. As its concentration in the blood rises to between 0.05 and 0.1 per cent, higher centres of the brain which control judgment, self-criticism and learnt inhibitions cease to operate effectively. Anxiety is thus reduced and the individual has a sense of well-being and excitement. Between 0.1 and 0.5 per cent, depression of brain activity causes the person to be less alert, have a hazy awareness of the surroundings, lose muscular coordination and become sleepy. At blood alcohol levels greater than 0.5 per cent, vital centres of the brain which control respiratory rate, heart rate and blood pressure become impaired. This may lead to respiratory failure and/or shock associated with low blood pressure. Coma and death usually result at blood alcohol levels of approximately 0.55 per cent.

There are some people, known as alcoholics, who have a physiological dependence on alcohol. Although there is probably a genetic predisposition to alcoholism, it is believed that the main cause is social. One factor is thought to be personality type. A person with a low tolerance to anxiety, for example, has a stronger push to use alcohol to relieve stress than do other people who are less sensitive.

For the alcoholic, alcohol assumes the characteristics of food. The body cells become so adapted to alcohol that they operate poorly in its absence. Continued excessive drinking causes inflammation of the stomach lining and poor digestion of food. Nausea makes food unpalatable. These factors result in loss of essential nutrients. Nerves, particularly in the legs, begin to degenerate and the excessive drinker experiences pain and weakness. Liver degeneration, caused by a number of changes to the cells collectively termed cirrhosis, usually results in death of the alcoholic.

SUMMARY

The pancreas consists of two types of glandular tissue: acini and islets of Langerhans. The acini produce digestive enzymes in an alkaline solution. They are exocrine glands and their products are secreted into the pancreatic duct. Islets of Langerhans are endocrine glands. They do not have ducts but secrete their products, insulin and glucagon, directly into the bloodstream. These hormones control blood glucose levels.

The liver consists of many lobules. The cells of each lobule take up materials from the blood (hepatic artery and hepatic portal vein). These materials may be stored, converted to other forms, or redirected to other organs. Metabolic wastes are either secreted to the bile duct or diffuse into the hepatic portal vein, where they are removed by the kidney or the lungs.

? Review questions

18.29 (a) Where are insulin and glucagon produced?
(b) Where do they act? How do they get to this site?

18.30 How does the secretion of pancreatic juice differ from the secretion of insulin?

18.31 Protein-digesting enzymes are secreted from the glandular tissues in an inactive form. Explain why this is so.

18.32 Explain why the liver is such a large organ.

18.33 Describe a liver lobule.

18.34 The liver has two blood vessels entering it. Explain the significance of this.

18.35 List five functions of the liver.

18.4 Gas exchange

18.4.1 Structure of the system

The human gas exchange surface consists of a pair of lungs situated in the thoracic cavity and connected to the exterior by a series of air passages. The only attachment of the lungs in the thoracic cavity is at the point of entry of the major air tubes and blood vessels. Between the two lungs are the heart, with its major blood vessels, and the oesophagus.

Each lung is almost completely surrounded by an expandable space called the **pleural cavity**, which is completely lined by **pleural membranes**. The surface of the lungs, the inner surfaces of the thoracic cavity, the lateral sides of the organs between the lungs and the upper surface of the diaphragm are covered in these membranes. The pleura are lubricated with fluid. This reduces friction between the various surfaces in the thoracic cavity as they move over each other in performing their functions.

Air enters the nostrils, where hair and mucus act as filters, and capillary beds warm the air before it passes above the soft palate to the back of the throat or pharynx. The buccal cavity also opens into this area. Two major passages lead off from the pharyngeal cavity: the oesophagus and the **trachea**.

The voice box or **larynx**, with its **vocal cords**, is found at the anterior end of the trachea. The opening to the larynx is called the glottis and this is

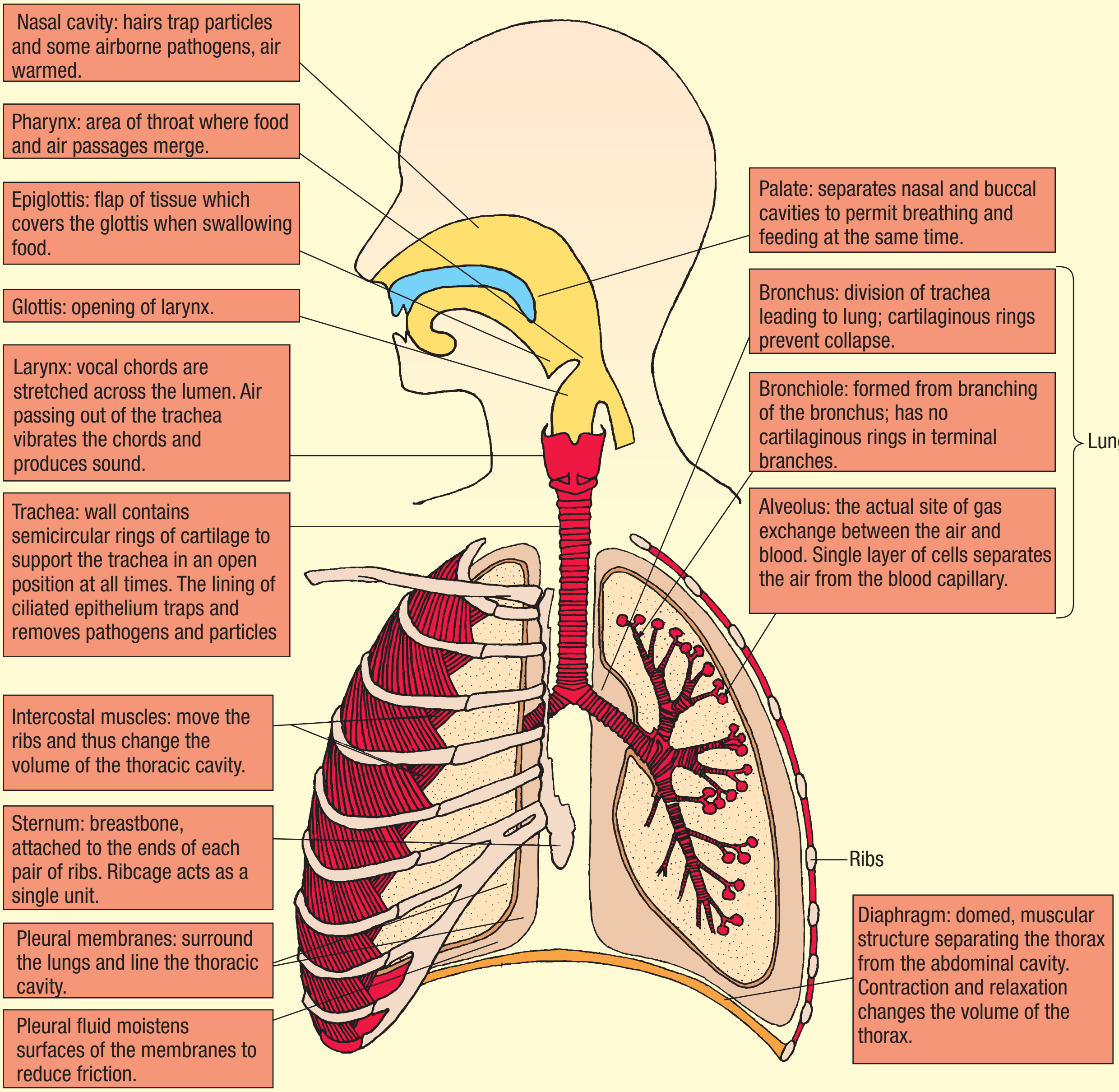


Figure 18.24 Structure of the human gas exchange system

protected by an upwardly directed flap, the epiglottis, which prevents food from entering it. Air passing outwards through the larynx vibrates the cords and thus produces sound.

Air passes into the trachea and its branches, the right and left **bronchi** (singular *bronchus*). Within the human lung each bronchus divides again and again into **bronchioles**, which ultimately give rise to about a million terminal passages called **alveolar ducts**. These ducts each end in a cluster of bubble-like spaces, the **alveoli** (singular *alveolus*). Collectively the alveoli of the two human lungs have a surface area of about 70 square metres. Blood vessels permeate the lung tissue. Thus the lungs consist of bronchioles, alveolar ducts, alveoli and blood vessels which are held together by connective tissue.

The walls of the trachea, bronchi and major branches contain incomplete cartilaginous rings that hold them open, and allow smooth muscles to control their diameter. The incomplete cartilage rings also allow lengthening and shortening of the tubular structures. The internal surfaces are lined with ciliated epithelium in which are interspersed many goblet cells. The goblet cells produce copious mucus which traps dust, bacteria or any other foreign particles entering with the air. The beating of the cilia moves this mucus, with its trapped matter, towards the pharynx. The mucus is constantly removed through the mouth and nasal passages.

As the branches of the bronchioles become smaller, the cartilage disappears and the walls become thinner. The alveolar walls are covered by a capillary network and are extremely thin, being composed of only one layer of flattened cells. This ensures rapid exchange of gases between the alveolus and capillary. Certain cells in the wall of the alveolus secrete a lubricating fluid which decreases surface tension on the walls, allowing them to remain open more readily. Phagocytic cells are also present and are important in the removal of foreign bodies. Elastic connective tissue between the alveolar walls and capillaries allows expansion and gives the walls support.

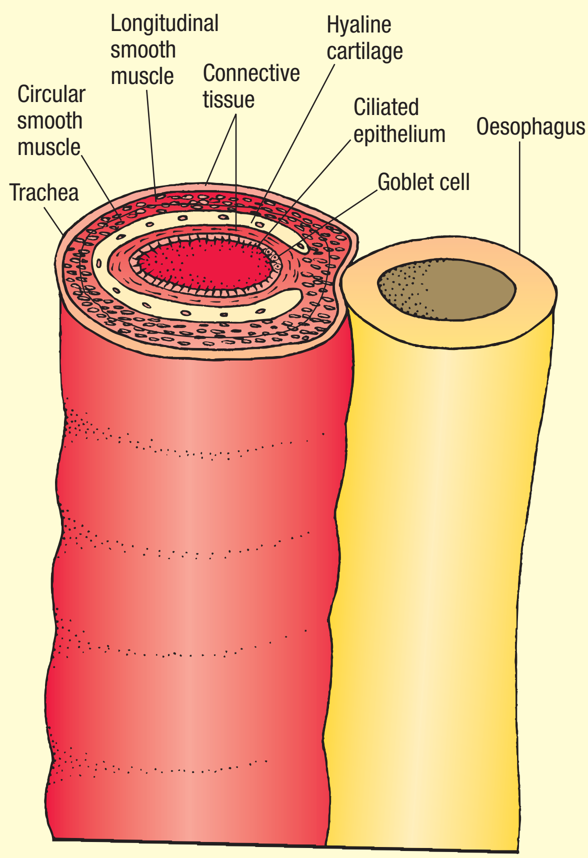


Figure 18.25 Transverse section of the trachea, showing the position alongside the oesophagus

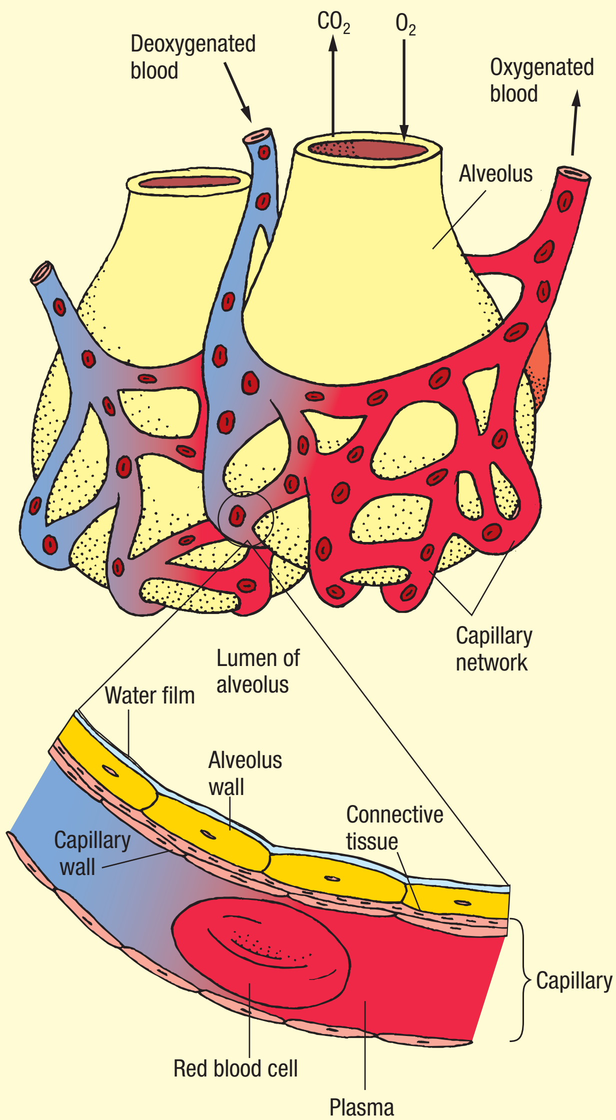


Figure 18.26 Alveoli and their blood supply

18.4.2 Ventilation

The thoracic cavity, in which the lungs are located, is a closed box supported externally by the ribs. It is separated from the abdominal cavity by the dome-shaped diaphragm. Changes in the volume of the thorax immediately cause changes in the pressure of the air in the lungs. This results in the flow of air into and out of them. Active movement of air into and out of the lungs is termed **ventilation**. Movement of air into the lungs is called **inspiration**; its movement out of the lungs is **expiration**.

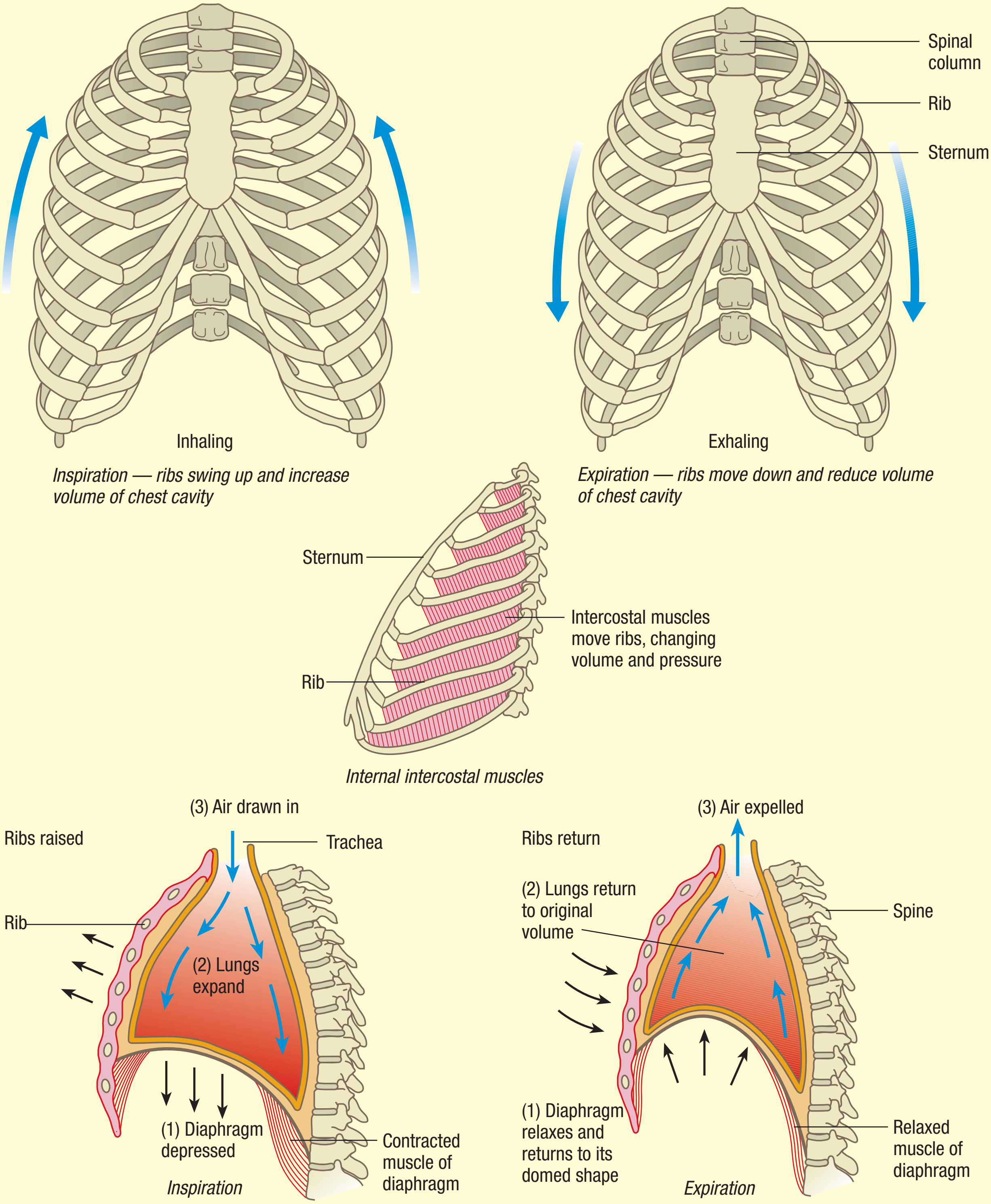


Figure 18.27 Action of the ribs and diaphragm in human ventilation

Changes in the volume of the thoracic cavity are brought about by two main types of muscular action. On inspiration, one set of muscles between the ribs (**external intercostal muscles**) contract while the other set (**internal intercostal muscles**) relax. This causes the ribs to move up and out. Because the ribs are attached to the sternum, this increases the diameter of the thoracic cavity. Simultaneously, the muscles of the diaphragm contract, flattening and lowering it and effectively increasing the length of the thorax. The combined effect increases the volume of the thoracic cavity. This results in a thoracic pressure that is lower than the external atmospheric air pressure. Atmospheric air moves into the air passages and lungs along the pressure gradient: that is, from higher external pressure to lower internal pressure.

On expiration, the internal intercostal muscles contract and the external intercostal muscles relax, causing the ribs to move down and in, and decreasing the diameter of the thoracic cavity. The muscles of the diaphragm relax, allowing it to become more dome-shaped and decreasing the length of the thoracic cavity. This results in a decreased thoracic volume and air pressure in the lungs that is higher than atmospheric pressure. Air is expelled from the lungs under pressure.

The lungs are passive and take no active part in the ventilation process.

During active exercise other muscles also come into play during the respiratory cycle. Abdominal muscles increase pressure within the abdomen, which is transmitted to the thorax in expiration. The size of the nostrils and glottis are increased by muscles during inspiration and thus reduce resistance to air flow.

During normal breathing, the respiratory movements occur about sixteen times per minute in young human adults. The total capacity of the human lung is about 5.5 litres, but even with the most forced expiration only about 4 litres of air can be expelled. Thus a certain **residual volume** of air remains in the lungs at all times. The maximum amount of air that can be ventilated during forced breathing is termed the **vital capacity**. This capacity depends very much upon fitness and is greater in athletes than in non-active people. The volume of air moving in and out of the lungs during normal breathing is known as the **tidal volume** and is approximately 500 mL.

18.4.3 Control of human ventilation

During normal ventilation, the breathing rate is controlled by two centres in the medulla of the hindbrain. Stimulation of the inspiration centre sends nerve impulses which bring about the contraction of the external intercostal and diaphragm muscles. The lungs inflate.

Special receptors, sensitive to the degree of stretching of the lungs, relay information back to the medulla. When the lungs are fully inflated, the expiration centre comes into play by inhibiting the action of the inspiration muscles. These muscles relax. In periods of exercise or emotional excitement, the expiratory centre also stimulates contraction of the internal intercostal muscles and brings about a more forced expiration.

The respiratory needs vary with different levels of body activity. To maintain homeostasis, therefore, both the depth and rate of respiration must be capable of adjustment. As the metabolic rate increases, so the oxygen requirement and carbon dioxide production will increase. If too little oxygen is supplied, then asphyxiation occurs. Conversely, too much oxygen can destroy cells by unwanted oxidations. Associated with low oxygen supply is a high carbon dioxide accumulation. This results in a

Table 18.6 Ventilation in humans

Part of respiratory tract	Inspiration	Expiration
Diaphragm	Contracts and flattens downwards.	Relaxes and moves upwards to dome shape.
Intercostal muscles	External intercostal muscles contract.	Internal intercostal muscles contract.
Rib cage and sternum	Move upwards and outwards.	Move downwards and inwards.
Thorax volume	Increases.	Decreases.
Air pressure	Pressure decreases inside thorax and lungs.	Pressure increases inside thorax and lungs.
Air movements	Higher external air pressure drives air into lungs at low pressure.	Air forced out of lungs by thorax compression and elastic recoil of lungs.

lowered pH in the tissue fluids, which can cause enzyme inhibition. Carbon dioxide forms carbonic acid in solution, thus a low pH in blood and tissue fluids indicates a high carbon dioxide content.

The most important factor in the control of ventilation is the concentration of respiratory gases in the blood. Several centres (**chemoreceptors**) for detecting gas levels exist:

- pH and oxygen sensors of the blood in the carotid bodies—nodules of tissue in the carotid arteries leading to the brain
- pH and oxygen sensors of the blood in the aortic body—nodules of tissue in the aorta
- pH sensors of tissue fluids in centres of the medulla oblongata (hindbrain) adjacent to the inspiration and expiration centres.

The respiratory centres of the medulla are directly affected by changes in gas concentrations in the blood and thus in tissue fluids. Nerves must transmit the information to these respiratory centres from the carotid and aortic bodies.

For humans, detection and removal of carbon dioxide is critical. The concentration of oxygen in the air is relatively high. A control system that detects blood oxygen levels only could result in an accumulation of carbon dioxide in the tissues. This would cause the internal pH to change and thus disrupt metabolic activities.

Thus inspiration and expiration centres are responsible for the rate of ventilation. A third centre, the pneumotaxic centre, controls the depth of breathing. Increased levels of carbon dioxide stimulate the autonomic nerves arising from the respiratory centres to bring about appropriate increased changes in the depth and rate of ventilation. These changes are accompanied by changes in heart rate and dilation of the arteries. As the body's immediate needs are exceeded by this increase, a negative feedback operates to slow down these processes again. A negative feedback system is a control system which reverses an existing trend.

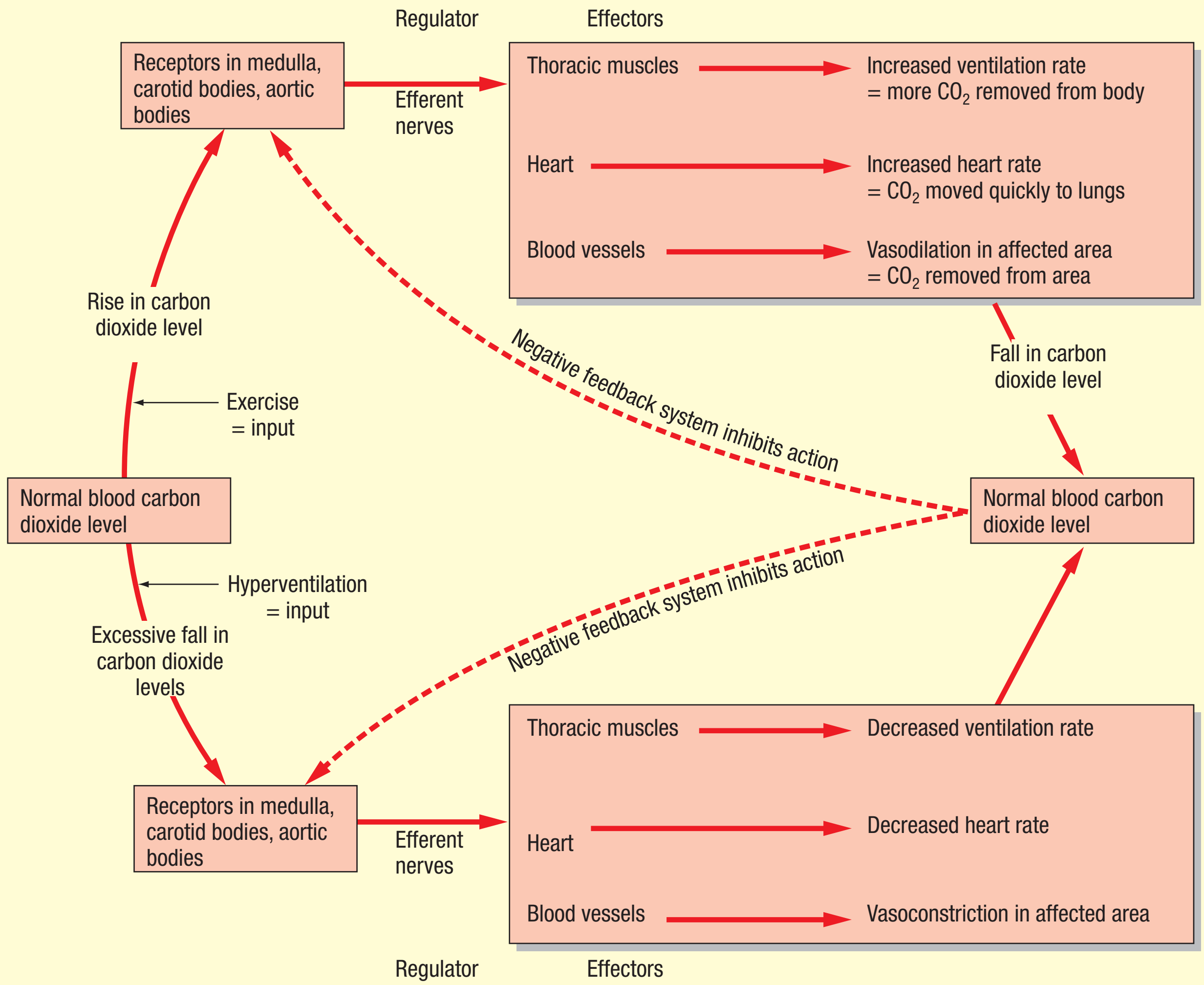


Figure 18.28 Control of carbon dioxide levels in the blood

Case study 18.7: Adaptations of mammals to extreme environments

Diving

Mammals are primarily terrestrial tetrapods living at altitudes at or near sea level. Some mammals, such as the whale, seal and dolphin, have returned to the aquatic environment, and have evolved special adaptations of the respiratory and cardiovascular systems. They depend primarily on the levels of oxygen in the blood to control ventilation. This is because carbon dioxide is more soluble in water than is oxygen, and it can therefore be rapidly removed to the aqueous surroundings. Since oxygen concentration in the environment is already low, the level of oxygen in the blood which supplies the cells becomes the critical factor.

Although a human will die of asphyxiation within 7–8 minutes without air, some seals can remain underwater for half an hour, and certain whales for as long as 2 hours.

An increased lung capacity in these animals would only give them unwanted buoyancy and an increased volume of nitrogen. Nitrogen is a gas which goes into solution under the extra pressure caused by increased water depth. This produces nitrogen narcosis (the 'narks' in human divers), which has an effect similar to alcohol intoxication, as the animal descends. On ascent the nitrogen in blood and tissue fluids can come out of solution as bubbles of nitrogen gas and cause paralysis (the 'bends' in human divers).

Diving mammals have been found to empty the lungs as much as possible by forced expiration immediately before diving. When whales and seals dive deeply they descend rapidly and soon reach depths which compress the thorax and lungs. Their thoracic cavity is adapted to allow compression without physical damage. This compression forces out alveolar air and so prevents nitrogen from diffusing into the blood.

The major adaptations for diving in these animals lie in the cardiovascular system:

- They have a higher blood volume and oxygen-carrying capacity than is found in terrestrial mammals.
- Their muscles contain extremely large quantities of the pigment myoglobin, which stores oxygen.
- Blood supply is shunted away from the muscles and skin but maintained to the heart and brain. This allows the heart to reduce its stroke rate.
- Anaerobic respiration, with the production of lactic acid, occurs in the muscles during the dive. The oxygen debt is restricted to the muscles, due to vasoconstriction during diving. When the animal surfaces it hyperventilates to increase oxygen uptake and remove the lactic acid. Diving mammals can tolerate far higher lactic acid levels in the muscles than can terrestrial mammals.

Similar adaptations for diving have been found in all vertebrate groups; for example, the beaver, platypus, penguin, crocodile and turtle.

Humans can free-dive to incredible depths using similar techniques.

High altitude

Living at high altitudes poses a different set of problems for animals. At increased heights above sea level there are atmospheric changes in pressure, gas composition and temperature. These changes are primarily reflected in animals as a decrease in available oxygen. The production of carbon dioxide by the tissues remains constant.

Although the absolute humidity of atmospheric air (the actual amount of water vapour it contains) changes with temperature, that of the alveolar air does not. Mammals maintain a constant temperature, so the alveolar surfaces are always moist. At sea level the absolute humidity of the alveolar air does not interfere with the percentage composition of other gases present. At high elevations, where the total atmospheric pressure is decreased, the unchanged pressure exerted by the constant volume of water vapour is very significant. It accounts for a large proportion of the volume available for gases in the alveolar spaces.

Because of the constant partial pressure of water vapour and carbon dioxide in the alveoli, the availability of oxygen decreases with increasing elevation more rapidly in the alveoli than it does in the atmosphere. Partial pressure refers to the contribution a particular component makes to the total pressure of a system.

As a person ascends above sea level, the decreasing availability of atmospheric and alveolar oxygen results in a decrease in blood oxygen levels. Homeostatic control brings about an increase in lung ventilation rate. At about 4000 m above sea level, anoxia (oxygen deficiency) begins to be evident. There is drowsiness, headache, mental fatigue, nausea and sometimes euphoria. At higher elevations, the climber experiences impaired judgement and an inability to perform manual tasks. This may be followed by muscular convulsions and unconsciousness.

After several days at high altitudes, a certain degree of acclimatisation or physiological adjustment to the lowered oxygen levels occurs. The kidneys correct the decreased pH associated with high levels of carbon dioxide in the tissues. There is increased ventilation and increased production of red blood cells and haemoglobin. There is also an increase in blood volume and number of tissue capillaries. After long periods of time at high altitudes, the tissues themselves acquire more enzymes which increase the efficiency of oxygen utilisation. People who have lived in high altitudes for many years also develop a very large chest cavity, which allows greater ventilation capacity.

While indigenous people of the high Andes have more red blood cells that their lowland contemporaries, and athletes are able to increase their red blood cell count by training at high altitudes, Tibetans living in the Himalayans have adopted a different adaptation. Their red blood cell count is similar to people living at lower altitudes. Their survival strategy depends on an increased level of nitric oxide in the blood. This chemical causes dilation of blood vessels and thus increased blood flow. With more blood passing through the alveoli there is a greater chance of picking up any available oxygen. A third strategy has been found in the Ethiopians of the Semien Mountains. Although they have no more red blood cells (and thus haemoglobin) or nitric oxide in the blood than their lowland relatives and the haemoglobin is exactly the same, 95 per cent of the haemoglobin in the arteries is saturated with oxygen. Exactly how this happens is not understood at this time.

SUMMARY

Gas exchange between the environment and the blood system occurs in lungs.

Air is taken in through the mouth and nostrils into the trachea. Air passing over vocal cords in the larynx (at the anterior end of the trachea) can produce sound. The trachea passes into the thorax. The thoracic cavity is an enclosed space (pleural cavity) surrounded by the rib cage and muscles of the body wall and diaphragm. The trachea subdivides into smaller and smaller elements—the two bronchi, bronchioles and alveolar ducts. These eventually end in blind sacs—the alveoli—the walls of which are only one cell layer thick.

The trachea, bronchi and larger bronchioles have muscular walls and incomplete rings of cartilage. Their internal surfaces are lined with many mucus-secreting goblet cells and ciliated cells.

The lungs consist of bronchioles, alveolar ducts, alveoli and blood vessels, held together by connective tissue. The entire surface of the lungs and the surface of the thoracic cavity are covered with lubricated pleural membranes. Air moves into and out of the lungs as a result of differences in air pressure between the external environment and the thoracic cavity.

Review questions

18.36 Draw and label the significant features of the human gas exchange system.

18.37 What are the structural features of the human trachea?

What functions do they serve?

18.38 Actual gas exchange occurs between the alveolus and the capillaries. Describe the features of these structures which are adaptations for gas exchange.

18.39 During ventilation the lungs are passive and take no active part in inspiration and expiration. How then, is air moved into and out of the lungs?

18.40 What is the difference between vital capacity and tidal volume?

18.41 Explain the significance of the detection of carbon dioxide levels in the blood of humans.

18.42 The respiratory needs change with different levels of activity. How are these changing requirements accommodated by humans to achieve homeostasis?

18.43 List features exhibited by aquatic mammals such as whales which are adaptations for long periods underwater, often at considerable depth. Beside each feature listed, indicate its function.

18.44 Describe features of the atmosphere—both environmental and alveolar—which make living at high altitudes difficult for humans.

18.45 What physiological adjustments occur in people who are subjected to high altitudes for an extended period of time?

18.5 Transport

The transport system in humans is typical of all mammals. Materials are transported throughout the body in a liquid medium. Three different fluids are involved: tissue fluid, blood and lymph.

The **tissue** (or **intercellular**) **fluid** surrounds individual cells. It acts as a mediating fluid between the blood and the cells.

Blood moves through a series of tubular vessels. These vessels, the **arteries**, **veins** and **capillaries**, vary in size, in the structure of their walls and in function. The pumping action of the muscular heart moves the blood through the vessels. This is aided by other movements of the body.

Lymph is carried in lymphatic vessels. It picks up tissue fluid and particulate matter and returns these to the blood system. The lymph is very important in the body's immune response (see Chapter 5).

18.5.1 Structure and function of blood

Blood is a highly specialised connective tissue consisting of several cell types suspended in a fluid medium, the **plasma**. Figure 18.29 shows the types of blood cells found in mammals and the functions they perform.

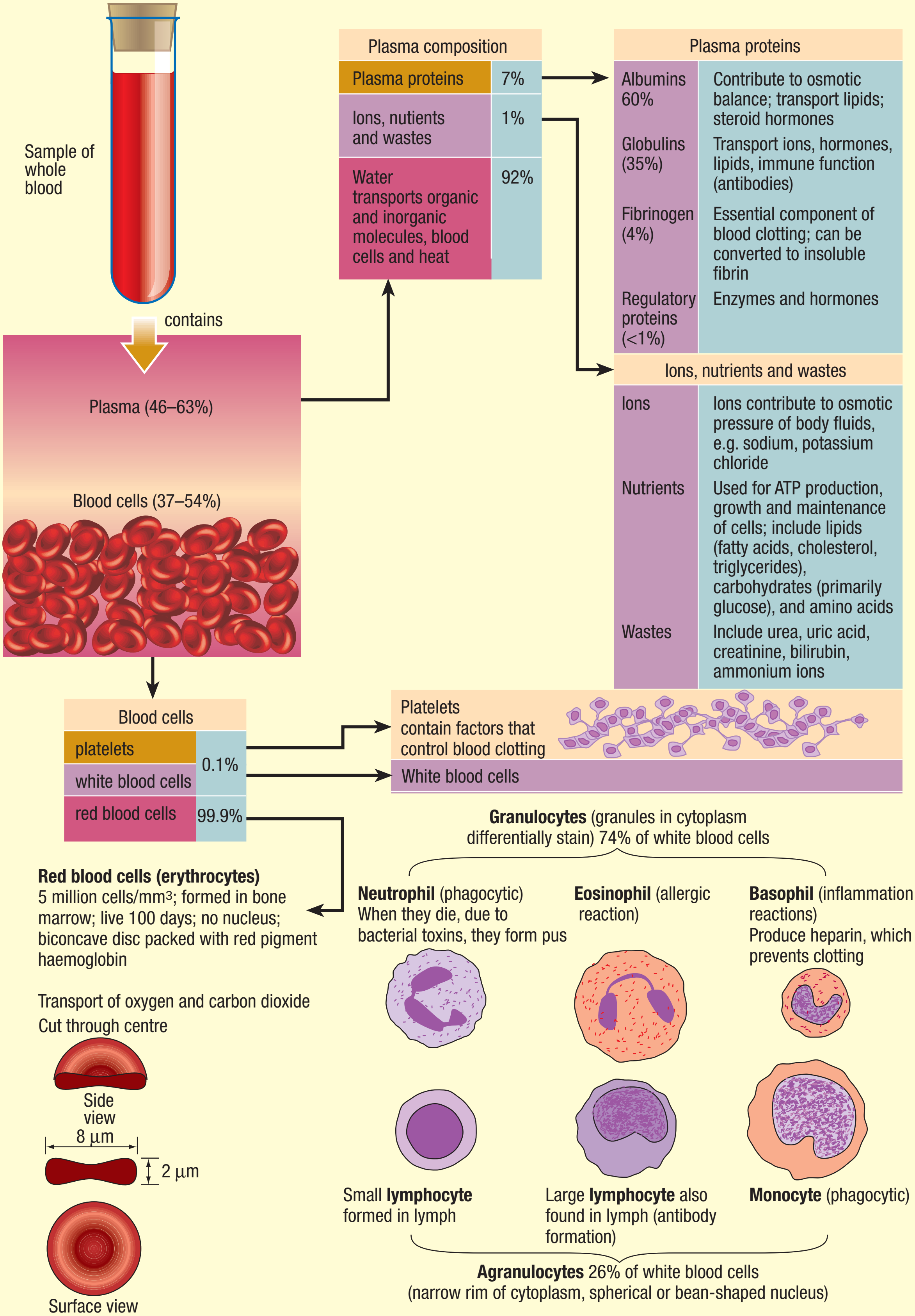


Figure 18.29 Types of mammalian blood cells

Table 18.7 Composition and function of transporting fluids in mammals

Fluid	Composition	Functions
Plasma (55% of blood)	92% water 7% proteins Serum and fibrinogen	Transport of nutrients, waste products, hormones and heat
Tissue fluid (bathes living cells)	Similar to plasma but has less protein	Cell homeostasis Transport
Lymph (inside lymph vessels)	No protein Rich in lipids Contains lymphocytes	Transport to veins Phagocytosis of bacteria

The main function of the red blood cells (**erythrocytes**) is to transport oxygen from the respiratory surfaces to the tissues. Mature red blood cells have no nucleus and must therefore be constantly produced in the bone marrow. This occurs at a rate of about 1.5 million per second. Their biconcave shape ensures a maximum ratio of surface area to volume for the uptake and release of respiratory gases. The shape also ensures smooth flow through fine blood vessels, their diameter being about the same as that of the finest capillaries.

The inside of a red blood cell is packed with the red pigment **haemoglobin**. This is a complex protein containing four iron haem groups. Each haem group can carry one oxygen molecule. The lack of a nucleus makes it possible for more haemoglobin to be included within the cell, and thus for a large amount of oxygen to be carried. A single red blood cell can carry 1000 million oxygen molecules.

Carriage of oxygen

Oxygen diffuses into the red blood cell across its thin elastic membrane and combines with the haemoglobin to form **oxyhaemoglobin**. This is a loose union which allows rapid attachment and detachment.

$$Hb + 4O_2 \underset{\text{tissues}}{\overset{\text{lungs}}{\rightleftarrows}} HbO_8$$

haemoglobin + oxygen ⇌ oxyhaemoglobin

Haemoglobin has a strong affinity for oxygen. In areas of the body where the oxygen concentration is high—for example at the alveoli of the lungs—oxygen is rapidly taken up by the haemoglobin. When blood carrying oxyhaemoglobin encounters an area of low oxygen concentration at actively respiring tissues, the oxygen is unloaded from the haemoglobin. This allows the blood to transport oxygen at a rate sufficient to supply all the cells with their needs.

Oxygen dissociation curves

An **oxygen dissociation curve** can be obtained from experimental analysis of the percentage saturation of blood with oxygen at different introduced oxygen levels (Figure 18.30). The pressure exerted by the oxygen molecules in air is known as its partial pressure or tension. Partial pressure of a substance is a measure of the pressure its molecules contribute to the total pressure exerted by a mixture.

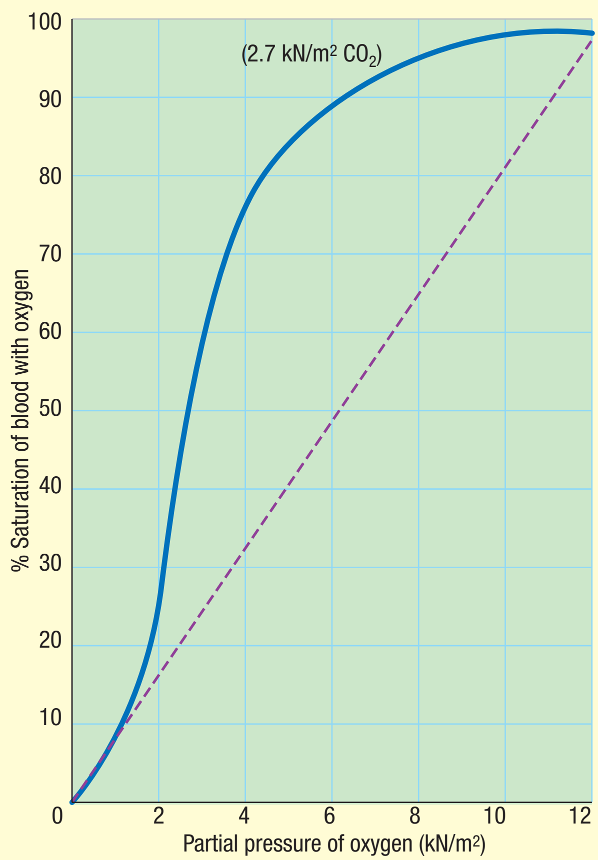


Figure 18.30 Oxygen dissociation curve for human blood

The curve indicates that blood can become fully saturated at a relatively low oxygen tension. If the relationship were linear (the broken line), the percentage oxygen saturation at any particular oxygen tension would be lower. For example, at 6.0 kN/m^2, the actual saturation is 90 per cent, whereas a linear relationship would give about 48 per cent saturation of blood.

As well as facilitating the loading of oxygen at the respiratory surfaces, haemoglobin rapidly releases it at low oxygen tensions; for example, in the tissues which are constantly using oxygen in cellular respiration. The steep part of the curve represents the range of oxygen tensions encountered in the tissues. A small drop in oxygen tension produces a large drop in percentage saturation of the blood. A large amount of oxygen is released from the haemoglobin to the tissues requiring it.

An increase in carbon dioxide levels, as occurs in the tissues, has a profound effect on the oxygen dissociation curve. It reduces the amount of oxygen that can be carried by oxyhaemoglobin. The oxygen dissociation curve is shifted downwards and to the right. This shift is named the **Bohr effect**.

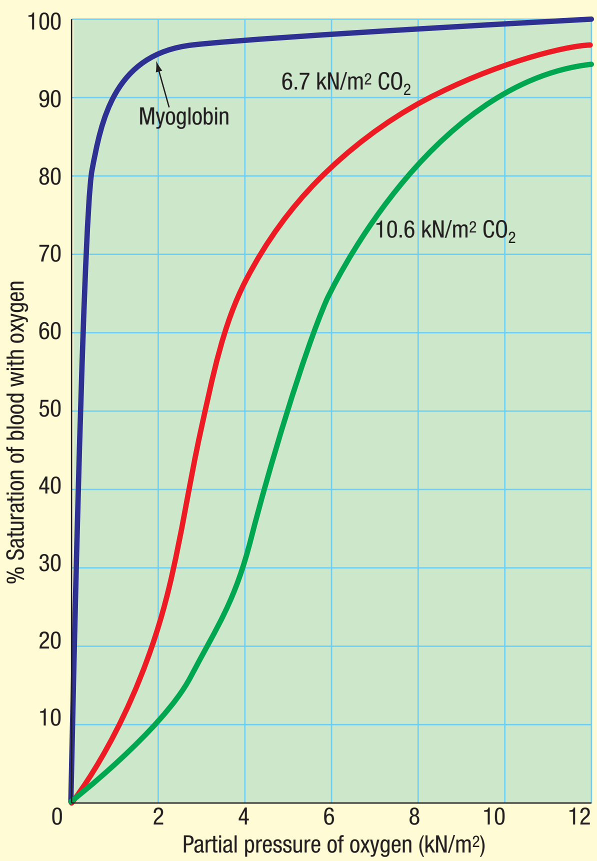


Figure 18.31 The Bohr effect

An increase in the amount of carbon dioxide present causes haemoglobin to release oxygen at higher-than-normal oxygen tensions. The release of oxygen in actively respiring tissues is therefore accelerated to accommodate the needs of the cells. At the gas exchange surfaces, where carbon dioxide is constantly being released, the haemoglobin can take up oxygen at lower tensions. The Bohr effect favours uptake of oxygen at the gas exchange surfaces and its release in the tissues.

Although haemoglobin has a strong affinity for oxygen, its affinity for carbon monoxide is even greater. **Carboxyhaemoglobin** is formed, and the colour of the haemoglobin is changed to a bright cherry red. This union takes place at the oxygen-carrying sites, thus preventing its uptake. Carbon monoxide, therefore, is a powerful respiratory poison. Since this is present in motor vehicle exhaust fumes, it has serious environmental effects.

There are two other respiratory pigments found in humans—**fetal haemoglobin** and **myoglobin**. Both of these pigments have oxygen dissociation curves to the left of that for adult haemoglobin. They take up oxygen at lower tensions than adult haemoglobin.

Fetal haemoglobin must obtain oxygen through the placenta from the maternal system. This is why it must have a greater affinity for oxygen than the haemoglobin of the mother.

Myoglobin is a special pigment found in muscles. It takes up oxygen from haemoglobin for storage. Myoglobin releases oxygen only when the oxygen tension is extremely low; for example, in severe muscular exertion. Athletes who are under a training regime gradually build up the amount of myoglobin in their muscle tissues.

Carriage of carbon dioxide

Carbon dioxide diffuses from the tissues into the blood. As a result of chemical reactions, most of the carbon dioxide is transported as bicarbonate ions in the red blood cells, and some is combined with haemoglobin.

Chemistry of carbon dioxide transport

Carbon dioxide diffuses from respiring tissues into the red blood cells, where it combines with water to form carbonic acid (H_2CO_3). The enzyme carbonic anhydrase accelerates this normally slow reaction, resulting in more carbon dioxide being carried in the red blood cells than in the plasma.

The carbonic acid then dissociates into negative bicarbonate ions (HCO_3^-) and positive hydrogen ions (H^+). The increased acidity in the red blood cells causes the haemoglobin to release oxygen molecules. These are replaced by the hydrogen ions, forming very weak **haemoglobinic acid**, HHb. The Bohr effect thus results from increased acidity in the red blood cells, rather than directly from increased carbon dioxide tension.

Excess bicarbonate ions diffuse across the membrane of the red blood cell into the plasma. The membrane is relatively impermeable to positive ions and this results in a net positive charge inside the cell. A flow of chloride ions (Cl^-) from the plasma into the red blood cell counteracts the ionic imbalance. This is known as the **chloride shift**. Thus both ionic and electrical conditions are balanced during transport of carbon dioxide.

Some carbon dioxide in the red blood cells also combines with amino acids in the haemoglobin molecule. This produces a **carbamino group**, $HbCO_2$.

About 5 per cent of the carbon dioxide dissolves in the plasma, again forming carbonic acid. This also dissociates into bicarbonate and hydrogen ions. In this case, the hydrogen ions are taken up by plasma proteins to form weak proteinic acids.

When the red blood cells reach the lungs (where oxygen tension is high and carbon dioxide tension low), the reactions are reversed. Carbon dioxide is rapidly released from the blood and haemoglobin molecules are again available for oxygen uptake.

18.5.2 The functions of plasma proteins

Of the 7 g of plasma proteins per 100 mL of plasma, approximately 5 g are albumin and 2 g are globulins. There are very small amounts of other proteins.

Albumin is primarily concerned with regulating the water content of cells and tissues through osmosis.

The globulins are a mixture of different proteins. Two groups of globulins that are of particular significance are the gammaglobulins and fibrinogen. The gammaglobulins are rich in antibodies. They are produced by plasma cells and large lymphocytes. Their function in the immune response was described in Chapter 5. Fibrinogens are an essential component in blood clotting. These, and all other plasma proteins, are formed in the liver.

Blood clotting

Elaborate mechanisms have evolved to prevent the accidental loss of blood when a vessel is severed.

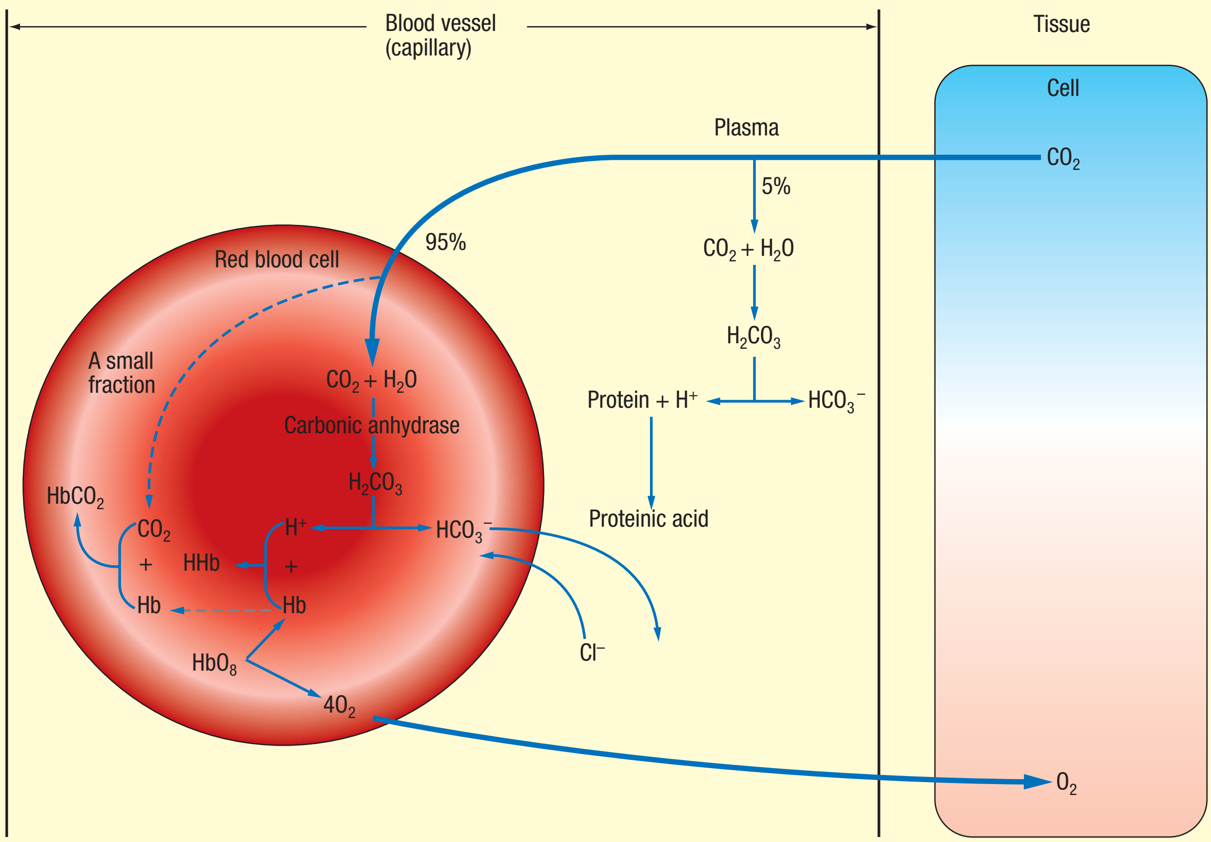


Figure 18.32 Transport of carbon dioxide in blood

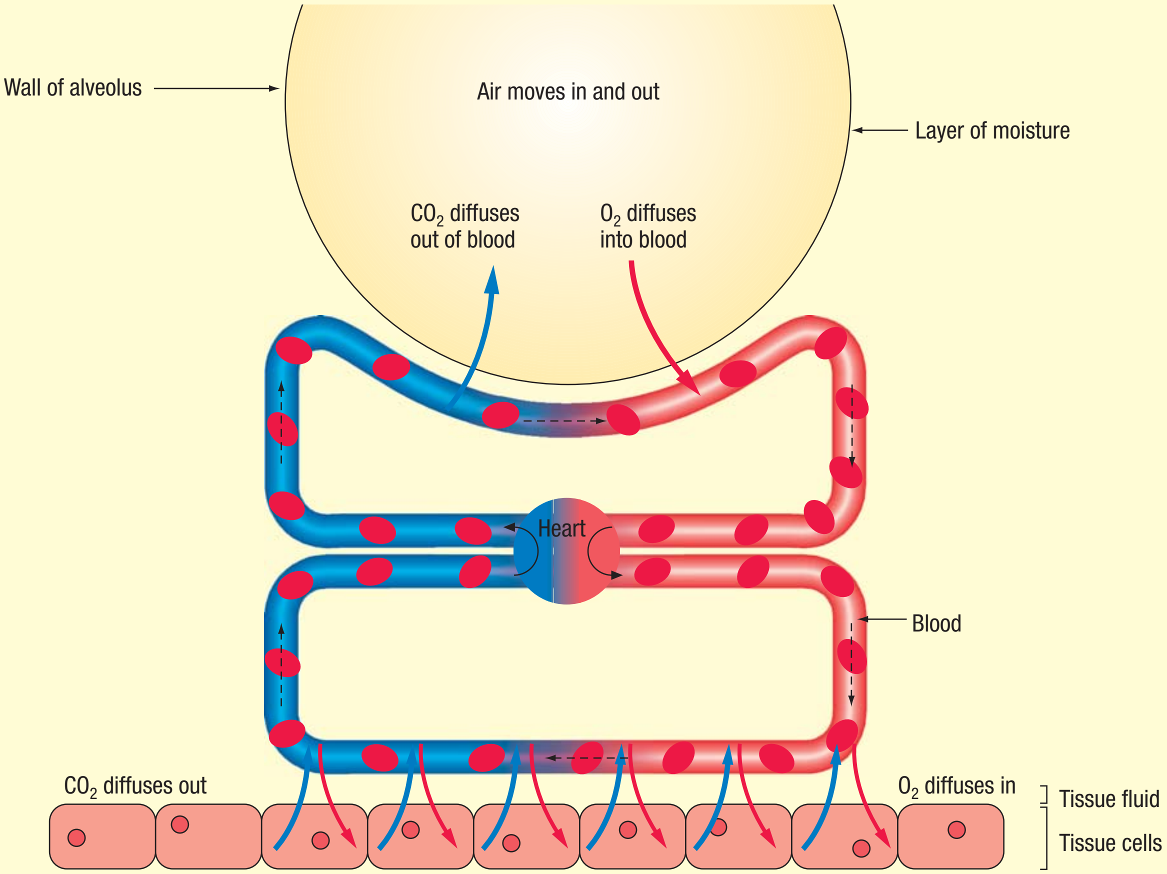


Figure 18.33 Exchange of gases at the respiratory surfaces and in tissues

One of these mechanisms is to form a solid clot to plug the broken vessel.

Clotting involves the conversion of soluble fibrinogen to insoluble fibrin. This involves a series of complex chemical reactions, each requiring a specific protein factor. These reactions are set in action when the damaged tissue releases a lipoprotein called thromboplastin. They are summarised in Figure 18.34.

Normal blood usually contains a small amount of thromboplastin. It also contains a strong anti-coagulant, heparin. Heparin is produced in the liver

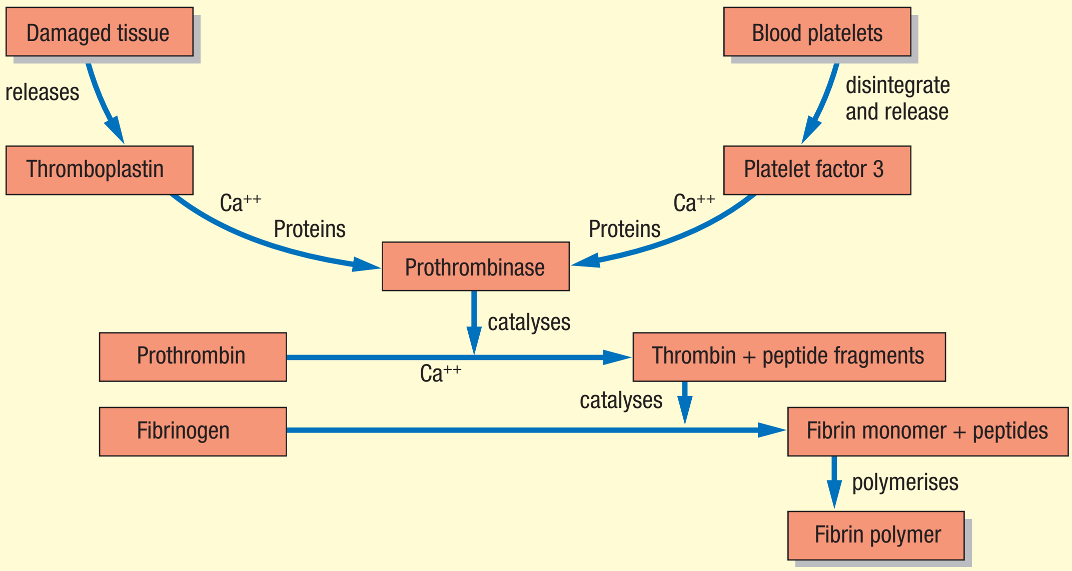


Figure 18.34 Formation of fibrin in blood clotting

and lung cells, and inhibits the conversion of prothrombin to thrombin in the general circulation. The synthesis of prothrombin in the liver requires an adequate supply of vitamin K.

18.5.3 The circulatory system

The mammalian circulatory system consists of a series of vessels through which blood is pumped as a result of the rhythmic contractions of the heart. In mammals the system is termed a **double circulatory system**, because the blood passes through the heart twice in its circuit around the body.

In the first passage through the heart, deoxygenated blood returning from the body is pumped to the surfaces of the alveoli in the lungs for gas exchange; and oxygenated blood is pumped back to the heart. This is the **pulmonary circulation**. The **systemic circulation** is the second passage of blood through the heart. Oxygenated blood flows from the heart to the body tissues, and deoxygenated blood flows back to the heart.

The structure and function of the heart

The human heart contracts about 70 times per minute. The muscle forming the heart is myogenic. This means that its rhythmic contraction is generated by the cardiac muscle itself rather than from an external source. Only its rate of contraction is coordinated by the nervous system.

Cardiac muscle cells form a branched network. Individual cells are tightly connected by intercalated discs. These discs ensure the rapid and uniform spread of contractions throughout the heart.

The continuous action of the heart muscle demands a constant source of energy. As a result, cardiac muscle cells contain a large number of mitochondria. They are also well supplied with oxygen through a system of blood vessels (coronary arteries) spread over the heart wall.

The human heart is a double pump situated between the two lungs. It is surrounded and fully contained by a fluid-filled sac, the **pericardium**. The pericardial fluid protects the heart and reduces friction between the heart wall and surrounding tissues when the heart is pumping.

Each half of the heart serves a separate portion of the circulation. The right half receives deoxygenated blood from the general systemic circulation and pumps it to the lungs. The left half accepts oxygenated blood from the lungs and pumps it into the general systemic circuit again. Thus, although acting in unison, the two halves of the heart act as separate pumps.

Blood from the systemic circuit enters the **right atrium** (was called the auricle) of the heart.

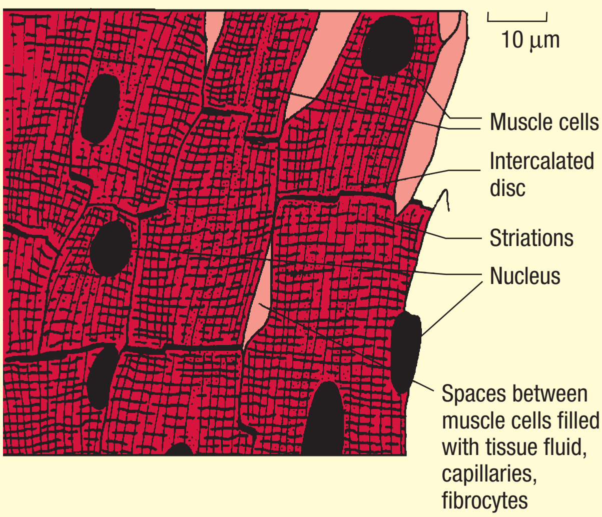


Figure 18.35 Microscopic structure of cardiac muscle

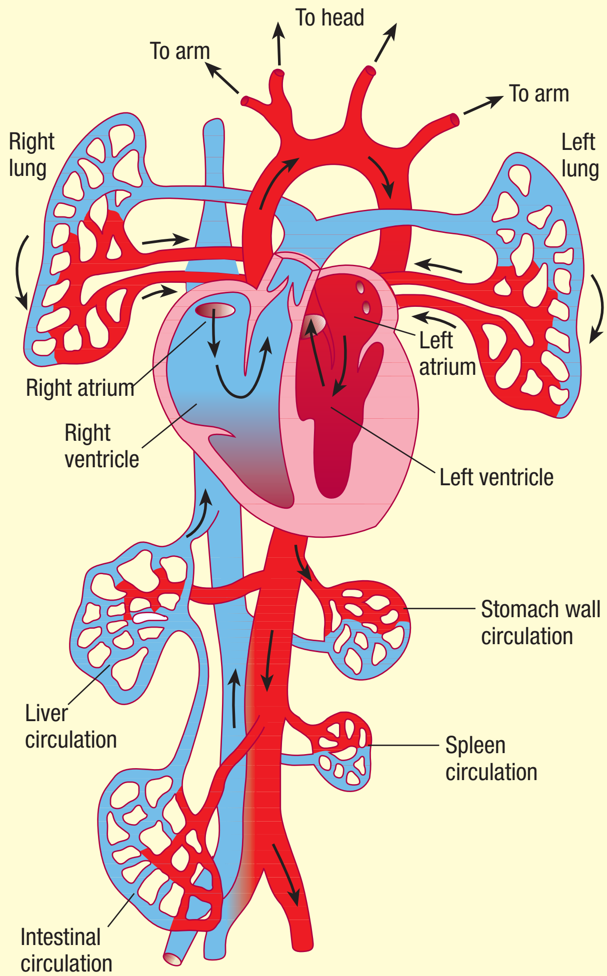


Figure 18.36 Diagrammatic representation of the double circulation of blood

Simultaneously blood from the lungs enters the **left atrium**. From the atria the blood flows into the corresponding **ventricles** on the two sides of the heart. The ventricles contract in unison, expelling blood into the arteries. Blood flows from the right ventricle to the lungs and from the left to the general body circulation. Valves within the heart prevent the blood from flowing through it in the opposite direction.

The volume of blood pumped by the right side of the heart muscle must, over a short period of time, equal the volume pumped by the left side. Since the pulmonary circulation is much shorter than the systemic circulation, its normal volume of blood is much smaller. This imposes less frictional resistance to blood flow, and as a consequence there is less pressure drop through the pulmonary circuit than through the systemic circuit. The right side of the heart, therefore, does not need as great a pumping force as the left. This difference is reflected in the comparative thickness of the ventricular walls: the muscular walls of the left ventricle are much thicker than those of the right ventricle.

Each side of the heart has a valve between the atrium and the ventricle, termed the **atrioventricular valve**. Although they are similar in structure, the right side has three cusps or flaps, whereas the left side has only two. The right valve is therefore called the **tricuspid valve** and the left the **bicuspid valve**.

The valves are funnel-shaped with the free edges of their cusps hanging down into the ventricular cavity and anchored by strands of connective tissue (chordae tendineae). At the point of attachment of each of the chordae tendineae to the ventricular wall there is a small hillock of muscle called a papillary muscle. As the ventricles contract, increasing blood pressure within them forces the cusps of the atrioventricular valves together. The valves close and prevent blood from passing back into the atria. The chordae tendineae prevent the cusps from being pushed up into the atria by the blood pressure developed in the ventricles.

The pulmonary artery (leaving the right ventricle) and the aorta (leaving the left ventricle) both have a valve at the junction with their ventricle. These are **semilunar valves**. Each is composed of

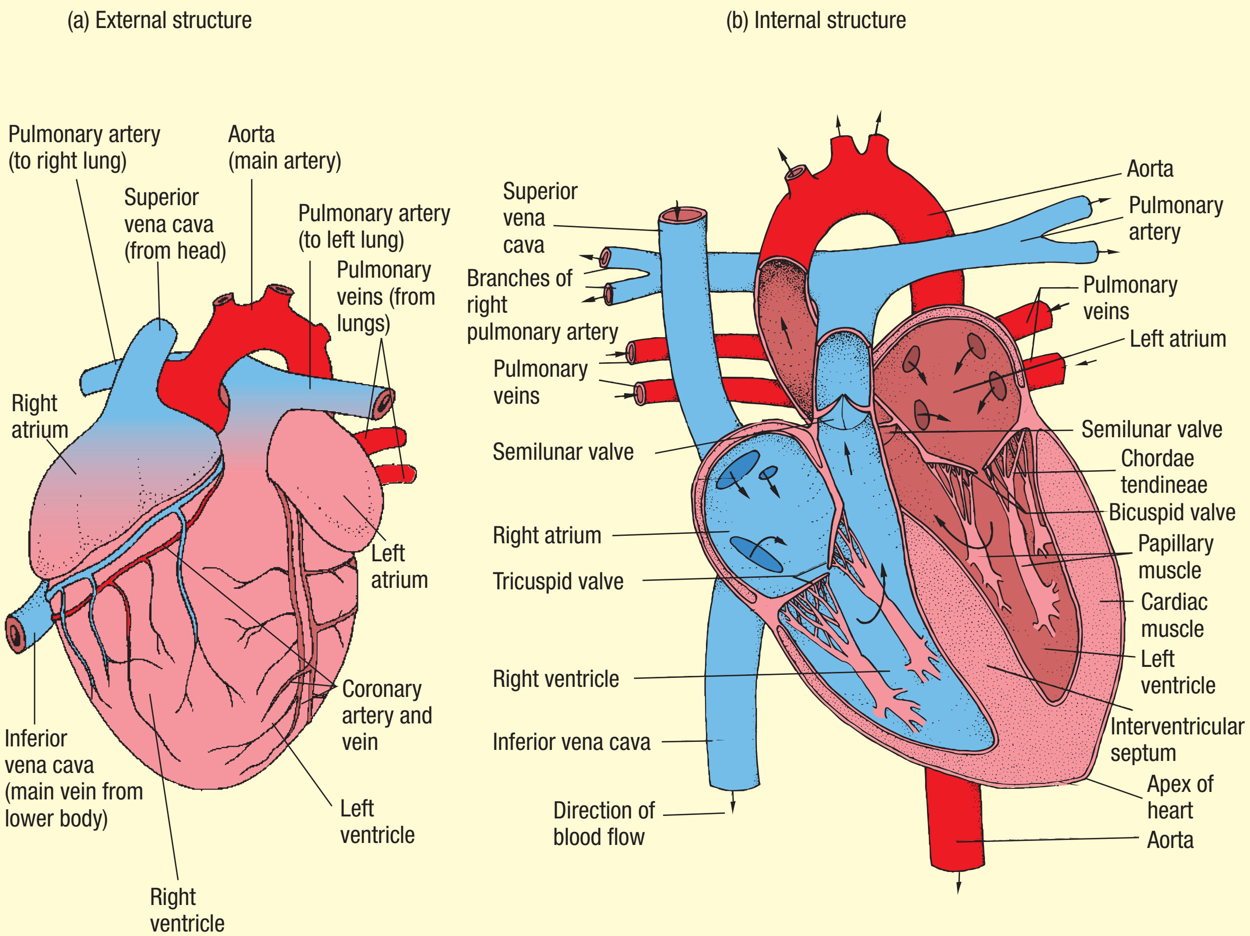


Figure 18.37 Structure of the heart

three pocket-like cusps with the pocket opening directed away from the ventricular chamber. These pockets fold outwards against the arterial walls when the valves are open (ventricles contracting). They fit neatly together to block the opening when the valves are closed (ventricles relaxed).

The cardiac cycle

The **cardiac cycle** is the sequence of events which takes place during the completion of one heartbeat.

The contraction of the chambers of the heart is called **systole** and relaxation is called **diastole**. Contraction of the heart muscles, which are situated mainly in the ventricles, brings about a decrease in volume. The pressure of blood in the chambers increases. Relaxation of the ventricular muscle results in an increased volume and decreased blood pressure. Blood pressure in the atria results in the flow of blood through the atrioventricular valves into the ventricles.

During systole of the ventricles, blood is ejected under pressure into the pulmonary artery and the aorta. The blood pressure in those arteries rises to a maximum. The maximum arterial pressure is termed the **systolic pressure**. While the ventricles are relaxed and are being refilled with blood from the atria, the pressure in the arteries falls as a result of run-off of blood into the other vessels (capillaries and veins). Arterial blood pressure thus decreases to a minimum just before the next ventricular systole. This minimum arterial pressure is called the **diastolic pressure** because it coincides with ventricular diastole.

In young human adults the aortic blood pressure fluctuates, on average, between 120 mm of mercury (systolic) and 80 mm of mercury (diastolic). This is recorded as 120/80. Wide variations from the average occur in normal adults depending on the degree of physical training and other factors. Pulse pressure is the change in pressure between systolic and diastolic pressure. This can be felt as a wrist or neck pulse.

Control of the cardiac cycle

The intrinsic nature of heart muscle causes its fibres to contract and relax automatically, but the rate of heartbeat is controlled by the central nervous system. Increased demands by the body for more oxygen or nutrients are transmitted to the brain from various internal receptors. An appropriate message is then sent to the heart to increase its rate of beat.

The centre for coordinating heartbeat is found in the base of the brain (the medulla oblongata) and nerves to the heart are part of the autonomic nervous system. These nerves are not under conscious control. There are two divisions of these nerves to the heart. The sympathetic nerves, which emerge from the spinal cord adjacent to the heart, increase beat rate. The parasympathetic nerves, branches of the vagus nerve, leave the medulla oblongata directly and slow down beat rate. Stimulation of either nerve is related to body requirements and operates to maintain homeostasis.

Other factors also affect the heart rate. High pH and low temperatures, for example, decelerate heart rate; low pH and high temperatures accelerate it.

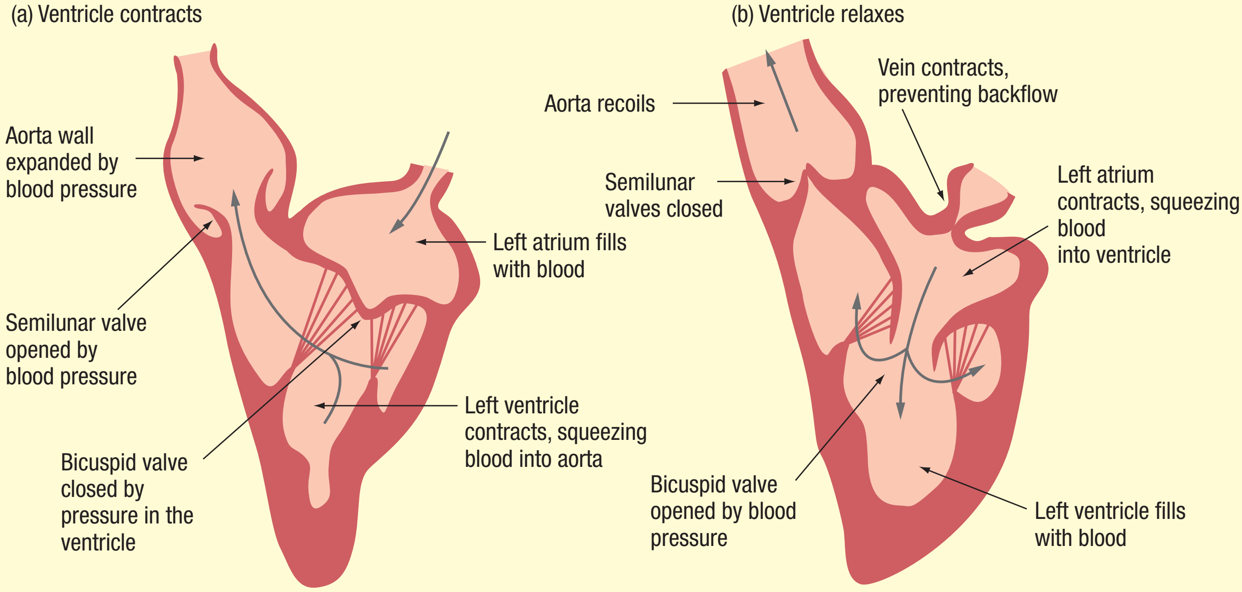


Figure 18.38 Development of aortic blood pressure (left side of the heart only shown)

1. The heart muscle is relaxed (diastole).
Deoxygenated blood enters the right atrium and oxygenated blood enters the left atrium.
As the atria fill with blood, the pressure rises and forces the atrioventricular valves to open.

2. The two atria contract simultaneously, forcing more blood into the ventricles.
This contraction causes constriction of vessels entering the heart, thus preventing flow of blood into the atria from them.
Almost immediately the ventricles contract, forcing the closure of the atrioventricular valves and the semilunar valves open.
Turbulence of the blood in the contracted ventricles produces a long, low-pitched sound – 'lub'.

3. The ventricles relax.
The high blood pressure in the aorta and pulmonary artery tends to force some blood back towards the ventricles, causing the closure of the semilunar valves.
This closure, and the backflow of blood against the valves, produces the second heart-sound – a relatively short, high-pitched 'dub'.

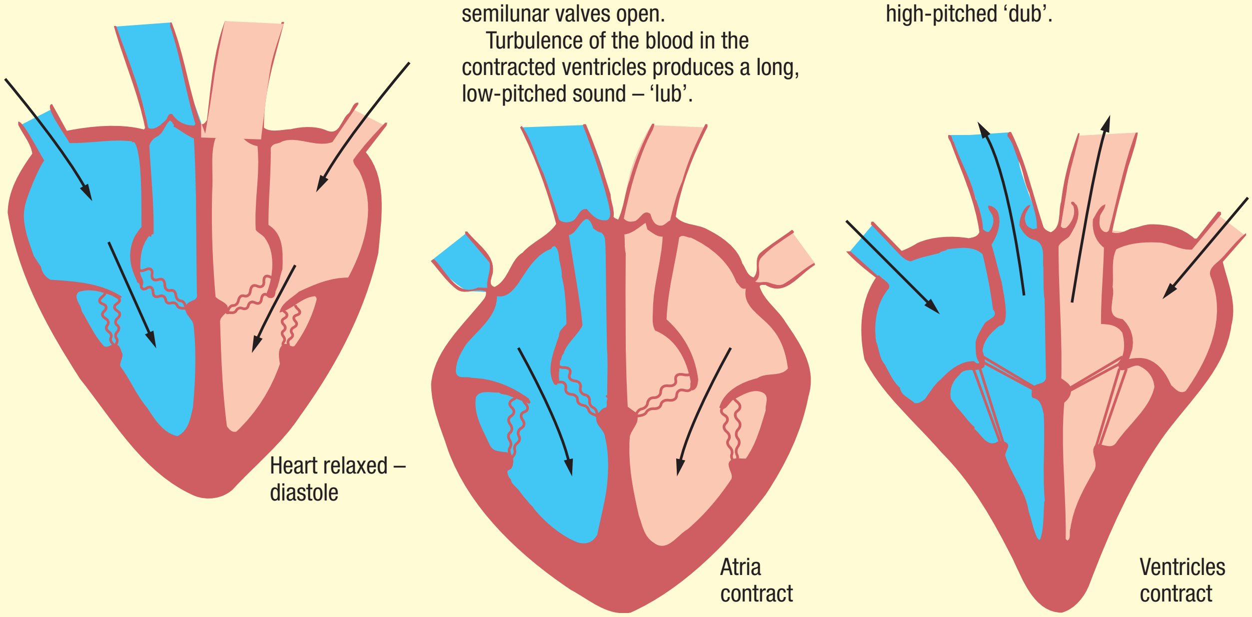


Figure 18.39 The cardiac cycle

The nerves stimulate the cardiac muscle at a specific part of the right atrium, the **sino-atrial node** (S-A node) or pacemaker. The rate of heartbeat is transmitted, by stimulation of one of the two types of nerves, to the cardiac muscle. Stimulation causes a series of chemical changes to occur in the cardiac muscle cells at the node, and this brings about muscle contraction. Since each muscle cell is intimately connected to an adjoining cell, these chemical changes pass from cell to cell, causing a wave of muscular contraction to occur across the atrium walls.

The atrial muscles are completely separated from those of the ventricles by connective tissue, except for a region in the right atrium called the **atrioventricular node** (A-V node). The tissues in these regions transmit the wave of contraction from the atria to the ventricles, causing them to contract. Stimulation of the A-V node is transmitted to the ventricular muscles by special Purkinje fibres. Thus systole starts with the contraction of the atria, followed by ventricular contraction.

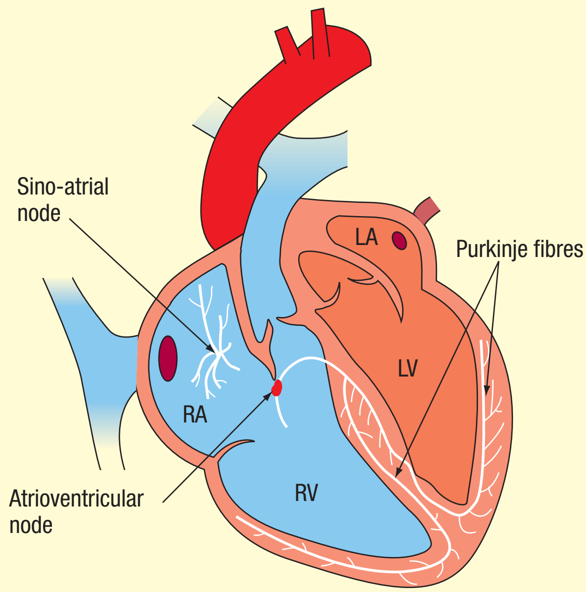


Figure 18.40 Positions of the S-A and A-V nodes and Purkinje fibres in the heart

Once cardiac muscle has begun to contract, it cannot respond to another stimulus until it begins to relax. The chemical changes bringing about the contraction must be returned to the resting or relaxed state before another contraction can occur. This period of time between contractions is known as the refactory period. It is longer in cardiac muscle than for other types of muscle. The long refactory period allows the muscle to contract vigorously and rapidly without becoming fatigued.

An electrocardiograph can record changes in electrical charges resulting from the chemical changes during the contraction of the heart muscle. Thus irregularities in the cardiac cycle can be detected.

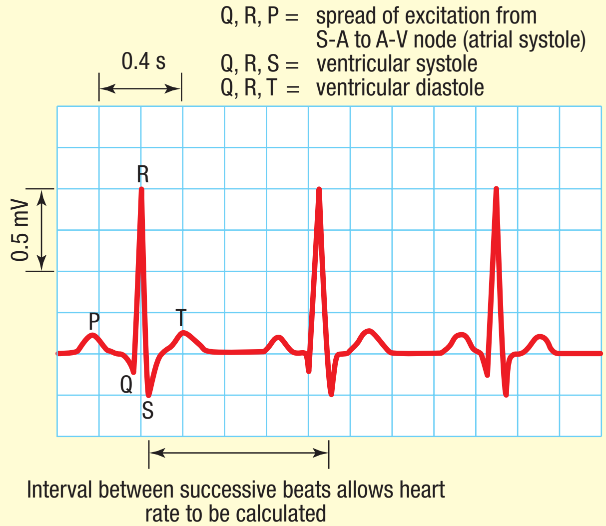


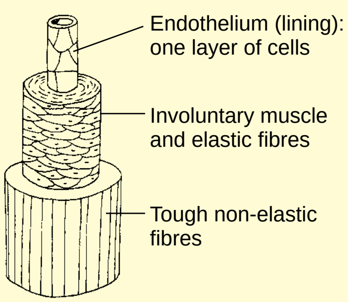
Figure 18.41 An electrocardiogram (ECG)—heartbeats recorded on an electrocardiograph

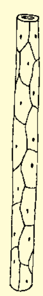
The vessels of the circulatory system

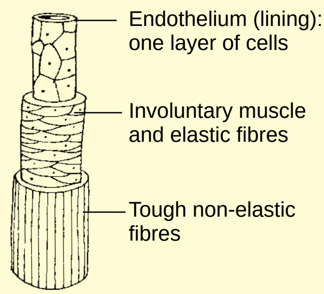
The vessels involved in the circulatory system are the arteries, veins, capillaries and lymphatic vessels. Table 18.8 summarises some differences in structure and function of the blood vessels.

Table 18.8 Comparision of the structure and function of arteries, veins and capillaries

Arteries	Capillaries	Veins
Transport blood away from the heart	Link arteries to veins	Transport blood towards the heart
Thick muscular walls	Walls one cell thick, no muscle	Thinner, less muscular walls
Elastic tissue	No elastic tissue	Less elastic tissue than arteries
Can contract	Cannot contract	Cannot contract
No valves	No valves	Valves present
Circular cross-section	Circular cross-section	Oval cross-section
Not permeable	Permeable to tissue fluid and white blood cells	Not permeable
High blood pressure	Intermediate blood pressure	Low blood pressure
Rapid flow	Slow flow	Slow flow
Pulse	No pulse	No pulse







The lymphatic vessels are similar to veins in general structure but have blind ends in the tissues and empty their contents into the veins as they enter the heart.

The large arteries leaving the heart are subjected to high pressure and so must be thick. The middle layers of the arteries are composed mainly of elastic fibres which enable them to dilate during ventricular contraction. When the ventricles relax, the muscles in the artery walls contract. This produces an even flow of blood along the length of the arteries.

Friction between the plasma and the artery walls reduces pressure. Further away from the heart, where blood pressure is lower, the artery walls contain more smooth muscle fibres which are innervated by sympathetic nerves. Nervous stimulation controls the diameter of these vessels and thus blood flow. As the diameter decreases, blood pressure will increase.

Blood passes from the arteries into smaller branches called **arterioles**. These vessels can further regulate blood flow. They either shunt blood directly to the **venules** or constrict at capillary junctions, as seen in Figure 18.42. Arterioles become finer and finer. They eventually lead into capillaries which form a vast network pervading all parts of the body.

No cell is more than 0.5 mm away from a capillary. The diameter of the capillary lumen is approximately that of a red blood cell. Capillary walls are composed of a single layer of cells which are permeable to all blood components except red blood cells and plasma proteins.

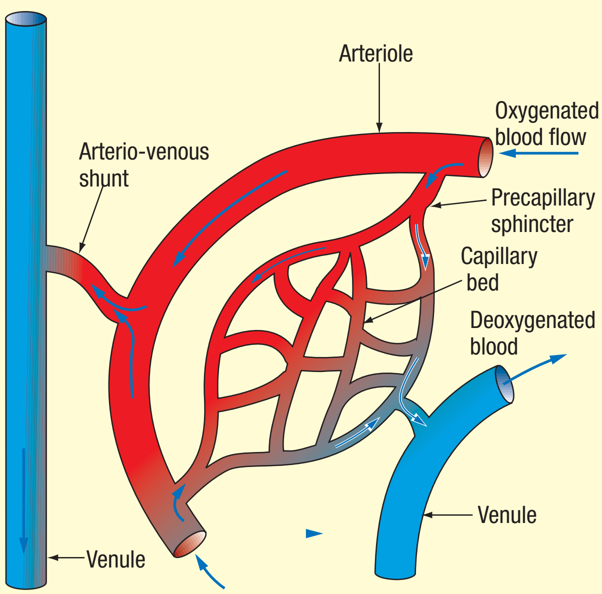


Figure 18.42 Possible routes taken by blood between arterioles, capillaries and venules

Blood under pressure enters the capillaries. The blood pressure forces the contents (other than red blood cells and plasma proteins) through the minute spaces between the cells of the capillary wall. This forms intercellular or tissue fluid which surrounds the cells. Exchange of materials between the cells and blood is made in this tissue fluid. Fluid is then returned either to the capillary at the venous end or to the lymphatic vessels.

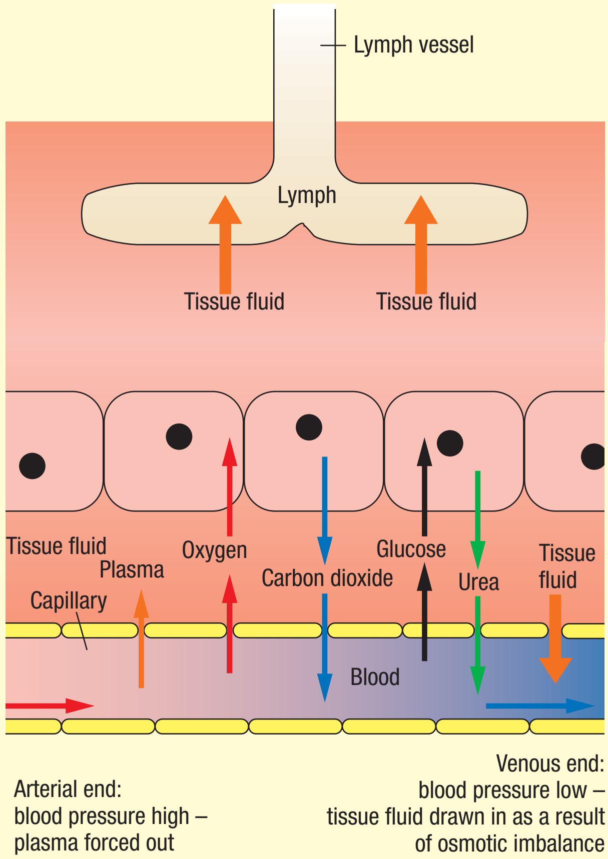


Figure 18.43 The formation of tissue fluid

Return of blood to the heart

Loss of fluid at the arterial end of the capillaries leads to a rapid fall in blood pressure and thus rate of flow. Since the red blood cells and the large plasma proteins cannot leave the capillaries, an osmotic imbalance is developed in the capillaries as they move through the tissues. This results in a net flow of tissue fluid back into the capillaries at the venous end of the network.

Blood from the capillaries drains into thin-walled venules which join to form veins. The lumen of the vein is much larger in diameter than the artery, due to the smaller amount of muscle cells and elastic fibres present in the walls. Semilunar valves, formed by folds of the inner walls of the veins, are present to prevent backflow of blood and thus maintain a unidirectional flow. Veins cannot contract. Return of blood to the heart requires an 'outside' influence. This is achieved in the following ways:

Muscle pressure

Pressure is exerted on the veins by the contraction of surrounding muscles. This produces a 'milking' effect.

Movements during breathing

During inhalation the thoracic volume is actively increased by the actions of muscles which raise the ribs and lower the diaphragm. This decreases the pressure within the thoracic cavity, resulting in inflation of the lungs. The major veins in this region are also dilated by this lower thoracic pressure. This creates a low blood pressure in the veins, which draw blood into them from lower regions of the body.

Simultaneously, the abdominal cavity decreases in volume due to the lowering of the diaphragm. This raises the pressure, which compresses the abdominal veins and pushes blood into the thoracic region.

Exhalation involves lowering the rib cage and raising the diaphragm, thus decreasing the volume of the thoracic cavity and raising its pressure relative to the atmosphere. This action compresses the veins, and so pushes blood forward into the heart.

Negative pressure in the heart

A negative pressure is generated in the heart by relaxation after systole. Suction of blood into the heart occurs. It is thought that some of the energy developed during contraction of the ventricles is stored in both the cardiac muscle fibres and the connective tissue surrounding both individual fibres and bundles of fibres. This allows for a very rapid recoil of the cells at the completion of the contraction. The result is a sudden expansion of the heart: that is, a negative pressure which pulls the blood into the ventricles.

Gross motion of the heart

For every action there is an equal and opposite reaction. When the heart contracts it jets downwards as a recoil to the blood being pumped from the heart upwards. This downward motion stretches the elastic tissues that hold it in place. During diastole the heart springs back upwards, meeting the inflow of blood head-on. The resulting high relative velocity of blood and heart accelerates the heart's filling process.

In quadrupeds with long, thin legs such as the camel and giraffe, the lower extremities contain virtually only tendons, attached to the muscles in the upper portion of the leg. Propulsion of the venous blood from the foot region depends on specialised tissue in the pads of the 'feet' which are

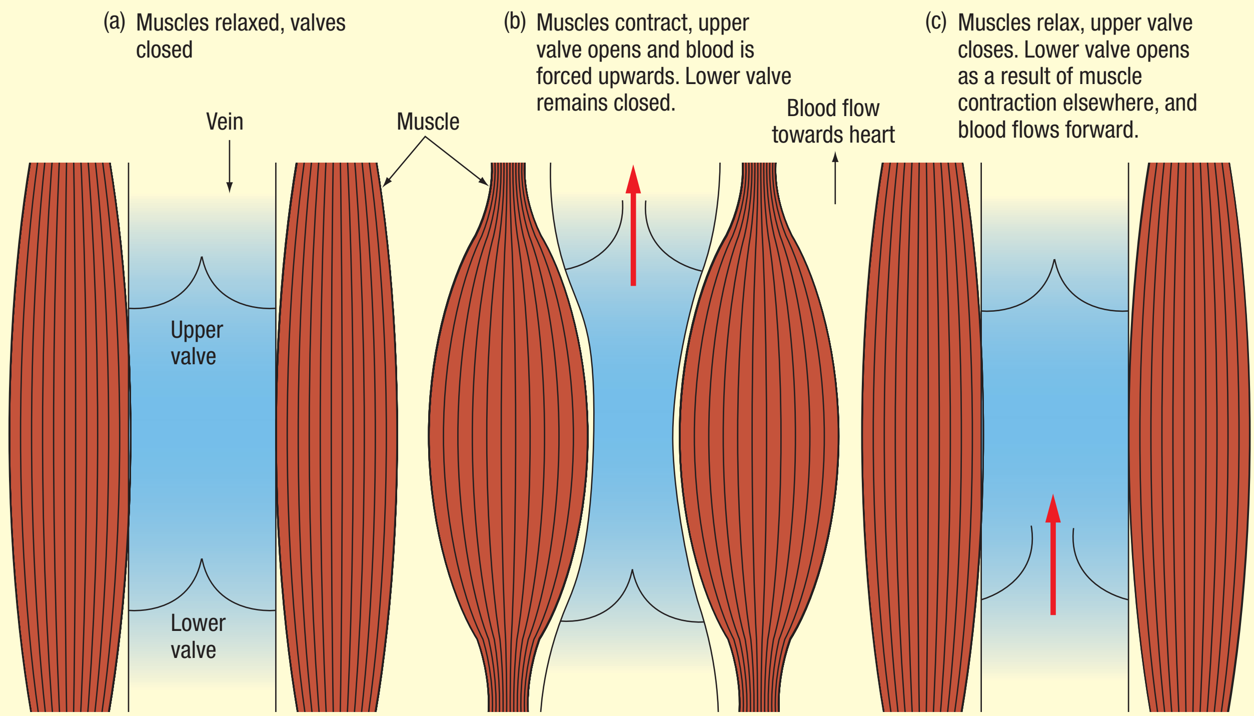


Figure 18.44 The 'milking' effect of muscles on blood in veins

compressible vascular beds. When weight is placed on these, blood is squeezed upwards into the veins.

Hepatic portal vein

Arteries are vessels which leave the heart and end in a capillary bed; veins are vessels which begin in a capillary bed and enter the heart. In some cases, however, a vessel both begins and ends in a capillary bed. These vessels are termed **portal veins**. They function as a short-circuit between two organs. The hepatic portal vein short-circuits the general circulation by taking absorbed nutrients directly from the small intestine (site of digestion and absorption) to the liver (the major organ for metabolism).

Case study 18.8: Varicose veins

Valves in the veins prevent backflow of blood. If these valves stretch, they no longer close properly and gravity causes blood to accumulate in the extremities. The surface veins become enlarged and are called varicose veins. This can be a very painful condition. Some of the symptoms are fatigue, heaviness, aching, burning, throbbing, itching and cramps.

Stretching of the valves is primarily caused by obstruction to the veins or prolonged pressure placed upon them. Although heredity plays a part in the predisposition to varicose veins, environmental factors are a significant cause. Pressure on the veins is usually caused by prolonged standing. People in professions such as nursing, teaching, hospitality industries and sales are therefore prone to this condition.

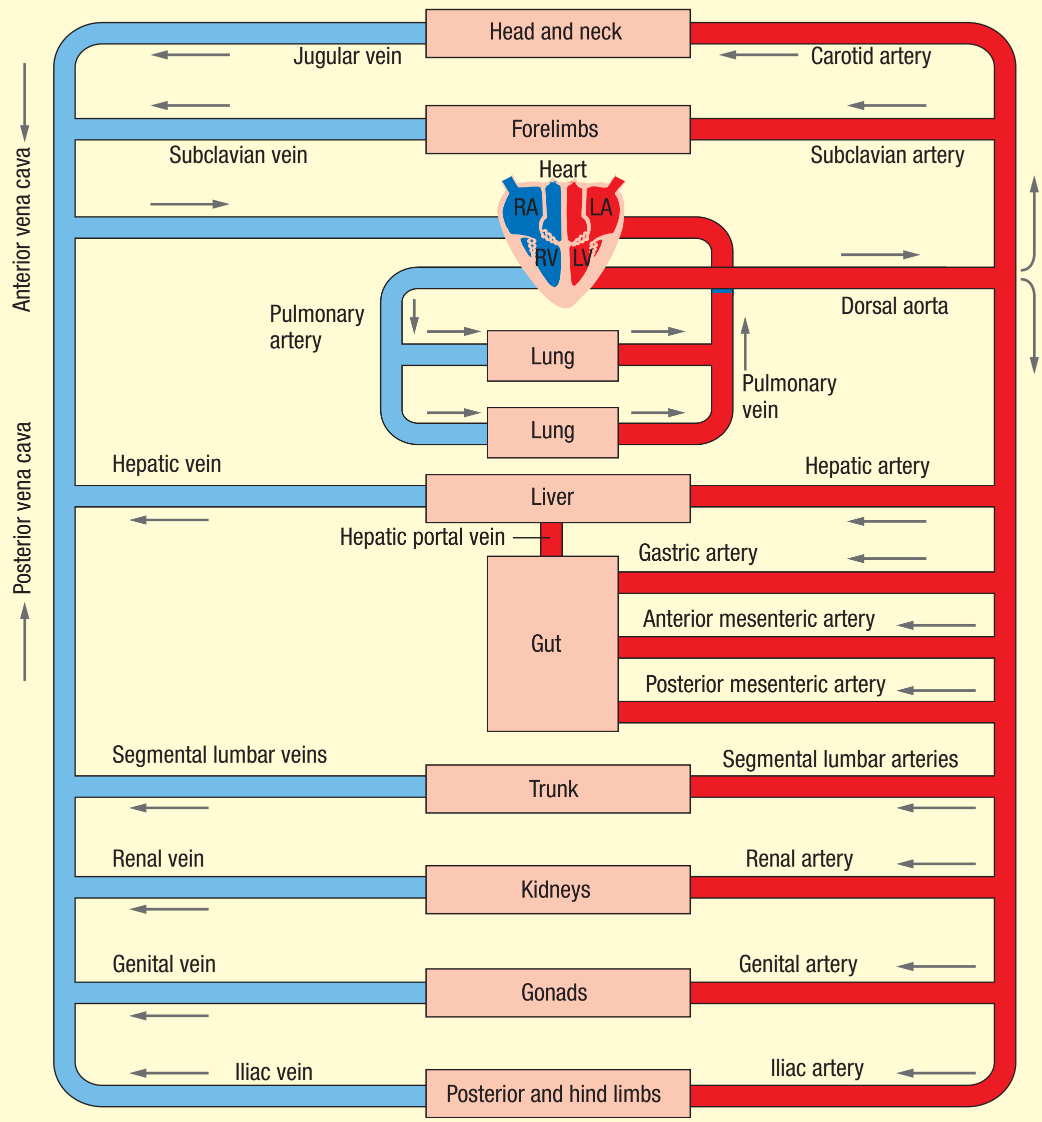


Figure 18.45 Schematic diagram showing the principal arteries and veins of a human

Although up to 20 per cent of the population suffers from varicose veins, more than twice as many women as men are afflicted. This appears to be hormone-related. Approximately 75 per cent of pregnant women develop varicose veins. Increases in the hormones oestrogen and progesterone during pregancy are believed to increase the blood volume by 20 per cent in the female. They also cause relaxation of tissues throughout the body, including the vein valves. As pregnancy continues, the increased size of the uterus adds further pressure on the veins of the pelvis. In the majority of cases, any varicose veins developed during pregnancy disappear within a few months of giving birth.

Suggestions to decrease the chance of developing varicose veins include:

- exercise
- avoiding being overweight
- elevation of the legs above heart level several times a day
- not crossing the legs at the knee
- avoiding standing for long periods. If this is unavoidable, gently bounce on the balls of the feet every few minutes.

There are various treatments for varicose veins:

Sclerotherapy

Injection of a saline solution into the affected veins causes them to close. The body then reroutes the blood through alternative, healthy vessels.

Laser treatment

Laser treatment is used for only small or 'spider' veins. Like sclerotherapy, it closes off the veins.

Surgery

Surgery involves stripping the veins, or ligation (tying them off).

18.5.4 HOMEOSTASIS THROUGH CONTROL OF THE CIRCULATORY SYSTEM

The rate of heartbeat has been shown to be controlled by a centre in the brain in response to body demands. Thus, during activity when body musculature requires more oxygen, the heart is stimulated to beat faster. Sensors in the body transmit information to the cardiac centre and an appropriate response is made. Some sensors—for example, the baroreceptors in the wall of the aorta—detect blood pressure. Others detect chemical changes in the blood; for example, the carotid bodies situated in the walls of the carotid artery detect levels of carbon dioxide.

In addition to changes in heart rate, the cardiac centres can control the degree of dilation or contraction of the arteries and arterioles. Thus blood can be shunted to certain areas in particular situations. After a heavy meal, more blood will be shunted to the small intestine for absorption of digested nutrients, with a subsequent decrease in blood supply to the body musculature. With heavy exercise, on the other hand, more blood will be directed to the actively metabolising muscles. Brain cells, however, cannot go without an oxygen supply and the flow of oxygenated blood to this organ must be maintained at a constant level.

The ability of the body to change the rate of flow of blood to the various body tissues is important in achieving homeostasis—to maintain constant conditions within the body in spite of changing internal and external environmental conditions.

One of the features of birds and mammals is that they are endotherms. They can maintain a constant internal body temperature regardless of external environmental temperatures using physiological mechanisms. Endothermy depends upon an efficient double circulation which ensures the complete separation of oxygenated and deoxygenated blood. This ensures a more effective uptake of oxygen from the respiratory surfaces and a greater supply of oxygen to the tissues. Thus the cells can actively metabolise at all times.

Part of the energy derived from cell respiration is released as heat. If too much heat is generated in the internal organs, it must be released before protein denaturation occurs. If an increase in body core temperature is detected, then nervous stimulation causes vasodilation of the peripheral vessels at the outside of the body, and thus loss of heat to the atmosphere. This can be seen in the flushed skin of an athlete after a race as more blood enters the skin area.

Similarly, when heat needs to be conserved, constriction of the peripheral vessels reduces the volume of blood to these areas and thus heat loss. This can often be observed, for example, as a blue tinge to the ears, mouth and nose in very cold conditions.

A particular adaptation of the circulatory system is that of the counter-current. This strategy is used in a variety of organs in the body. For example, counter-currents in the:

- mammalian kidney maintain correct plasma balance
- nasal passages conserve water and heat
- skin either release or conserve heat.

In all cases, the counter-current involves the exchange of 'matter' or energy between two vessels in very close proximity in which fluid is flowing in opposite directions. In most cases, the counter-current exchange depends on an established diffusion gradient and is therefore a passive action. In some situations—for example, the kidney—active transport against a concentration gradient occurs.

Case Study 18.9: Conservation of heat in mammals through counter-currents

Mammals living in conditions of a constant temperature extreme have evolved special adaptations. Thus animals living in hot, dry conditions tend to have large, highly vascularised ears which increase the surface area for heat loss. Animals such as the arctic fox have small ears and relatively short, horny foot pads in which there is a very small amount of blood circulation. These features reduce heat loss to the cold environment. High altitude areas are also very cold. Mice are normally nocturnal animals. The moorland mice of Mt Kilimanjaro (approximately 3500 m altitude), however, are active during the day. The night temperature is so cold that this behavioural adaptation reduces heat loss. In addition, they have relatively large, thickly furred bodies (small surface area:volume ratio) and highly reduced ears and tails to further limit heat loss.

Whales swimming in polar waters have a tendency to lose body heat through the flippers and tail flukes. The veins that return blood from the flippers and the tail surround the arteries going to them. Warm blood from the body core is therefore surrounded by a jacket of cool blood flowing in the opposite direction. A large part of this heat is transferred from the artery to the vein before blood reaches the periphery. As well as preventing excessive heat loss, this pre-warms the venous blood before it reaches the core, further conserving body energy. In this case the counter-current system is one in which the two opposing fluids are separated only by the walls of two vessels.

A slightly different situation occurs in the nasal passages. Inhalant air is heated as it passes through the nose and the upper respiratory tract, so that it reaches the lungs pre-warmed to core temperature. The heat for this process is released by the blood vessels in the respiratory tract and as a consequence they lose heat. Expired air therefore passes over cooler blood vessels and heat is transferred back to them from the air. The nose acts as a heat regenerator. In the camel this strategy is adapted even further to conserve moisture from the exhaled air with specialised tissue in the narrow nasal canal. In this situation the counter-current flows are separated in time—during inhalation and exhalation.

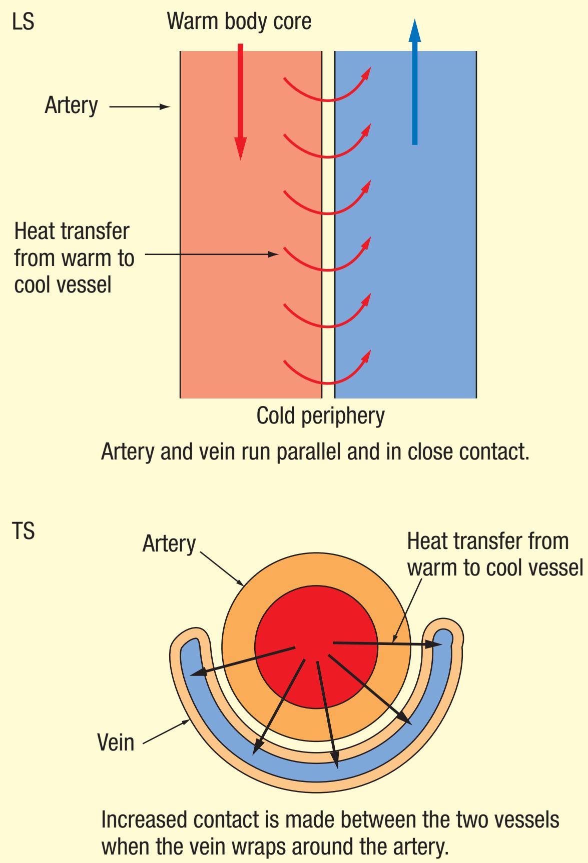


Figure 18.46 Model of the counter-current system where heat is transferred between fluids moving in opposite directions as a result of a temperature gradient between them

18.5.5 The lymphatic system

Not all of the tissue fluid returns to the capillaries. Some is taken up by the lymphatic vessels and forms a fluid called lymph. Lymph is moved through the vessels by the contraction of the muscles surrounding them and backflow is prevented by valves. At points along the major lymph vessels are **nodes**, a meshwork of canals, in which lymphocytes accumulate. The nodes filter out bacteria and other foreign matter, which are ultimately destroyed by phagocytosis. The nodes also produce lymphocytes which are involved in antibody formation. The lymph is returned to the blood vascular system near the heart into two of the major veins.

SUMMARY

Human blood is composed of red cells (erythrocytes), white cells (leucocytes) and platelets suspended in plasma. Dissolved substances are transported in the plasma and respiratory gases in the red blood cells. White blood cells are involved in antibody, inflammation and allergic reactions as well as phagocytosis.

Platelets and the plasma protein fibrinogen are important agents in blood clotting.

The circulation system consists of heart, arteries, capillaries and veins.

The heart is divided into four chambers: two atria and two ventricles. Blood is propelled through the heart by a series of contractions of the heart chambers.

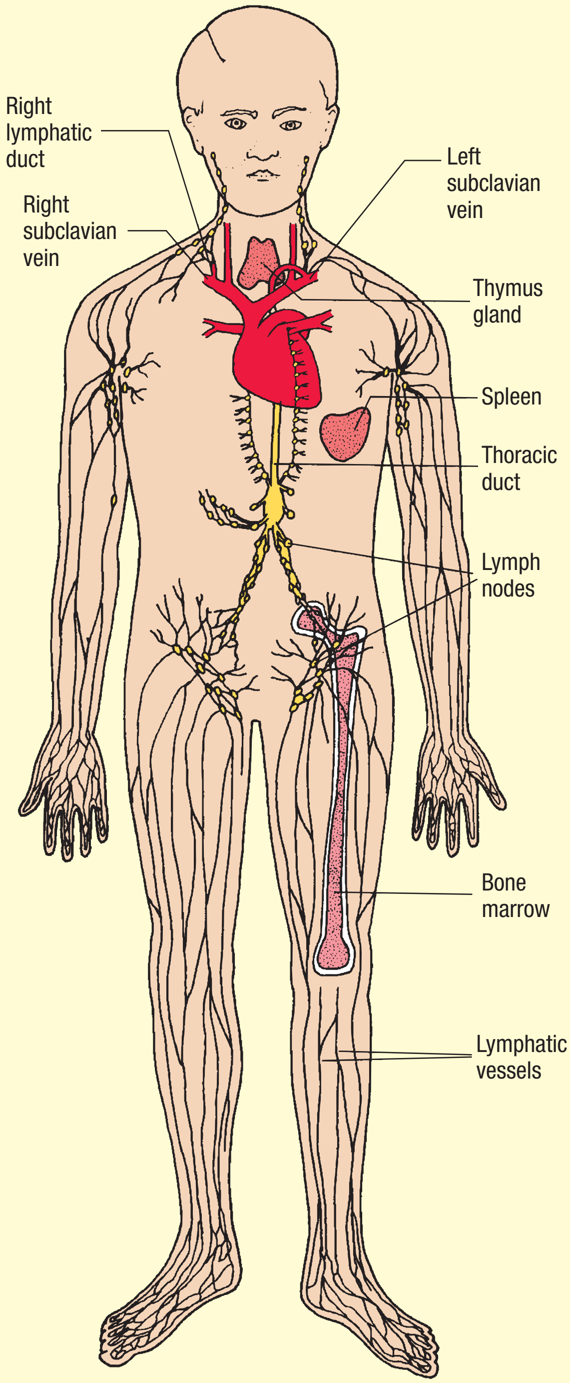


Figure 18.47 The lymphatic system of the human body

The ventricles have thick muscular walls, and valves between them and the atria prevent blood from flowing in the wrong direction.

Humans have a double circulation system: blood flows through the heart twice for every complete circuit of the body. The heart is completely divided into right and left sides. The right side receives deoxygenated blood from the body and passes it on to the lungs for gas exchange before it returns to the left side of the heart. The left side receives the oxygenated blood and, due to the great thickness of the left ventricular walls, pumps it under high pressure through the major arteries to the body tissues. The same volume of blood passes through each side. Only the pressure of the expelled blood varies.

Arteries are blood vessels that leave the heart. Exchange of material cannot occur between the arteries (or veins) and tissues due to the thickness of their walls, which consist of several tissues. Arteries break up into capillaries which come into intimate contact with the tissue cells. Exchange of materials occurs between the capillaries, the extracellular fluids and the cells.

Blood pressure is maintained in the arteries due to their thick muscular walls, which contain highly elastic fibres.

Capillaries re-form into veins, which are less muscular and elastic than arteries, and which return the now deoxygenated blood to the heart.

Back-flow of blood in the veins is prevented by valves. Blood pressure is negligible in the veins and thus blood is moved in them through pressure from contractions of surrounding muscles and negative pressure in the thorax and heart.

Tissue fluid which is not returned to the veins is collected by lymphatic vessels, forming lymph. This fluid has a high proportion of white blood cells which are phagocytic. Lymph is returned to the major veins as they enter the heart.

Review questions

18.46 Define the following terms:

(a) artery
(b) atrium
(c) atrioventricular
(d) arterial pressure
(e) valve
(f) blood
(g) bicuspid valve
(h) capillary
(i) coronary vessel
(j) closed circulation
(k) diastole
(l) double circulation
(m) lymph
(n) plasma
(o) platelet
(p) portal vein
(q) red blood cell
(r) serum
(s) semilunar valve
(t) systole
(u) tissue fluid
(v) tricuspid valve
(w) vein
(x) ventricle
(y) venule.

? **18.47** List the constituents of blood and, for each, give a function.

18.48 Why is the protein fibrinogen an important constituent of plasma?

18.49 Explain how each of the following is carried in the red blood cell:

(a) oxygen

(b) carbon dioxide.

18.50 What factors contribute to the following?

(a) loss of carbon dioxide and uptake of oxygen at the alveoli of the lungs

(b) release of oxygen from haemoglobin at the tissues

18.51 Sketch the oxygen dissociation curve. Explain how this curve illustrates loading and unloading of oxygen in red blood cells.

18.52 What is the Bohr shift?

18.53 Why is the chloride shift necessary in the carriage of carbon dioxide by the blood?

18.54 Figure 18.48 shows some of the structures visible in a ventral view of a section through the human heart.

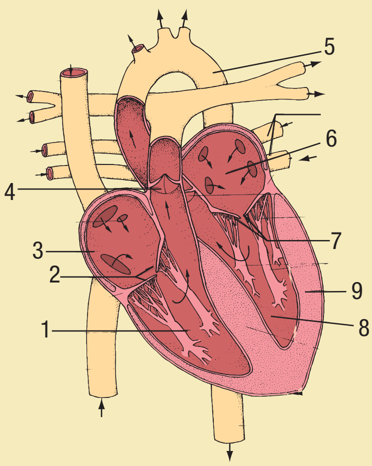


Figure 18.48

(a) Name the numbered parts.

(b) What is the significance in the difference in thickness between:

(i) 1 and 9

(ii) 6 and 9?

(c) Copy the following table. When the valve numbered 4 is closed, indicate by a tick in the relevant column of the table the condition of the numbered structures.

Structure	Condition	
	Contracting	Relaxing
1		
3		
8		
9		
2		

18.55 Cardiac muscle is myogenic and yet rate of heart-beat is controlled by the central nervous system.

(a) Explain the significance of this.

(b) Describe the effects of the different innervations to the heart.

(c) Describe how nervous stimulation to the heart is spread throughout the heart muscle.

18.56 A doctor tells her patient that he has a blood pressure of 140/85. The patient, not knowing what these numbers indicate, asks you to explain. What do you tell him?

18.57 List and explain the differences and different functions of plasma, tissue fluid and lymph.

18.58 (a) What is a counter-current system?

(b) Explain how a counter-current system could help mammals living in cold climates to conserve heat.

18.6 Excretion and Osmoregulation

The concentrations of chemicals dissolved and suspended in the cytoplasm, intercellular fluid and circulating fluid must be maintained within a particular range. This is achieved by osmoregulation and the excretion of metabolic wastes. In the majority of animals, an excretory system is involved in both processes.

Much metabolic waste material is removed from the animal through surfaces in contact with the environment. Carbon dioxide diffuses from the blood to the alveoli of the lungs and through skin surfaces. Salts may be removed through the skin; for example, by sweat in mammals. Salts are also secreted into the large intestine.

Like other animals, humans expend energy, in addition to that involved in general life functions, in locating a food source and processing the food into chemicals required by the body. The proportion of protein in the body of an animal is therefore very high. Proteins provide structural elements such as the muscles that bring about locomotion. As a result of their high metabolic demands, a large number of enzymes are required, and these too are proteins. Proteins, therefore, are significant nutrients for animals. Many omnivores (including humans) and carnivores cannot synthesise all of the amino acids they require for the production of specific proteins, and these essential amino acids must be obtained from another animal source.

Amino acids derived from cell replacements and those taken in as surplus to the body's requirements cannot be stored, and are broken down by the liver in vertebrates. In this process the nitrogen-containing amino group is removed. The products either enter the respiratory pathway or are converted to a storage material and ammonia.

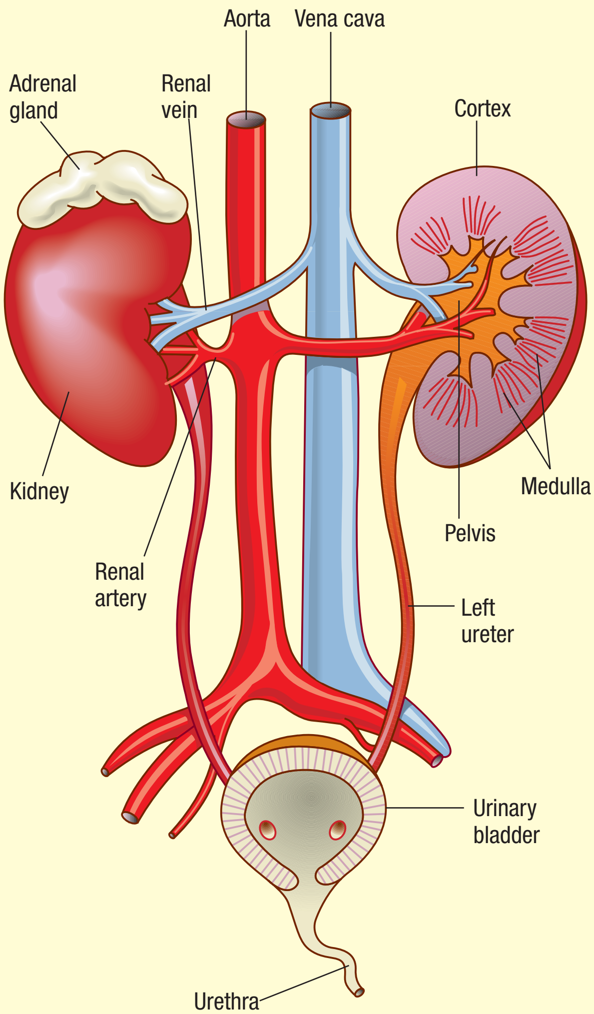


Figure 18.49 The human excretory system

Ammonia is highly toxic to animal cells and must either be rapidly removed from the body or converted to a less toxic compound such as urea or uric acid.

In mammals the removal of metabolic waste materials (**excretion**) and much of the regulation of body fluids (**osmoregulation**) are achieved by the excretory system. Since they are primarily terrestrial animals, mammals must conserve water and thus their nitrogenous waste material must be in a relatively soluble, non-toxic form. They excrete **urea**. The separation of excretory substances from blood and the conservation of water are performed in a pair of kidneys. Waste materials dissolved in water (**urine**) passes from the kidneys through the **ureters** to be stored in the **bladder**. The urine eventually passes to the external environment through the **urethra**.

18.6.1 Structure and function of the human kidney

The excretory system consists of a pair of kidneys which remove excretory products from the blood plasma. The urine so formed passes through the ureters to the bladder for storage. When the bladder is distended with urine, it releases the urine through a sphincter of striated muscle to a median urethra which discharges to the exterior. Although expulsion of urine is directed by the autonomic nervous system (i.e. it is not under conscious control), humans learn to control it by voluntary nervous activity. In the male the urethra passes through the penis and is also responsible for the discharge of semen.

The kidney is a bean-shaped organ. It is enclosed by a capsule of connective tissue and composed of two layers of tissue: an outer, darker-coloured **cortex** and an inner, lighter-coloured **medulla**, surrounding a central cavity.

The two kidneys are found at either side of the mid-dorsal line of the abdominal cavity. They are connected to the circulatory system via the **renal arteries** and **veins** and to the bladder via the ureters. Within the central cavity the top of the ureter expands to form the **pelvis**. The medulla is divided into lobes of approximately conical shape which are called the **pyramids**. The renal artery sends branches between the pyramids to the cortical region which is drained by branches of the renal vein.

The functional unit of the kidney is the **nephron.** Each kidney contains between one and two million nephrons embedded in loose connective tissue and richly supplied with blood. Each nephron consists of an elongated tubule closely associated at one end with a group of blood capillaries (the **glomerulus**) via a cup-shaped **Bowman's capsule** and opening at the other end into a **collecting duct**. Many nephrons open into each collecting duct, which drains into the pelvis and thus out through the ureter.

The nephron tubule has distinct portions. The Bowman's capsule, wrapping around the glomerulus, opens into the **proximal convoluted tubule** which is highly coiled. This leads to the U-shaped **loop of Henle** and on to the coiled **distal convoluted tubule**, which opens into the collecting duct. Only the loop of Henle and the collecting duct are in the medulla. The rest of the nephron is contained within the cortex of the kidney.

Blood enters the capillaries of the glomerulus from the **afferent arteriole**, a branch of the renal artery. It leaves in the **efferent arteriole** which breaks up into a capillary bed surrounding the nephron tubules. Thus blood passing through the renal tissues passes successively through two sets of capillaries before entering the venous drainage leaving the kidney.

Blood enters the glomerulus under high pressure. Water, ions and small molecules such as glucose, amino acids and urea are forced through the capillary wall and lining of the Bowman's capsule into the capsular space by **ultrafiltration**. The filtrate

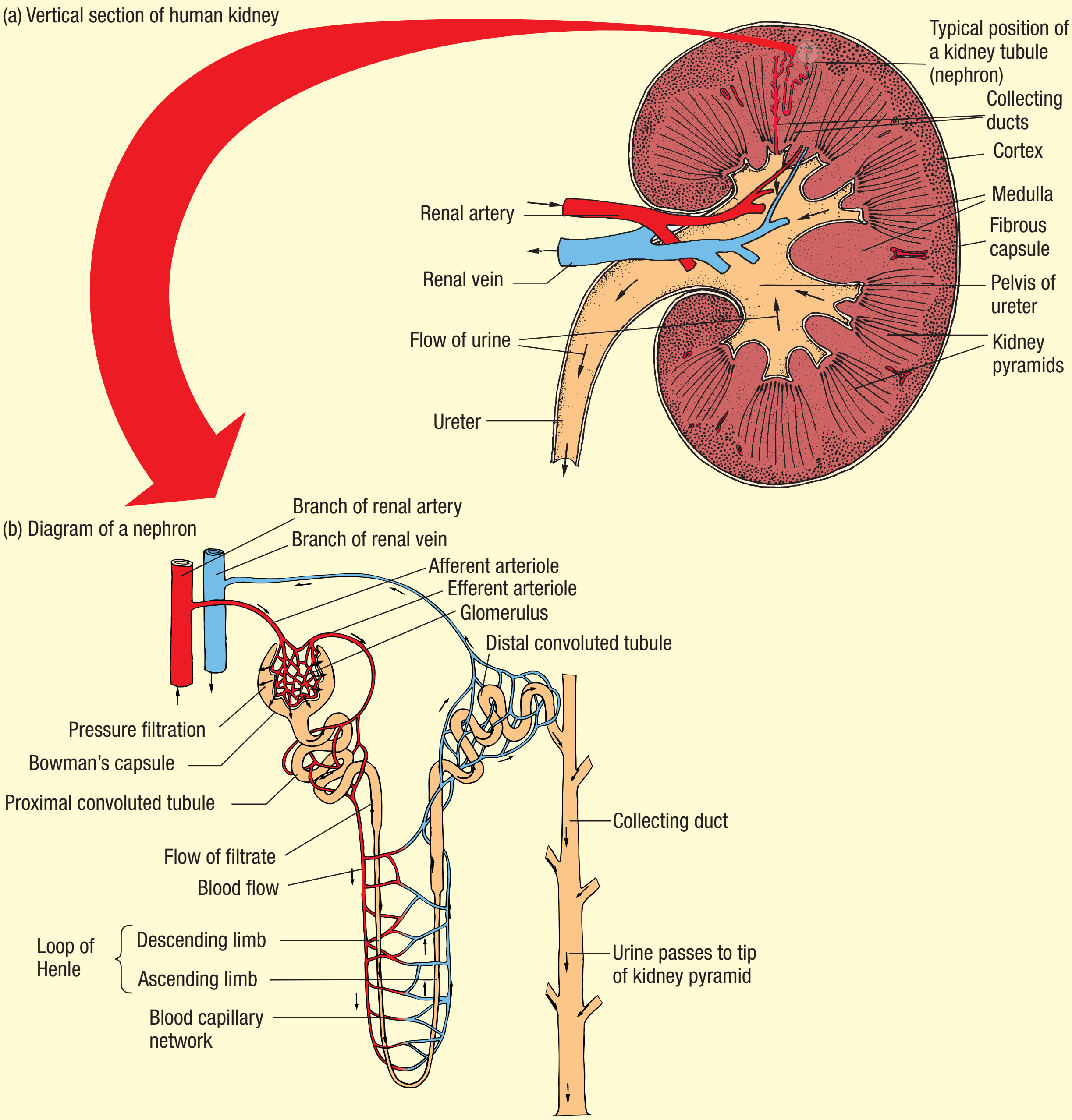


Figure 18.50 Internal structure of the human kidney

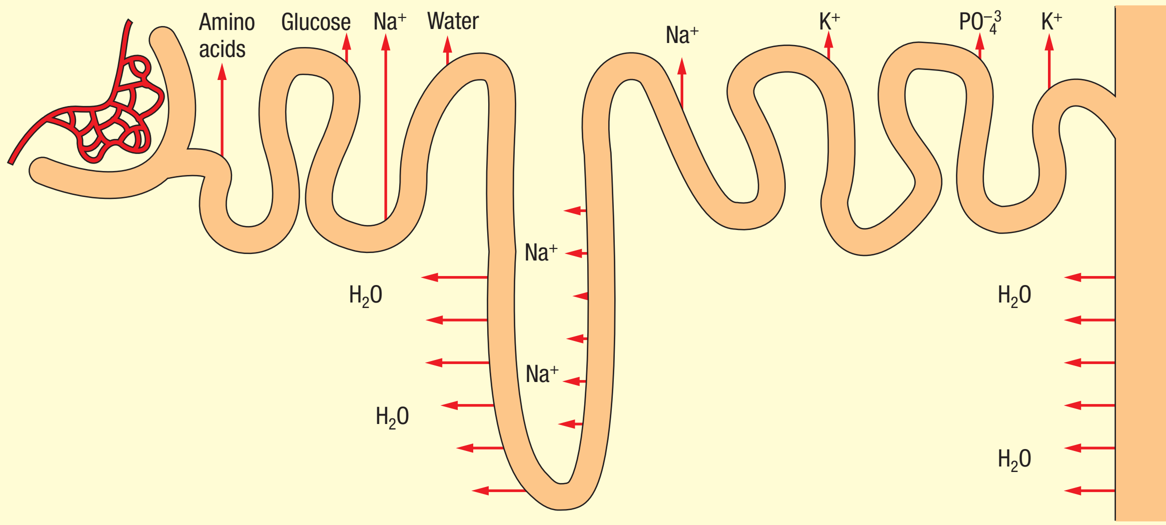


Figure 18.51 Summary of absorption in the nephron

has a composition similar to that of plasma but without the larger protein molecules. Blood cells normally do not leave the blood vessels.

As the filtrate passes along the tubule, many of the useful constituents are reabsorbed into the surrounding capillary network. Other substances are actively secreted into the tubule from the capillaries. Glucose and amino acids are actively absorbed by the cells lining the proximal convoluted tubule. The tubule cells have a brush border of microvilli to increase surface area for absorption and are heavily loaded with mitochondria for energy production. Sodium ions are also actively absorbed in the proximal tubule, creating an ionic imbalance which results in the passive diffusion of the negative chloride ions. Water leaves the tubule under the influence of the osmotic gradient established by the high plasma protein levels in the capillaries. The function of the loop of Henle is the reabsorption of water. The distal convoluted tubule appears to be responsible for the uptake of certain ions and secretory activities.

18.6.2 The loop of Henle as a counter-current multiplier

The loop of Henle enables mammals to reabsorb very large quantities of water from the filtrate, resulting in a urine that is hypertonic to the blood.

The walls of the descending loop are permeable to water but impermeable to sodium chloride and urea. In solution, sodium chloride dissociates into positive sodium ions and negative chloride ions. The walls of the ascending loop are impermeable to water and urea but actively pump sodium ions into the surrounding tissue fluid. The negative chloride ions follow along an ionic gradient. Thus the descending limb is surrounded by a highly concentrated tissue fluid, the concentration of which increases towards the base of the loop. Water therefore diffuses out of the descending limb. Some of the sodium chloride diffuses into the blood capillaries, followed by water. The flow of blood constantly removes these substances from the kidney into the general body circulation.

As the water is removed from the descending limb, the salt concentration of the filtrate increases and is hypertonic to the blood at the bottom of the ascending limb. Removal of salt from the ascending limb results in hypotonic filtrate at the start of the distal convoluted tubule. Further solutes are passed to the blood capillaries at this point.

At any given level of the loop, therefore, the sodium concentration in the descending loop is raised slightly above that in the ascending loop. The sodium concentration in the descending loop is always just below that of the fluid surrounding it, ensuring removal of water. This concentrating effect is multiplied along the length of the loop from top to bottom, so that the longer the loop, the greater is the concentration that can be reached. This system is therefore termed a counter-current multiplier.

The high concentration of sodium chloride in the tissue fluids also brings about diffusion of water from the collecting duct. The permeability of the collecting duct to water is regulated by hormones in a homeostatic feedback mechanism. The build-up of sodium ions around the base of the loop of Henle creates an osmotic gradient between this region and the urine in the collecting duct. If the walls of the

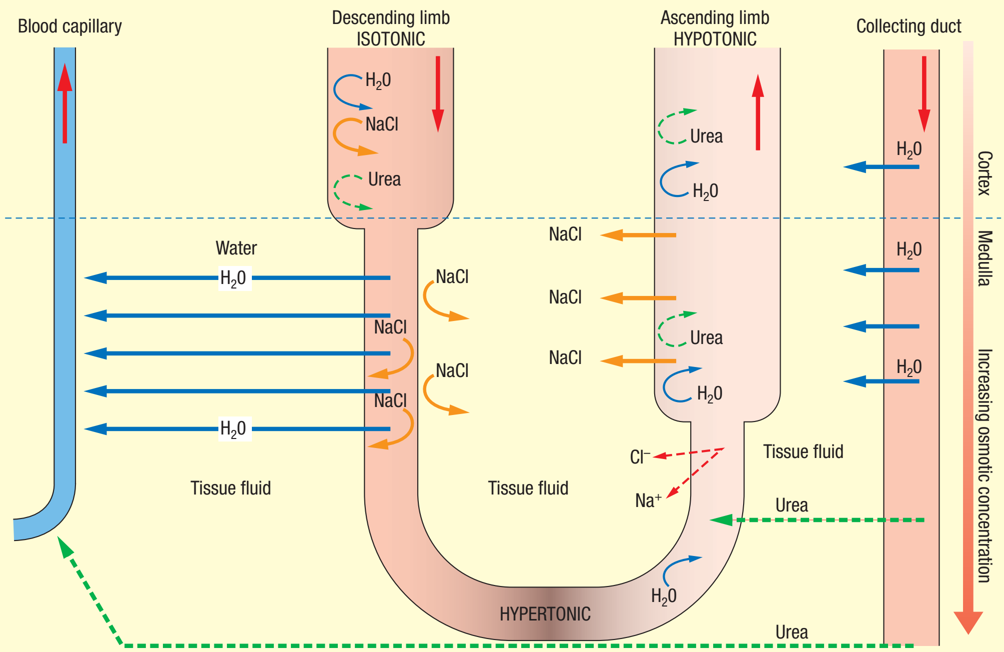


Figure 18.52 The role of the loop of Henle in water reabsorption

collecting duct are permeable to water, osmotic withdrawal of water from the duct to the surrounding tissues occurs. The water passes to the capillaries. The higher the sodium concentration in these conditions, the greater is the amount of water that can be withdrawn from the urine. The urine so produced will be scant and highly concentrated. If, however, the walls of the collecting duct are impermeable to water, then no further changes to the concentration occur and the animal excretes copious, dilute urine.

The amounts of sodium, potassium, phosphate and calcium reabsorbed by the distal tubule cells are regulated by hormones from the adrenal and parathyroid glands, depending on their levels in the plasma.

18.6.3 Hormonal control of water balance

Several different hormones help to control the body's water content. The most important is

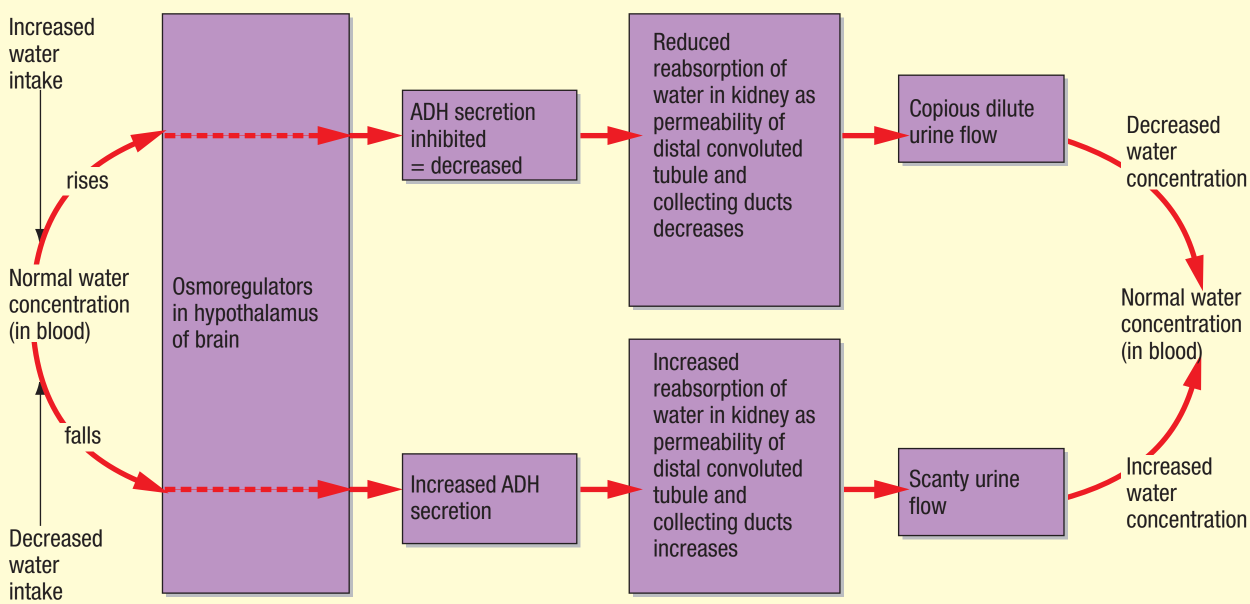


Figure 18.53 Hormonal feedback control of water balance

antidiuretic hormone (ADH). Osmoreceptor cells in the hypothalamus, a region of the brain, stimulate the posterior lobe of the pituitary gland, at the base of the brain. When the water level of blood and thus of tissue surrounding the osmoregulator cells is low, ADH is released by the pituitary. The released ADH is carried by the blood to the kidneys, where it increases the permeability of the collecting tubules to water. Water is, therefore, retained in the body until a normal water balance is attained.

If the fluid bathing the osmoreceptor cells has a higher-than-normal water content, stimulation will not occur and less ADH will be released. The permeability of the collecting duct to water will decrease and a more dilute urine will be excreted.

Case study 18.10: Solvents and kidney failure

The human kidneys are crucial in osmoregulation and excretion. A build-up of waste products is toxic to the body. Complete renal failure usually results in death within a few days. When complete failure occurs, the person may be placed on a dialysis machine until a kidney transplant can be undertaken. In haemodialysis, a syringe is inserted into an artery (usually in the arm) and blood passed through this to a machine. There it passes through a selectively permeable (dialysis) tube, where wastes pass by diffusion into a balanced salt fluid. The cleansed blood is then returned to a vein.

Damage to the kidneys which may lead to renal failure can occur in many ways. Industries where a variety of solvents are used have been shown to contribute to this disease. In many cases the solvents may be inhaled. More serious cases occur when a person becomes accidentally immersed in the solvent or swallows it.

Those solvents known to cause renal damage include:

- carbon tetrachloride—until recently, used in dry-cleaning and in fire extinguishers. Although the use of carbon tetrachloride has been banned from most industries, it is still used under stringent controls in some situations.
- ethylene glycerol—used as an antifreeze in automobiles
- turpentine—used as a solvent for enamel paints, and so for cleaning paint brushes. Turpentine is responsible for 'painter's disease'. The production of high-quality water-based paints has decreased the prevalence of this disease.
- white spirit—used as a solvent to remove stains from clothing
- toluene and xylene—ingredients of paint.

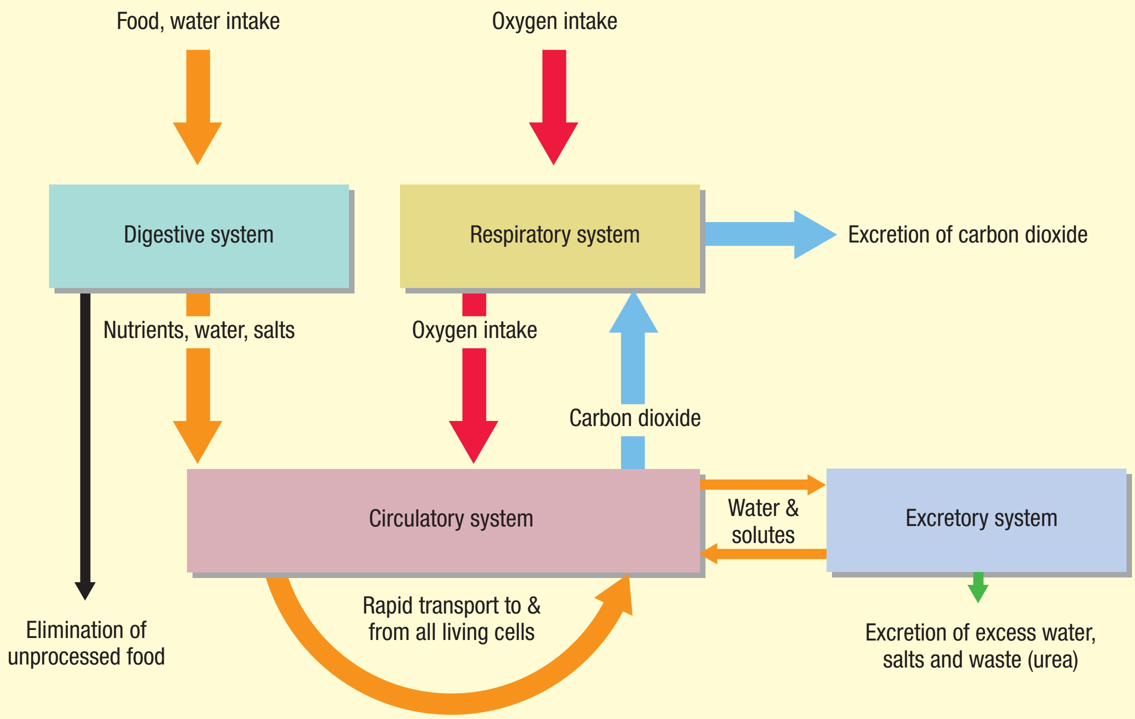


Figure 18.54 Connections between digestive, respiratory, circulatory and excretory systems

SUMMARY

Metabolic wastes are excreted through the skin, the respiratory and the urinary systems.

The human urinary system also acts as an organ of osmoregulation.

Blood carrying wastes passes into the kidney. The wastes are removed and the water balance normalised. The urine so formed leaves the kidneys in the ureters to the bladder, where it is stored until removal through the urethra.

The functional unit of the kidney is the nephron. Blood serum containing small molecules enters the nephron under pressure. Constituents such as glucose, salts and water are reabsorbed by the nephron tubules. The amount of water which is lost in the urine is controlled at both the loop of Henle and the collecting ducts.

Review questions

18.59 Define the following terms relating to the kidney:

(a) Bowman's capsule
(b) pyramid
(c) isotonic
(d) ureter
(e) cortex
(f) ultrafiltration
(g) medulla
(h) hypertonic
(i) hypotonic
(j) convoluted tubule
(k) loop of Henle
(l) glomerulus
(m) urethra
(n) pelvis.

18.60 Describe three ways in which humans lose water from their bodies.

18.61 The structure in a mammal which takes urine from the bladder to the exterior is called the:

A. urethra.
B. ureter.
C. uriniferous tubule.
D. cloaca.

18.62 The Bowman's capsule is found in the region of the kidney called the:

A. pelvis.
B. pyramid.
C. cortex.
D. medulla.

18.63 Read through the following account of kidney function and then fill in the most appropriate word or words to complete the account.

Blood entering the kidney from the … (a) … passes into an afferent arteriole which divides to form the … (b) … inside the cup of a … (c) … Much of the blood is forced into the tubule by the process of ultrafiltration. Only blood cells and large molecules such as … (d) … and some fluid remain in the blood vessel. The filtrate is a watery fluid rich in food substances such as glucose and … (e) . . Normally all the glucose is reabsorbed by the blood vessels surrounding the proximal convoluted tubule. Most of the … (f) … are also reabsorbed, causing a passive movement of water out of the tubule due to the osmotic gradient now exerted by the blood. Further reduction of the water content of the filtrate takes place when … (g) … occurs in the loop of Henle as a result of … (h) … being actively pumped out of the … (i) … limb of the loop. This forms a very high osmotic gradient between the loop of Henle and the … (j) … resulting in water being withdrawn and production of a … (k) … urine. Any increase in the osmotic pressure of the blood stimulates … (l) … in the … (m) … to bring about increased release of … (n) … by the posterior pituitary gland. This hormone … (o) … the permeability of the collecting duct wall so that … (p) … leaves it.

18.64 Explain the effect that each of the following will have on the quantity and composition of urine.

(a) drinking a large amount of water
(b) eating a very salty meal
(c) a hot dry day
(d) low arterial pressure.

18.65 Explain the function of the kidney in:

(a) excretion
(b) osmoregulation.

EXTENDING YOUR IDEAS

1. IB In order to show that a certain developmental trait is controlled by a given hormonal substance, it is insufficient to simply demonstrate that application of that substance affects the characteristic in question. What additional information is necessary?
2. UB Describe the passage of glucose molecules absorbed by capillaries in the small intestine to the brain cells of a person.

3. The table below shows the speed of conduction of a nerve
UB impulse along axons from three different species of animals.

Species	Diameter of axon (μm)	Speed of conduction (m/s)
A	7	1.2
B	500	33.0
C	15	90.0

Which one of these three species is most likely to possess myelinated nerve fibres? Give a reason for your answer.

4. UB The drug atropine acts predominantly by depressing the activity of the parasympathetic nervous system. Suggest why atropine could have useful applications in dental surgery and eye examinations.

5. UB The poison arrow frog of South America, *Dendrobates lehmanni*, has bright red and black colouration. The frog produces a potent poison in its skin. This chemical, curare, causes skeletal muscle relaxation. Indians of the area use the poison to coat their hunting arrows.

(a) What function would the poison serve for the frog?

(b) Suggest why the frog is brightly coloured.

(c) Suggest the mechanism which brings about muscle relaxation in prey shot with poisoned arrows.

(d) List two reasons why capture of prey is more effective using poisoned arrows.

6. UB The desert bearded dragon (*Ctenophorus nuchalis*) uses pigment cells, or melanocytes, to control body temperature. When skin melanocytes are expanded, the skin darkens. When they contract, the skin lightens. The expansion of the melanocytes is controlled by melanocyte stimulating hormone (MSH), secreted from the anterior pituitary gland. Contraction of the cells is brought about by the sympathetic nervous system under direction from the thalamus. Both actions are stimulated by thermal skin receptors. MSH secretion can also be stimulated by light intensity receptors in the eye. Based on your knowledge of human control systems:

(a) Suggest how change of skin colour acts in temperature regulation of these reptiles.

(b) Assuming that skin colour change was the only temperature control mechanism, propose the sequence of colour changes undergone in the day-active lizard between dawn and dusk. Explain your proposal.

7. UB Figure 18.55 shows parts of the digestive systems of a herbivore and a human (not drawn to scale).

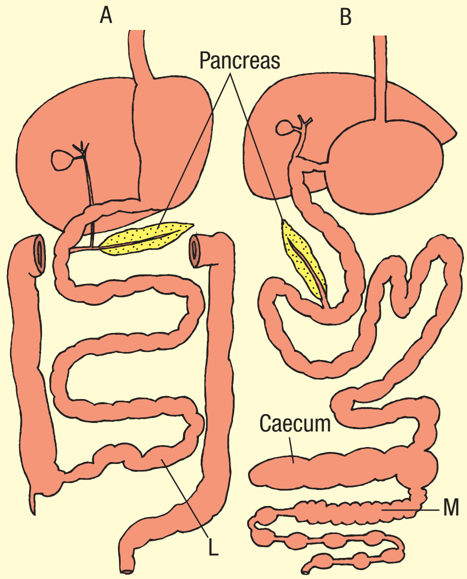


Figure 18.55

(a) Which diagram, A or B, shows the human digestive system?

(b) Give the name, and state one function, of parts L and M.

(c) Explain how the function of the caecum is related to the diet of animal B.

(d) What function, apart from the production of insulin, is carried out by the pancreas?

8. UB 'Digestion of food within the human alimentary canal can be likened to the decomposition by organisms such as fungi, in that digestion effectively takes place in the external environment of the organism.'

(a) Do you agree with this statement? Explain your answer.

(b) Compare and contrast (in general terms) the digestive processes of a decomposer and a human.

9. IB 'Right-handed people find it easier to brush the teeth on the left, so more teeth on the right suffer from dental caries (decay). The opposite is true for left-handed people.'

Rephrase this statement as a testable hypothesis. Design an experiment to test the hypothesis.

10. UB People suddenly exposed to air in an underground car park often feel faint. Using the Bohr shift to illustrate your answer, suggest a reason for this.

11. Research and comment on the statement: 'Those mammals with the longest loops of Henle can produce the most concentrated urine.' **UB**

12. During hibernation, the oxygen dissociation curve of the squirrel shifts to the left, as shown in Figure 18.56. **UB**

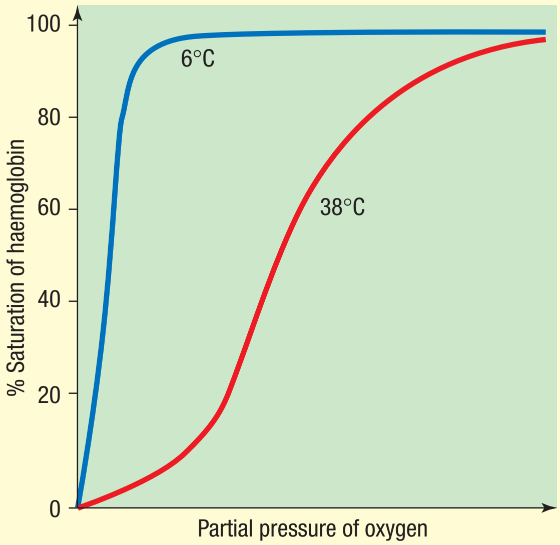


Figure 18.56

Explain how this might be an advantage to a hibernating animal.

13. The table below gives information about substances filtered from blood in normal human kidneys, and excreted as urine. **UB**

Substance	Approximate daily quantities	
	Filtered through glomerulus (g)	Excreted in urine (g)
Water	180×10^3	1.5×10^3
Sodium (as Na^+ ions)	550.0	2.5
Glucose	187.0	0.0
Amino acids	8.5	0.1
Urea	51.0	30.0

Of the filtered water, 80 per cent is reabsorbed in the proximal convoluted tubule and in the descending loop of Henle. Using this information and your own knowledge, construct a bar graph to show the mass of water reabsorbed daily in:

(a) the proximal convoluted tubule and descending limb of the loop of Henle

(b) the ascending loop of Henle

(c) the distal convoluted tubule and collecting ducts.

14. During spring and summer, when food is readily available, the women of several African tribes (e.g. the Bush People of the Kalahari Desert) store large amounts of fat in their buttocks. Research this phenomenon and suggest its adaptive significance. **UB**

19 HUMAN REPRODUCTION, GROWTH AND DEVELOPMENT

19.1 REPRODUCTION

In common with other complex animals, mammals in general and humans specifically can reproduce only sexually. This involves the production of male gametes (spermatozoa) in the testis and female gametes (ova) in the ovary of separate individuals. The human species has forty-six chromosomes (the diploid condition) and each gamete has twenty-three chromosomes (the haploid condition), one of each pair of chromosomes. The gametes are formed by meiotic division of special cells in the gonads. Fertilisation, the union of a male and female gamete, restores the diploid number of forty-six chromosomes. As humans are terrestrial animals, fertilisation is internal and requires a male intromittent organ, the penis.

19.1.1 THE MALE REPRODUCTIVE SYSTEM

The male reproductive system consists of a pair of testes, genital ducts, accessory glands and the penis. The **testes** (singular *testis*) are situated outside the abdominal cavity in the **scrotal sacs**. The mammalian core temperature is too high for effective sperm production. The location of the testes outside the body, and a heat exchange system between the spermatic artery and vein, lower the temperature in the testes by approximately 3°C. This ensures the production of viable sperm.

It is thought that human males may become infertile as a result of wearing tight nylon underwear and tight jeans. This tight clothing keeps the testes in contact with the body, which is at a higher temperature, and results in a raised temperature around the testes.

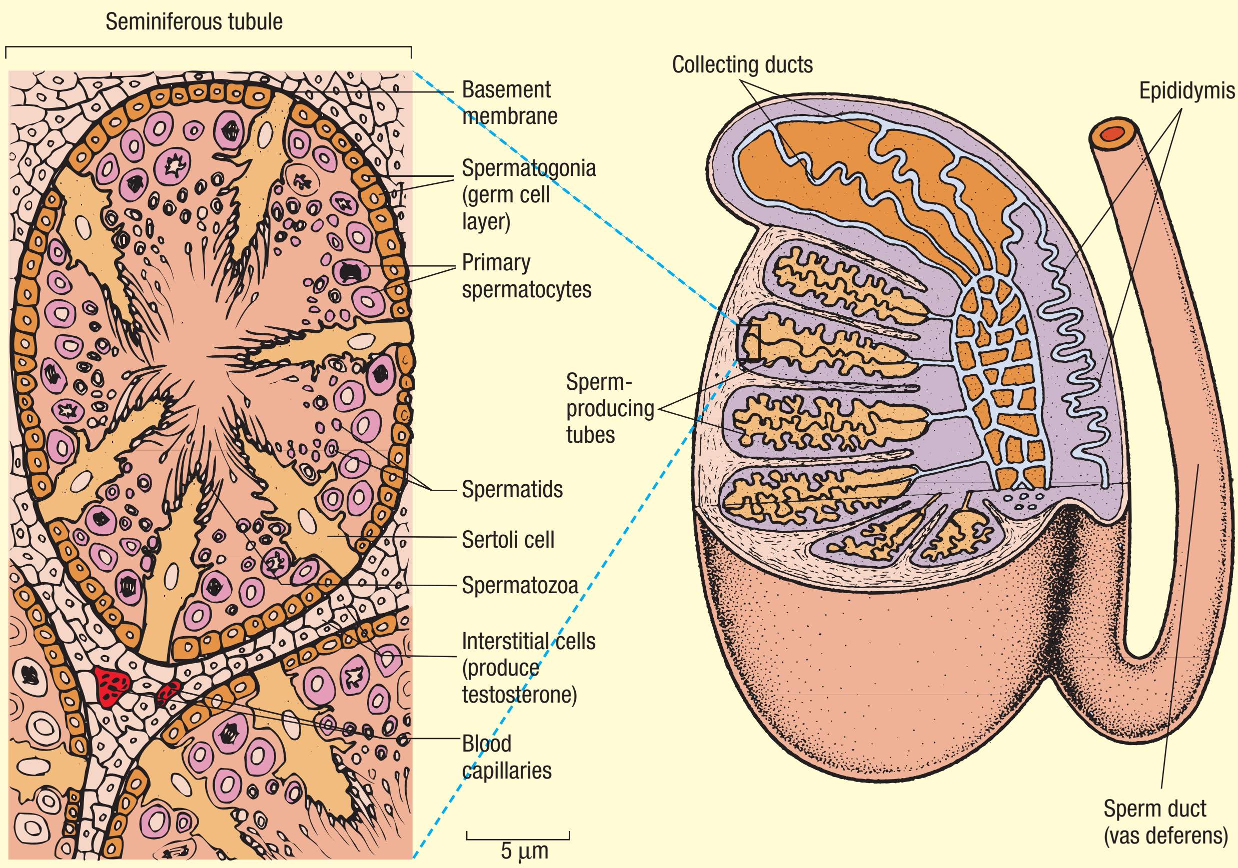


Figure 19.1 Section through a seminiferous tubule, showing spermatogenesis

The testis is an ovoid structure made up of long, coiled **seminiferous tubules** bound by a tough sheath. Between the tubules are interstitial cells. These cells produce the male hormone **testosterone** which is responsible for male sex characteristics, including the development of male external genitalia, behaviour patterns, hairiness, a developed muscular system and the development of the larynx. The cells are stimulated to produce their hormone under the influence of **luteinising hormone** (LH) from the anterior pituitary gland in the brain.

Under the influence of **follicle-stimulating hormone** (FSH) from the anterior pituitary gland, cells lining the seminiferous tubules undergo a period of mitotic cell division and growth in preparation for spermatogenesis. **Spermatogenesis** is the production of spermatozoa by meiotic division of cells called primary **spermatocytes**. Each diploid spermatocyte divides to form four haploid spermatids. Specialised protective 'nurse' cells in the seminiferous tubules, called **Sertoli cells**, provide nourishment for the spermatids, which mature into **spermatozoa** (singular *spermatozoon*). Once they are mature, they are released into the lumen (central cavity) of the tubule. Spermatogenesis begins only at puberty—the onset of sexual maturity.

Each spermatozoon takes about 70 days to form and approximately 10^7 spermatozoa are produced per gram of testis per day. Each consists of a head, a middle piece and a flagellum (tail). The head contains the haploid nucleus, which is covered by the **acrosome**—a structure enclosed by a membrane and containing hydrolytic enzymes. The acrosome penetrates the egg during fertilisation. The middle piece is a short neck region containing many mitochondria, and connects the head to the flagellum.

Sperm are transferred from the seminiferous tubules to a storage and maturation area, the **epididymis**, before entering the **vas deferens**. The vas

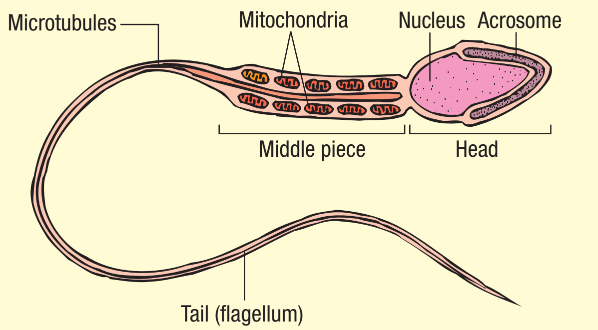


Figure 19.2 Structure of the mature human spermatozoon

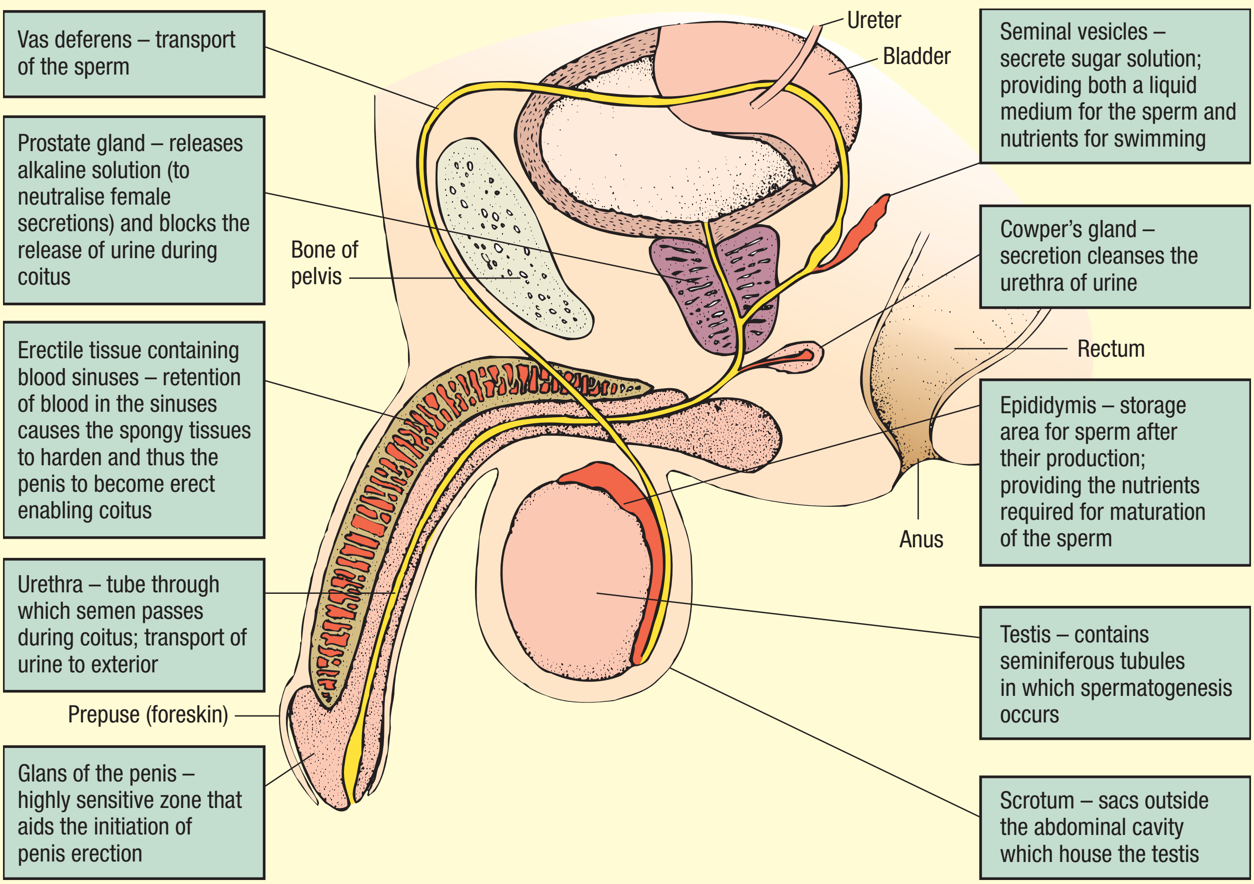


Figure 19.3 The human male reproductive system

deferens carries the sperm to the **urethra** which traverses the penis. Along its route, a large volume of various nutritive and fluid substances are added to the sperm from the accessory glands: **seminal vesicles**, **Cowper's gland** and **prostate gland**. These fluids and spermatozoa are collectively known as **semen**.

A vasectomy is an operation performed to prevent the release of sperm from the testis. A small incision is made in the scrotal sacs and each vas deferens is severed. The cut ends are folded back and tied off. It is a relatively safe procedure which requires only a local anaesthetic but cannot generally be reversed. The sperm cells are reabsorbed by the body. Normal ejaculation occurs, but with the absence of sperm.

19.1.2 The female reproductive system

The female reproductive system consists of paired **ovaries**, **Fallopian tubes**, **uterus**, **vagina** and external genitalia. The ovaries are attached to the wall of the body cavity by a fold of connective tissue, and are positioned close to the funnel-like structures that form the openings of the Fallopian tubes or oviducts.

The ovaries are about the shape and size of almonds. They are responsible for the production of female gametes and also female sex hormones. Enclosed in a connective tissue sheath, the ovary consists of an inner medulla and outer cortex. The cortex contains the germinal epithelium from which gamete cells are produced. The medulla contains connective tissue, blood vessels and mature follicles.

The production of a female gamete or **ovum** (plural *ova)* is termed **oogenesis**. It begins before birth and is completed only after the ovum is fertilised. During development of the female fetus, germ cells undergo repeated mitotic division to form diploid **primary oocytes**. They remain in a prophase I condition until just before they are released from the ovary. Enclosed in a single layer of follicle cells, the oocytes and surrounding tissues are termed **primary follicles**. Although approximately 200 000 primary follicles are present in the ovaries at birth, only about 450 ever develop into the haploid secondary oocytes which are released from the ovary.

From puberty, hormones are cyclically released from the anterior pituitary gland. They stimulate a primary oocyte to continue the suspended meiosis.

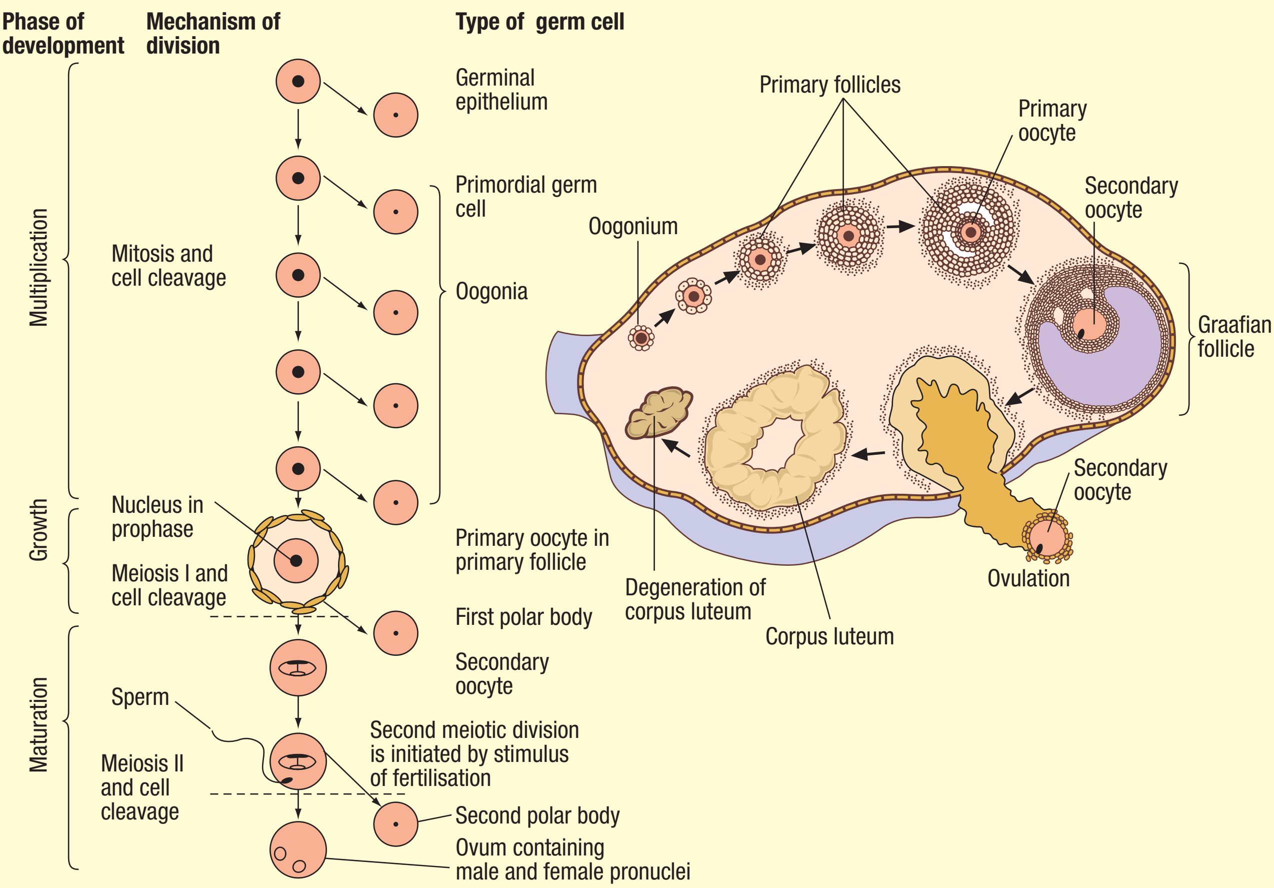


Figure 19.4 Oogenesis in the human female

The follicle cells surrounding the oocyte proliferate to form a wall of several cells thickness. Follicular fluid accumulates, forming a fluid-filled cavity surrounding the oocyte. The entire structure is now called a **Graafian follicle** and it slowly moves towards the surface of the ovary. At the same time the primary oocyte proceeds with the first meiotic division. Division of the cytoplasm in meiosis I is uneven, producing a large secondary oocyte and a small polar body. The polar body often degenerates and the secondary oocyte progresses as far as metaphase II. The secondary oocyte is released from the ovary in the process of **ovulation**.

After ovulation the role of the follicle in protecting and nourishing the oocyte comes to an end. The follicle undergoes a number of changes to form the **corpus luteum** (yellow body), a structure that produces the female hormone **progesterone**, associated with the anticipated fertilisation and pregnancy.

The secondary oocyte released from the ovary is drawn into one of the Fallopian tubes, or oviducts, by the muscular action of the funnel-like opening. The lumen of these tubes is lined with ciliated epithelium which, together with muscular movements of the walls, carries the female gamete towards the uterus. Sterilisation in women is usually achieved by severing the Fallopian tubes, in a process called **tubal ligation**. This is a more complicated operation than vasectomy and requires a general anaesthetic.

The uterus is a thick-walled, muscular organ which is lined with glandular epithelium with a plentiful blood supply. The lower entrance to the uterus is a muscular **cervix**. The narrow lumen of the cervix is normally closed with a plug of mucus which contains acidic, antibacterial chemicals which give protection from outside infections. This is important because the whole abdominal cavity is, in effect, open to the exterior via the reproductive tract.

The cervix opens into the vagina, a muscular organ which receives the penis during intercourse. Anterior to the opening of the vagina is a small erectile organ, the **clitoris**, which is homologous to the penis. The openings of the vagina and urethra, and the clitoris, are protected by two folds of tissue called the **vulva**. Within the walls of the vulva are glands that release mucus when the female is sexually aroused and thus aids lubrication during intercourse.

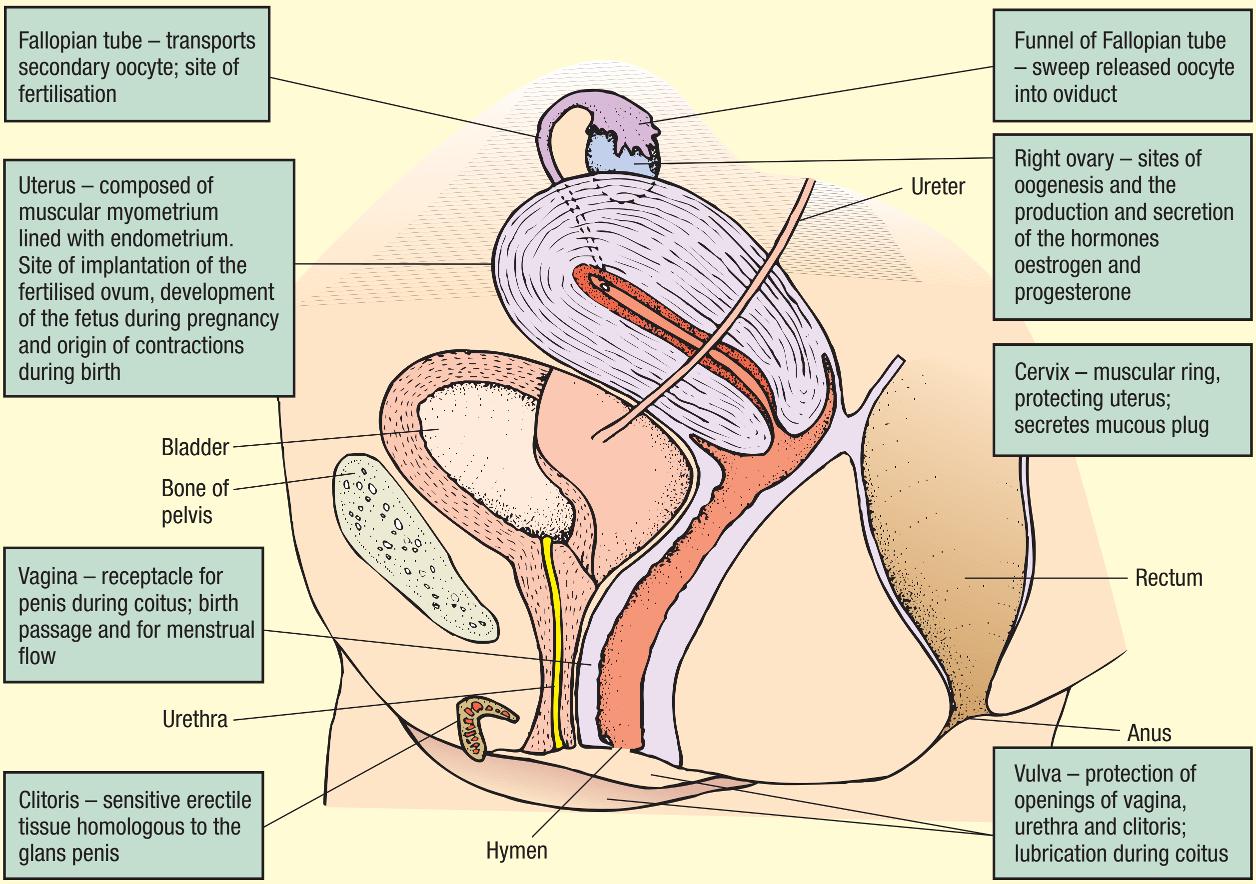


Figure 19.5 The human female reproductive system

19.1.3 Fertilisation

Under conditions of erotic excitement, the arteries in the male's penis dilate and the veins constrict. The increased blood pressure in the spongy tissue of the penis causes it to become erect and enables copulation or **coitus** to occur. As the penis becomes erect, the Cowpers glands at its base discharge a small amount of fluid which serves as a lubricant, aiding the movement of sperm along the urethra and the penetration of the penis into the vagina.

In the female, stimulation results in the distension of the clitoris and associated tissues by engorgement with blood. This is accompanied by secretion of a fluid into the vagina which lubricates its walls and neutralises its normally acidic environment. Although the acid conditions destroy invading bacteria, they also inhibit sperm, and so must be neutralised during coitus.

The moist vaginal wall stimulates sensory cells at the tip of the penis. This triggers a reflex contraction of the vas deferens which sweeps sperm down towards the urethra. In this process, sperm are mixed first with nutritive sugar secretions from the seminal vesicles, which activates them to swim, and then with secretions from the Cowpers and prostate glands. Cowpers gland releases a chemical which cleanses the urethra of urine. The prostate gland both releases an alkaline solution and blocks the release of urine from the bladder during coitus. The resulting suspension, semen, is expelled from the penis by powerful contractions of the urethra during **ejaculation**. This occurs with enough force to project the sperm into the cervix at the top of the vagina. Muscular spasms during ejaculation account for many of the sensations associated with orgasm which results in the slow release of blood from the engorged penile tissues back into the circulatory system.

Orgasm in females is also associated with muscular contractions followed by disengorgement of the tissues of the clitoris. At orgasm the cervix drops down into the upper portion of the vagina. This aids the movement of semen, which collects in a pool in the upper vagina, into the uterus. Simultaneous contractions in the uterus and Fallopian tubes help propel the sperm forward. Orgasm in females, although beneficial, is not essential for conception.

Rhythmic contractions of the tail of the sperm propel them through the watery mucus of the female genital tract. Movement of the sperm is aided by the muscular contractions of the uterus and Fallopian tubes.

Fertilisation takes place in the Fallopian tube. Sperm remain viable in the female genital tract for up to 72 hours but are highly fertile only for between 12 and 24 hours. When the sperm reaches the oocyte, acrosomal enzymes 'digest' the surrounding oocyte membranes, allowing entry of the sperm head and middle section. This causes changes in the plasma membrane of the oocyte to form an impenetrable **fertilisation membrane**, which prevents entry of any further sperm.

The presence of the sperm nucleus in the oocyte acts as the stimulus for completion of the second meiotic division of the secondary oocyte to form the ovum and second polar body. The second polar body immediately degenerates. The nuclei of the sperm and ovum unite to form the diploid zygote. This union, fertilisation, stimulates mitotic cell divisions to occur, and the forming mass of cells passes down the Fallopian tube to the uterus, where it will become embedded.

Case study 19.1: Infertility

Some couples are unable to have children. Although this may result from male impotence (inability to erect the penis and/or ejaculate semen) or incorrect timing of intercourse, it is usually associated with a defect in the gametes or reproductive tract.

The Fallopian tubes may become blocked due to a build-up of scar tissue following an infection. This prevents the passage of either the ovum or sperm. An operation to unblock the tubes can be performed, but is rarely successful.

A few females are unable to produce ova. Fertility drugs (massive injections of FSH) have been successful in some of these cases. The increased FSH levels stimulate secondary oocyte production. Often, however, more than one oocyte is released at a time and this may result in multiple births.

Some men produce no sperm, or so few that conception does not occur.

Deformed sperm (those with bent or multiple tails etc.) are unable to complete the journey to the Fallopian tubes. The production of such sperm appears to be affected by the environment. Thus exposure to ionising radiation, anaesthetic gases, lead, benzene, ethylene dibromide, chloroprene, carbon disulfide and organic solvents can reduce fertility and cause sperm damage.

Infertility can be caused by infections and sexually transmitted diseases. Adult males can become infertile after contracting mumps. Chlamydia, caused by the bacterium *Chlamydia trachomatis*, is the most common sexually transmitted disease. Teenage women are most susceptible to infertility from this disease since the bacteria are able to penetrate young cervical tissue easily. Inflammation resulting from the infection can result in blockage of the tubes. Gonorrhoea,

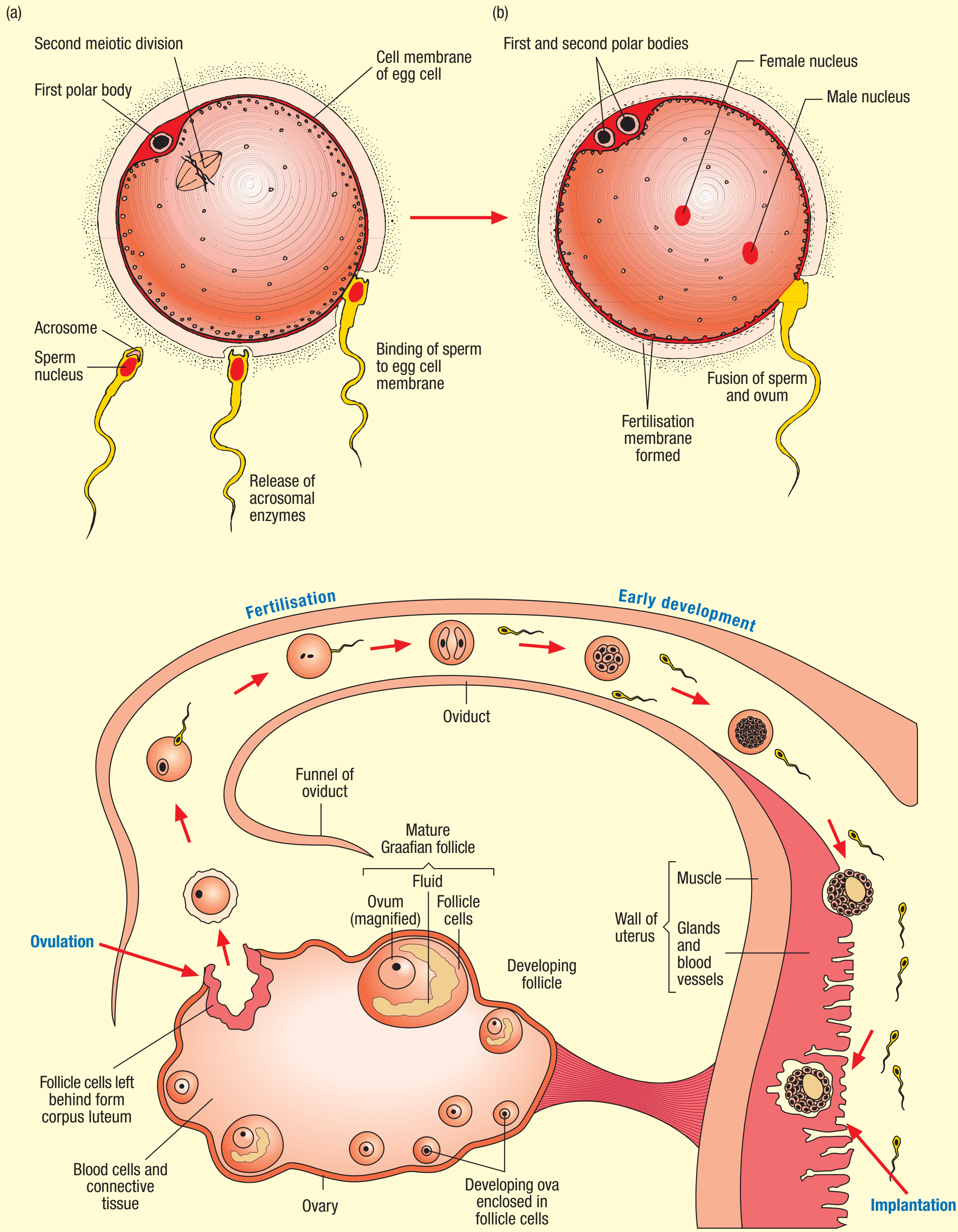


Figure 19.6 Ovulation, fertilisation, early development and implantation

another sexually transmitted bacterial disease, can also cause sterility, particularly in women. The discovery of antibiotics initially brought about the decline of diseases such as gonorrhoea and syphilis (which causes severe neurological damage and death). In recent years, however, there has been an alarming increase in the occurrence of these diseases, probably associated with the evolution of resistant strains of these pathogenic bacteria.

In some cases of infertility, **in-vitro fertilisation** (IVF) has been applied with some success. A fertility drug is given to the potential mother to increase her production of ova. The oocytes are surgically removed from the ovary just before ovulation. Sperm are collected from the potential father and screened to ensure their viability. Fertilisation occurs in a Petri dish containing a balanced nutrient medium. When the embyros are a few days old, a few of them are inserted into the uterus at the time they would have arrived had they been fertilised naturally in the Fallopian tube.

IVF has been accomplished using ova and sperm from a couple or using donor gametes. It is very expensive and has only a 10 per cent success rate. It is usually used in cases of blocked tubes. In cases where the couple can both produce viable gametes but the female is unable to carry the developing embryo, the embryo may be implanted into a surrogate mother. In the case of male infertility or impotence, artifical insemination (the artificial transfer of sperm to a normally functioning female reproductive tract) may be performed using donor sperm.

IVF, artificial insemination and surrogacy all raise legal and moral issues. What happens to the embryos not implanted after IVF? Do personal details of the donor of sperm for artifical insemination need to be made known to the potential mother? Do donors or surrogate mothers have a legal and/or moral obligation to the child they help produce? Do the costs justify the ends?

19.1.4 The menstrual cycle

The **menstrual cycle** occurs rhythmically from the onset of puberty until **menopause** (cessation of reproductive fertility in the female). Usually, it is interrupted only by pregnancy. Although the typical cycle is of 28 days duration, cycles as long as 40 days and as short as 21 days are common. There are two main phases to this cycle:

- the follicular phase, which can be further subdivided into menstruation (days 1–5) and proliferation (days 6–14), during which time the ovarian follicle develops and the uterus is prepared for implantation of an embryo; and
- the luteal phase (days 15–28), during which the uterine lining is further developed and enriched with blood vessels in preparation for pregnancy.

All phases of the female reproductive cycle are synchronised so that each occurs at exactly the correct time. The associated changes are orchestrated by the hormones produced in both the pituitary gland and the ovary.

Stimulated by follicle-stimulating hormone (FSH) and luteinising hormone (LH) from the anterior pituitary gland, the primary follicle grows into a Graafian follicle and the primary oocyte starts meiotic division. FSH acts primarily on the follicle cells. Simultaneously, LH causes ovarian tissue to produce the hormone **oestrogen**. The initial response to oestrogen is to repair the inner lining (**endometrium**) of the uterus from the previous menstruation. Over proceeding days, the amount of oestrogen increases until it reaches a level which, although preventing the release of FSH and LH by the anterior pituitary gland (negative feedback), stimulates their production and storage. Once oestrogen reaches a higher, critical concentration, it exerts a positive feedback on the anterior pituitary that results in a sudden release of the accumulated LH and FSH.

LH stimulates the primary oocyte to complete the first meiotic division to form the secondary oocyte. The second meiotic division of the secondary oocyte continues to metaphase II. LH also brings about ovulation at about day 14. The secondary oocyte detaches from the follicle wall and LH causes the Graafian follicle to change into the corpus luteum.

Swelling of the Graafian follicle, and its subsequent rupture at ovulation, causes damage to the oestrogen-producing ovarian tissues and thus a drop in oestrogen levels just prior to and after ovulation. The corpus luteum produces progesterone and oestrogen that cause thickening and increased vascularisation of the endometrium in preparation for implantation of a fertilised ovum.

In a negative feedback operation, progesterone inhibits FSH release so that no further follicles develop. Further increases in progesterone over the next 2 weeks result in inhibition of LH and subsequent cessation of corpus luteum production of progesterone. The sudden drop in progesterone levels causes breakdown of the uterine wall. The excess cells and blood are released from the associated capillary network and discharged over a period of the next 5 days or so (menstrual flow or **menses**). Again a negative feedback system, associated with the drop of progesterone, brings about renewed secretion of FSH and LH and thus the maturation of another primary follicle.

Prostaglandins are a group of hormones produced in the cell membranes of several tissues, particularly those of the male and female reproduc-

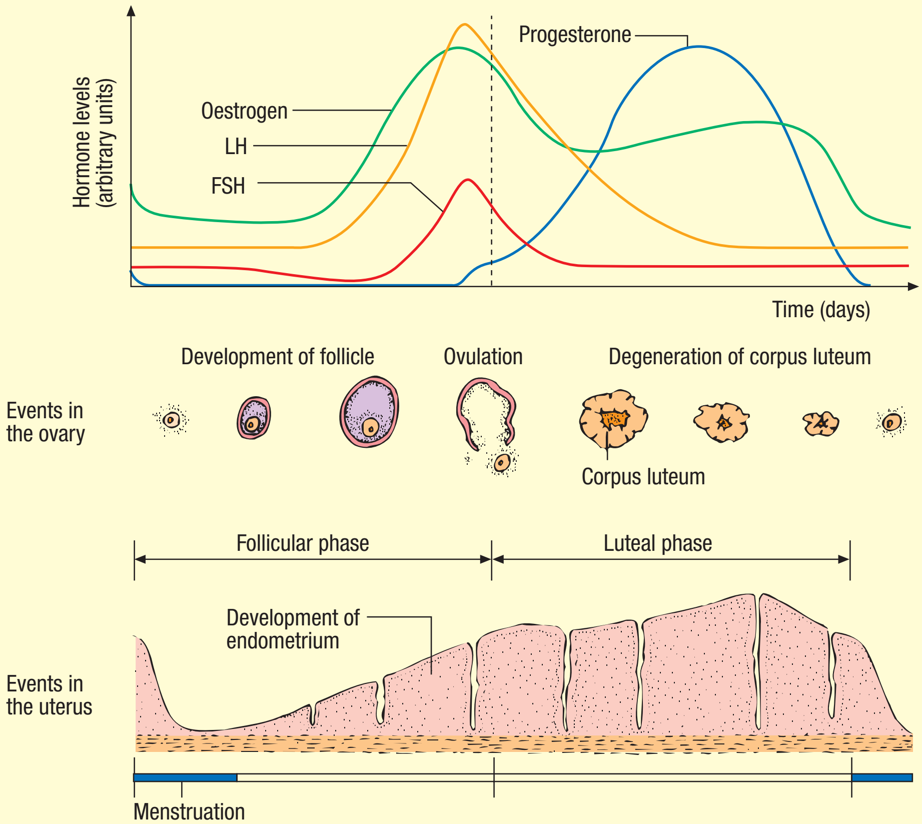


Figure 19.7 The human female menstrual cycle

tive tract. Those produced in the uterus are believed to be significant in stimulating the smooth muscle contractions associated with both menstruation and labour. Studies of women who experience severe uterine cramps during the first 2 days of menstruation have revealed that they secrete two to three times the amount of prostaglandins as those who do not experience cramps. Not only do the excess prostaglandins produce more powerful uterine contractions; they also reduce blood supply to the tissues. An oxygen debt is created in the uterine muscles which results in pain. It is thought that the prostaglandins may also act directly on pain nerve endings to cause them to fire more rapidly.

If the ovum is fertilised, it becomes implanted in the thick, spongy uterine wall and **pregnancy** results. If this occurs, the corpus luteum persists due to the release of a LH-like hormone released by the developing embryo. It continues to produce progesterone which, along with the oestrogen from the ovary, maintains the development of the uterus and prevents FSH production. The corpus luteum breaks down after about 3 months, by which stage the placenta is fully functional and produces progesterone and oestrogen. The placenta provides a diffusion pathway between fetal and maternal blood, and also produces both oestrogen and

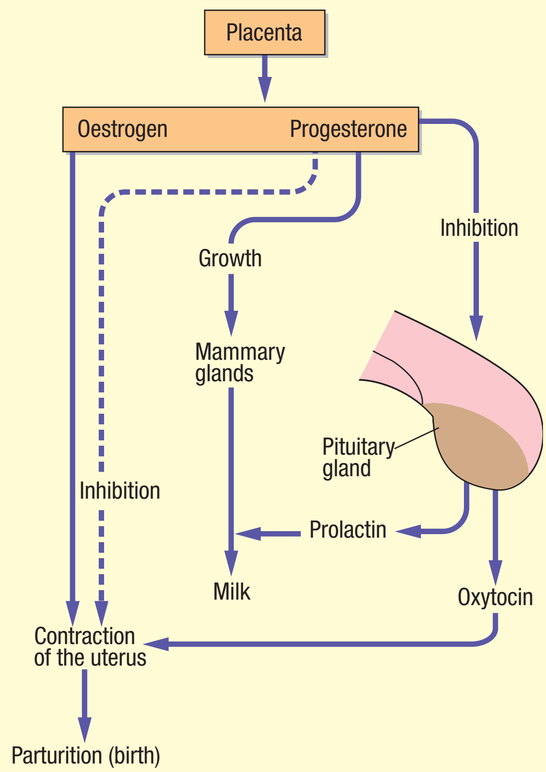


Figure 19.8 Action of the female hormones during pregnancy

progesterone. Both of these hormones are also responsible for increased growth of the mammary glands.

During the course of pregnancy, the oestrogen levels continue to rise while progesterone levels decline. At some critical level between the two hormones, the posterior pituitary is stimulated to produce **oxytocin**, which causes uterine contractions and the onset of the birth process, **parturition**.

Flow of milk is stimulated by the production of **prolactin** from the anterior pituitary at parturition. This is initiated by the sudden drop in levels of oestrogen and progesterone with the ejection of the **placenta** (afterbirth). Changes in hormone levels occasionally lead to a condition known as post-natal depression.

The time from fertilisation to birth is called the **gestation** period and in humans this lasts approximately 9 months.

Table 19.1 Major functions of human oestrogen and progesterone during pregnancy

Oestrogen	Progesterone
Stimulates growth of mammary glands	Stimulates growth of mammary glands
Maintains FSH release	Inhibits FSH release
Stimulates LH release	
Inhibits prolactin release	Inhibits prolactin release
Prevents infection of uterus	Inhibits contraction of uterine muscles
Increases size of uterine muscle cells	Increases vascularisation of uterine wall
Increases ATP production	
Increases sensitivity of uterine muscles to oxytocin	

19.1.5 Birth control

Eighty per cent of sexually active women, taking no precautions, become pregnant within a year. Many couples wish to prevent or delay pregnancy. Up until the 1960s the most common forms of contraception involved some form of barrier—for example, the condom, uterine cap and cervical coil—to prevent union of ovum and sperm or the implantation of the fertilised ovum.

Oral contraceptives ('the pill') were developed and became commercially available in the 1960s. They contain the hormones progesterone and oestrogen. When taken daily, the levels of these hormones inhibit release of FSH (and thus secondary oocyte development) and LH (and thus ovulation). They are normally taken for 21 consecutive days. During the next 7 days without them, the uterine wall breaks down and menstrual flow occurs.

The more recently developed 'morning after' pill contains the synthetic oestrogen, diethylstribestrol, which is believed to prevent implantation of a fertilised ovum. Current research is attempting to perfect a male contraceptive pill.

The common methods of contraception, their effectiveness and side effects, are reviewed in Table 19.2. Whatever the form of contraception used, however, it will be effective only if used consistently and correctly.

SUMMARY

The human male reproductive system consists of a pair of testes situated in scrotal sacs, genital ducts, accessory glands and the penis. Spermatogenesis takes place, under the influence of FSH, in the seminiferous tubules of the testes. Interstitial cells between the tubules release testosterone, which is responsible for male secondary sex characteristics. Accessory glands produce nutritive material and a fluid medium for transport of the spermatozoa, forming semen. The penis, the intromittent organ, enters the vagina of the female during copulation. The penis becomes erect on sexual arousal due to retention of blood in spongy spaces.

The female reproductive system consists of paired ovaries, Fallopian funnels, Fallopian ducts, single uterus, cervix, vagina, clitoris and vulva.

Prior to birth, germinal epithelium in the ovary produces primary oocytes surrounded by cells to form primary follicles by mitosis. At puberty, under the influence of FSH, the follicle cells form a mature Graafian follicle, while LH stimulates the primary oocyte to undergo meiosis I to form the secondary oocyte. Oestrogen, produced by ovarian tissue under the influence of LH, repairs the endometrium from the previous menstruation. As the level of oestrogen increases it initially inhibits release of FSH and LH and then stimulates a burst of their secretion, which causes the Graafian follicle to rupture and release the secondary oocyte. Ovarian tissue damage at this time results in a drop in oestrogen levels. The oocyte is drawn into the Fallopian funnel and down into the Fallopian tube.

Fertilisation occurs in the Fallopian tube. Penetration of the oocyte by the sperm results in the formation of a fertilisation membrane, and completes meiosis II in the secondary oocyte. Fertilisation is completed with the union of the male nucleus and the ovum.

Table 19.2 Methods of birth control

Mode of action	Method	Effectiveness	Advantages	Disadvantages
Sterilisation	Vasectomy or tubal ligation	100%	No artificial appliance required.	Normally irreversible.
Prevention of ovulation	Oral contraceptive	99%	Effective if taken as prescribed.	Increased risk of thrombosis; water retention, nausea, breast tenderness may occur.
	Injection contraceptive	100%	Administered only every 3 months.	Hormonal surge on injection may cause irregular bleeding.
	Implant contraceptive	100%	Each implant, which is placed under the skin, lasts 5 years.	May cause irregular menstrual bleeding.
Prevention of implantation	'Morning after' pill	unknown	Prescribed in emergencies, e.g. for rape victims.	Not suitable for regular use. Produces nausea, breast swelling, water retention and abdominal pain.
	Intra-uterine device, e.g. coil, loop	95%	Once fitted by a doctor, annual check-ups only are required.	Menstrual pain; infection or perforation of the uterus; ectopic pregnancy.
	Intra-vaginal ring	Unknown, but very reliable		Long-term effects yet to be assessed.
Barriers to sperm reaching the ovum	Female diaphragm or cap	80%	Available for use by all women. Best used with a spermicide.	Must be inserted before intercourse and left in for a further 6 hours. May cause irritation.
	Female condom	80%	Readily available and easy to fit; gives some protection against sexually transmitted diseases.	Long-term effects to be assessed.
	Male condom; best used with spermicide	90%	Readily available and easy to fit; gives some protection against sexually transmitted diseases.	Must be put in place after erection; may reduce sensitivity of penis.
	Spermicide	70%	Readily available and easy to apply.	May cause irritation.
	Douche	15%	Easy to use.	Must be used immediately after intercourse; may propel sperm through the cervix into the uterus.
	Withdrawal	10%		Timing is crucial; may cause frustration.
Natural method	Rhythm	60%	No appliance required; shared responsibility in birth control.	Must know when to abstain from intercourse; based on daily temperatures and cyclic changes in vaginal mucus.

After ovulation the Graafian follicle, under the influence of LH, forms the corpus luteum which produces the hormones progesterone and oestrogen. Progesterone:

- inhibits FSH and LH
- brings about proliferation and vascularisation of the endometrium in readiness for implantation by the embryo.

If pregnancy occurs, progesterone levels remain high and after 3 months the developing placenta starts to produce progesterone and oestrogen. The corpus luteum has a limited life. If pregnancy does not occur, the lack of LH causes it to degenerate. Levels of progesterone decrease. The uterine wall breaks down (menstrual flow). Low progesterone acts as a negative feedback to stimulate secretion of FSH and the cycle begins again.

During pregnancy the levels of oestrogen continue to rise and progesterone begins to decrease. At a critical ratio of oestrogen:progesterone, the posterior pituitary releases oxytocin, which brings about contractions of the uterine wall and thus parturition. Expulsion of the placenta at birth and the decrease in oestrogen stimulate the release of prolactin and thus milk production.

Review questions

19.1 Draw and label the following, giving a function for each structure labelled:

(a) the human male reproductive system

(b) the human female reproductive system.

19.2 Figure 19.9 represents a section through a mammalian ovary.

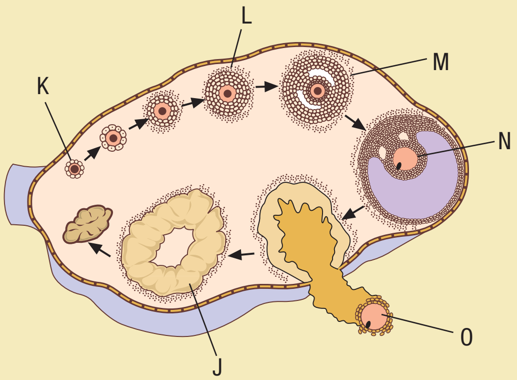


Figure 19.9

(a) Which of the following structures does the letter J indicate?

A. interstitial cells

B. corpus luteum

C. primary follicle

D. germinal epithelium

(b) Which of the following is the correct sequence in the development of the labelled structures?

A. J, O, N, M, L, K

B. N, O, K, L, M, J

C. L, K, M, J, O, N

D. M, K, L, N, O, J

(c) For each of the following, state whether it is haploid or diploid:

(i) secondary oocyte

(ii) primary oocyte

(iii) germinal epithelium

(iv) follicle cells.

(d) Name the hormone produced by J. What is the main role of this hormone?

19.3 Figure 19.10 shows the blood levels of the hormones involved in the control of the human menstrual cycle.

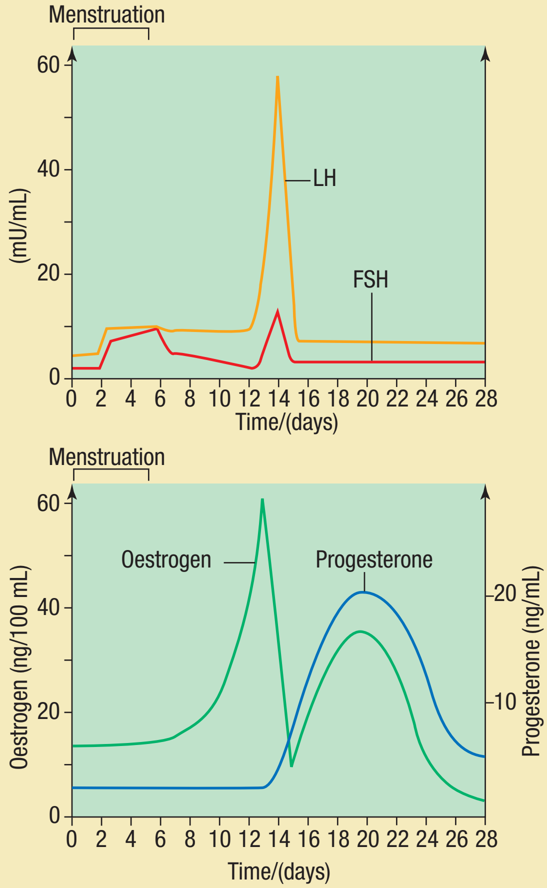


Figure 19.10

(a) For each hormone state:

(i) where it is produced

(ii) the organ(s) on which it acts.

?

(b) Using only the hormones named, show how negative feedback operates in this system. Is there any example of positive feedback operating? Explain.

(c) After menstruation, the uterus lining undergoes repair and then proliferation of secretory tissue. Name the hormones directly responsible for initiating:
 (i) repair
 (ii) proliferation of secretory tissue.

(d) Describe the development of the Graafian follicle from the oogonium to ovulation.

(e) Describe what hormonal events occur if fertilisation occurs.

19.4 (a) Make a fully labelled diagram of a human spermatozoon.

(b) Describe the passage of the spermatozoon from the epididymis to the site of fertilisation of the oocyte, including any additions to the sperm or changes in its structure.

(c) Describe the process of fertilisation.

19.2 Human embryonic development

The development of the fertilised egg into a young human ready for life in the external environment takes place inside the mother; that is, development is internal. Several steps occur in this development. The zygote undergoes a series of mitotic divisions (**cleavage**) to form a ball of cells. This process is energy-consuming and the human egg does not contain a large amount of yolk that stores energy-containing food. Ultimately the young will need to obtain its nutrients from the mother if it is to continue development. The ball of cells, therefore, is destined to form the embryo proper and the tissues of the placenta that will allow exchange of materials between the embryonic and maternal blood (see Section 17.6.4 and Figure 17.26 on page 452). The cells therefore start to differentiate. The initial process is that of **gastrulation**, where the basic body form of a tube within a tube composed of three tissue layers (ectoderm, mesoderm and endoderm) is established. The fate of these layers is shown in Table 17.6 on page 451). Finally, the organs and systems of the body develop from the three germ layers during **organogenesis**.

After fertilisation the human zygote is propelled down the Fallopian duct by the lining cilia and contractions of the wall. It is during this passage that cleavage begins. At 36 hours the first division occurs, and a ball of cells called the **blastula** forms by the third day. As the cells of the blastula continue to divide, a hollow central cavity is formed. One side of this ball of cells becomes thicker than the other. It is now called a **blastocyst**. The thicker side, the **embryonic disc**, is destined to become the **embryo**, whereas the thinner side of the blastula will become the **extra-embryonic membranes** (or tissues).

At about the eighth day the embryo makes contact with the tissues of the uterus. Chemical interaction between the blastocyst and the wall causes the outer epithelium of the uterine lining to break down, and the embryo becomes embedded in the nourishing tissue. This process is called **implantation**. During this time the extra-embryonic tissues develop, forming both the placenta and the protective amnion and chorion layers around the embryo.

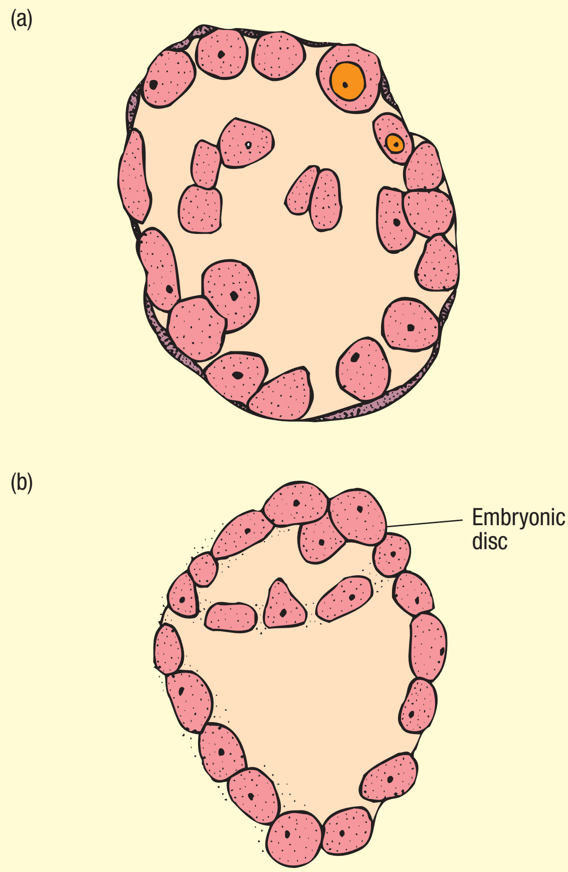


Figure 19.11 Early human development: (a) at 3 days (blastula); (b) blastocyst showing the embryonic disc

Case study 19.2: Diffusion across the placenta

The placenta allows exchange of materials between the mother and fetus without the two bloods mixing. The fetus's blood differs from that of the mother due to genes inherited from the father. Mixing of incompatible blood could bring about an immune response, resulting in clotting which could block vital organs and so result in death. Separation of maternal and fetal blood is therefore crucial.

Oxygen, water and essential nutrients for growth and development pass from maternal to fetal blood. Carbon dioxide, urea and other metabolic wastes pass from the fetus to the maternal blood and are later excreted by the mother's systems. Many maternal antibodies also pass into the fetus by diffusion across the placenta. This gives the developing fetus immunity to certain diseases.

The placenta acts as a barrier to some substances. For example, many maternal hormones which could cause developmental anomalies in the fetus are blocked, as are many pathogens and their toxins. This protection is not complete, however. Certain viruses and toxins, and many drugs, can pass into the fetus.

The rubella (German measles) virus, if contracted by the mother in the first 12 weeks of pregnancy, increases the risk of congenital (developmental) anomalies, which result from tissue disorganisation by the virus toxins. Rubella is associated with damage to fetal eyes, ears and heart.

The syphilis bacterium, *Treponema pallidum*, can pass across the placenta after the twentieth week of pregnancy. If it does not result in death during development or at birth, the baby is born with the disease.

Depending on their molecular size, many drugs can pass across the placenta. Tetracyclines, administered for protozoan and certain bacterial infections, can cause cataracts and bone abnormalities in the fetus if taken in early pregnancy. In later pregnancy, this drug accumulates in fetal bone and teeth, causing yellowing. Cytotoxic drugs, used in the treatment of cancer, are particularly dangerous during pregnancy since they disrupt cell division. Large doses of aspirin taken in late pregancy delay the onset and progress of labour.

Cannabis, LSD, opiates, alcohol and nicotine can all diffuse from maternal blood into fetal blood. Cannabis and LSD may cause growth retardation of the fetus and there is a growing body of evidence that they initiate chromosome damage. Babies born of women taking opiates are themselves addicted. At birth, removed from their supply of the drug, they suffer extreme withdrawal symptoms which interfere with metabolism and therefore growth. Some babies die as a result of their addiction.

Alcohol abuse during pregnancy can lead to mid-term abortion or premature labour. Many of these babies are physically and mentally retarded.

The cocktail of substances found in cigarette smoke, which pass into the mother's bloodstream and across the placenta, lead to alterations in the fetal heart and breathing patterns and restriction of the blood vessels in the placenta. These changes result in retarded fetal growth. Smoking during pregnancy is believed also to increase the likelihood of spontaneous abortion, congenital anomalies, stillbirth, or mental and physical retardation in later childhood.

19.2.1 Steps in human embryonic development

During the second and third week, the embryo grows to about 1.5 mm in length and the major body axis begins to develop. During the third week most of the major body organs (the central nervous system, heart and blood vessels, the primitive gut and muscles) begin to form. This is a crucial stage of development. A mild virus such as rubella, taking drugs, or exposure to low levels of X-rays at this

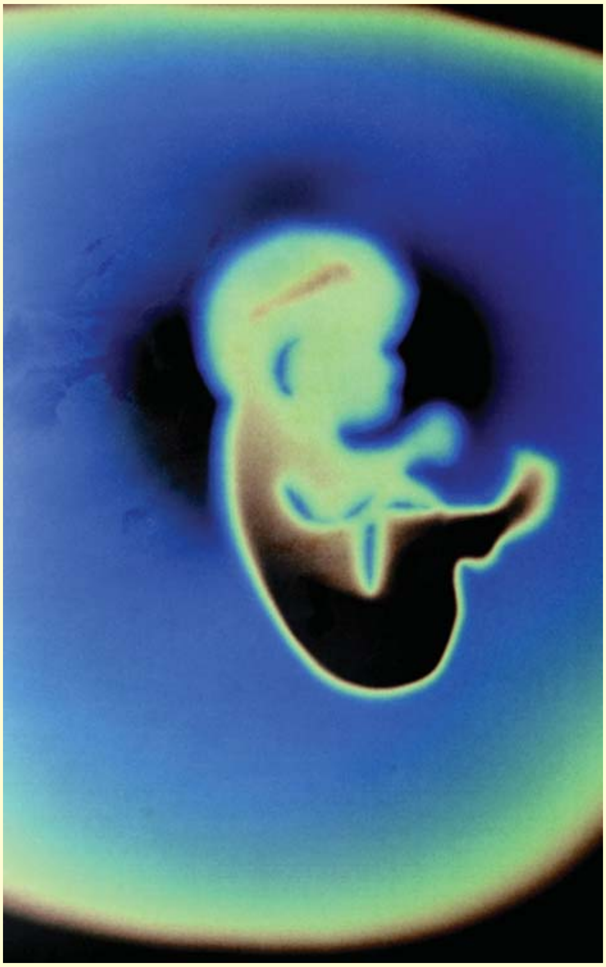


Figure 19.12 Human foetus at 3 months

stage can cause serious defects in the embryo, if it survives at all.

By 21 days the eyes begin to form and at 24 days the heart begins its first pulsations. At the end of the first month the embryo is 5.2 mm long and approximately 40 pairs of somites (segmented blocks of mesoderm) have formed, from which muscle, bones and connective tissue will differentiate. During the second month the embryo continues to increase in mass and length and, as it takes on a more and more human likeness (12 weeks), it is referred to as a **fetus**. Due to early development of the brain, the head is disproportionately large, although the formation of limbs and digits is obvious.

By the end of the first trimester (3 months) there is movement of arms and legs, reflex actions, facial expressions (e.g. frowning) and formation of the external genitalia, excretory system and respiratory system.

During the second trimester there is further elaboration of all systems, as well as increased growth. The most rapid growth is during the final trimester, where the fetus doubles its mass in the last 2 months. During this time many new nerve tracts are formed and brain cells are produced at a very rapid rate.

In the last month in the uterus, the baby usually acquires antibodies from its mother. These will give the baby some level of immunity for the first few months after birth, at which time it will develop its own immune system.

Birth, or parturition, takes place approximately 266 days after conception. Labour is divided into three stages: the dilation, expulsion and placental phases. Dilation lasts from 2 to 16 hours and begins with the onset of contractions and ends with the full opening of the cervix. At the start the contractions are fairly mild and occur at fairly regular intervals of 15–20 minutes. As the cervix dilates the contractions become stronger and more closely spaced. The fetal membranes usually rupture towards the end of the dilation phase.

The expulsion phase lasts 2–60 minutes, beginning with the appearance of the head at the cervix. During this time the contractions are very strong and are 1–2 minutes apart.

After the birth of the baby, the placenta is expelled by further uterine contractions. Minor uterine contractions continue to occur for a period after this, helping to stop the flow of blood and returning the uterus to pre-pregnancy size and condition.

Table 19.3 Embryonic development in the human

Age (weeks)	Size (mm)	Development
2.5	1.5	Embryonic disc flattened; neural groove indicated; ectoderm a single layer; extra-embryonic coelom present; allantois present.
4	5	Cylindrical body flexed and C-shaped; branchial arches completed; flexed heart prominent; all somites present; gut present but simple; neural tube closed; primary vesicles of brain present; eye and ear developing.
6	12	Head dominant in size; external ear appearing; gut becoming more complex; definite pulmonary lobes present; sexless gonads; cerebral hemispheres bulging.
8	23	Nose flat; eyes far apart; digits well formed; growth of gut makes body evenly rotund; fetal state is attained; branching bronchioles; testes and ovaries distinguishable; main blood vessels formed; skeletal bone formation starts.
10	40	Head erect; limbs well formed; nail folds indicated; intestines assume characteristic position; kidneys able to secrete.
12	56	Head still dominant; nose gains bridge; external genitalia; blood formation begins in bone marrow; notochord degenerating; epidermis three-layered; spinal cord definite internal structure.
16	112	Face looks 'human'; head hair appearing; muscles become spontaneously active; body outgrowing head; blood formation active in spleen; most bones distinct.
20–40	160–350	Body lean but better proportioned, wrinkled and red (at 8 months fat collects and rounds body); all body segments attain final development.

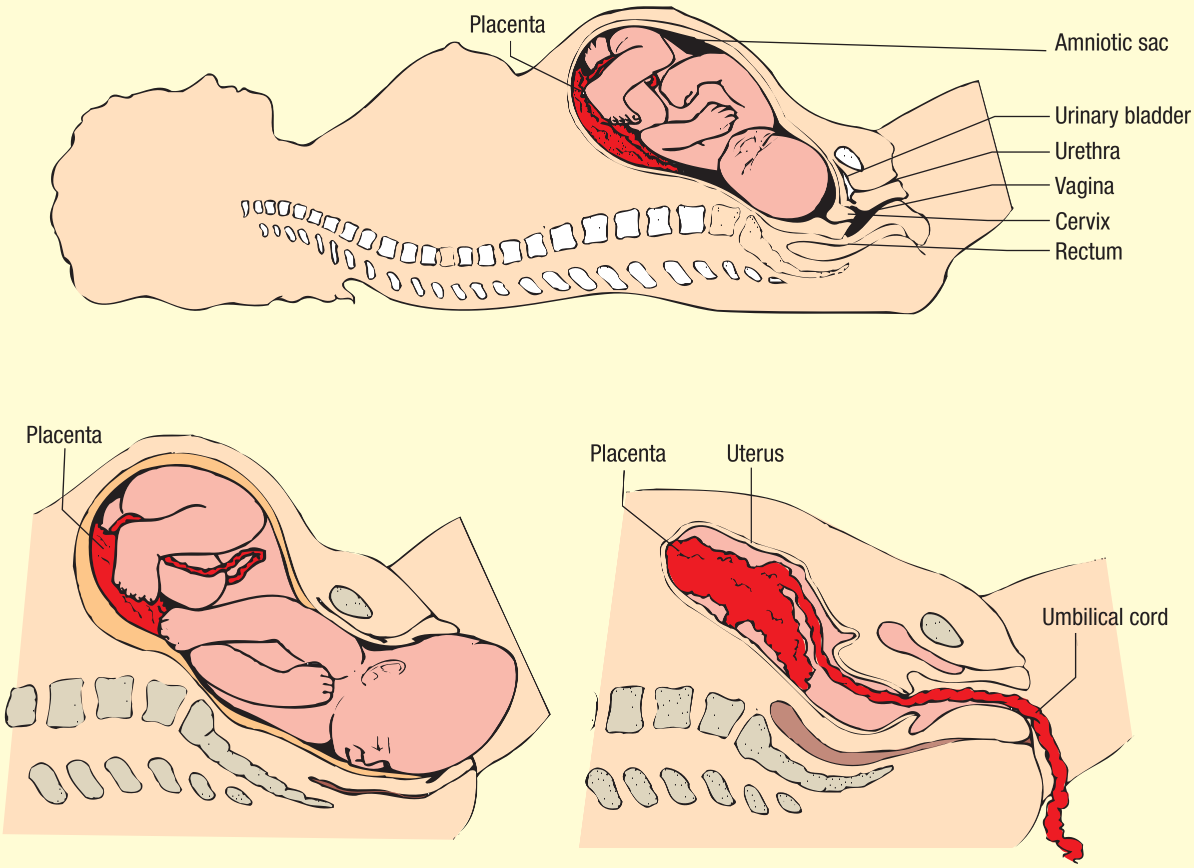


Figure 19.13 Parturition

SUMMARY

In human embryonic development the placenta develops within the first 2 weeks of conception. During the third week most of the major body organs begin to form—the central nervous system, heart, blood vessels, primitive gut and muscles. This is a crucial stage of development and a mild virus, taking drugs or exposure to low levels of X-rays can cause serious defects to the embryo if it survives. By the end of the first trimester (3 months) there is movement of the arms and legs, reflex actions, facial expressions and formation of the external genitalia, excretory and respiratory systems.

During the second trimester there is further elaboration of all systems, and the most rapid growth is in the final trimester.

Birth takes place approximately 266 days after conception. Labour is divided into three stages: dilation, expulsion and placental phase.

Review questions

19.5 Approximately how long after fertilisation does implantation occur in humans?

19.6 What functions are performed by the:
(a) muscles in the wall of the uterus
(b) amniotic fluid
(c) umbilical cord
(d) placenta?

19.7 Name five functions of the placenta.

19.8 Briefly describe a human fetus at the end of each trimester of pregnancy.

19.9 Although the placenta allows the diffusion of substances from the bloodstream of the mother to the bloodstream of the fetus and vice versa, it does not permit blood cells of either mother or fetus to cross into the bloodstream of the other. On the basis of your knowledge of the immune system (see Section 5.6.3), explain why this placental barrier is essential for the well-being of both mother and fetus.

19.2.2 Twins

Twins result when two embryos develop simultaneously. Twins can be either monozygotic or dizygotic.

Dizygotic twins result when two ova are fertilised in one cycle. They are commonly called fraternal twins. Because there are two blastocyts, each will develop completely independently and form extra-embryonic tissues. Each will have its own amnion surrounded by chorion enclosing the embryo, and individual placenta.

Since two eggs are released, two different sperm are involved in fertilisation. The twins will therefore have different combinations of their parental genes. Not only will they look and behave differently, they may be of different genders. Each twin could even have two different fathers.

Monozygotic twins result from errors during early cell division of a single zygote. The twins have the same genetic information and so must be the same gender.

The process of fertilisation stimulates mitotic cell division of the zygote. In the normal course of events the divided cells stay together to form a single ball of cells, the blastula, during the first 3 days of development. Over the next 2 weeks this differentiates into the embryo and the extra-embryonic tissues. It is during this early stage of cell division that twinning occurs. The cells do not remain together but separate into two embryonic discs that then develop independently.

There are several forms of monozygotic twins and they are classified according to the development of the amnion, chorion and placenta. If the separation zygote occurs very early after fertilisation, the twins each have their own amnion, chorion and placenta. About 8 per cent of identical twins develop in this way. These are classified as diamniotic/dichorionic twins.

In the majority of cases the embryonic disc separates between 4 and 8 days after fertilisation. Although these twins have separate amnions (the inner layer of the fluid-filled amniotic cavity surrounding the embryo) the outer chorionic layer surrounds both embryos. They can either have their own placentas or they will share a placenta. These are termed diamniotic/monochorionic twins.

If the cells of the embryonic disc separate after the eighth day, both embryos will develop within the same amnion and chorion and will share a single placenta. They are classified as monoamniotic/monochorionic. They account for less than 1 per cent of twinning. An interesting feature associated with these twins is that they are mirror-images of each other. Thus one will be right-handed while the other is left-handed. In one the hair whorls will be clockwise while they are anti-clockwise in the other. The presence of birthmarks will also demonstrate this reversed asymmetry.

If the twinning process occurs after the thirteenth day, the separation is not complete. The twins remain co-joined physically at any part of the body. This may be the entire torso or the top or sides of the head, the hips or the chests. While the joining may be superficial, it often involves sharing of vital organs. In the latter case surgical separation of the twins invariably results in the death of at least one of them. These co-joined twins are commonly called 'Siamese' twins after a famous pair of twins from Siam (now Thailand) who were joined at the breastbone.

Although monozygotic twins are genetically identical (i.e. clones), there are often considerable differences between the individuals, such as height,

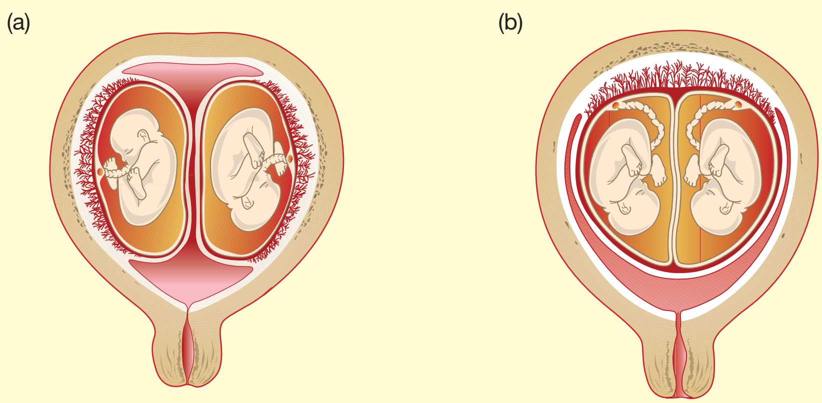
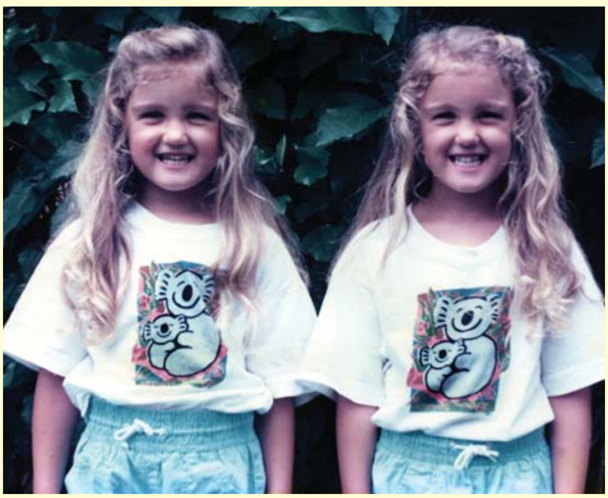


Figure 19.14 Condition of the embryonic membranes in twins: (a) Diamniotic/dichorionic with separate placentas; (b) Diamniotic/monochorionic with single placenta

(a)

(b)(i)



(b)(ii)

Figure 19.15 (a) Dizygotic (fraternal) twins; (b) monozygotic twins—(i) identical twins, (ii) mirror-image twins

head shape and size. This is because the environment in which an individual develops plays a significant role. From the onset of the twining process the two individuals could experience different pre-natal conditions. For those twins that share a common placenta, the nutrient supply and waste removal may not be identical across the entire placenta. Competition between the twins for resources could result in serious imbalance in exchange of materials with subsequent differences in the weight and size of each individual that could persist for life. This discrepancy in nutrient supply can be so great that the blood of one of the twins can become extremely viscous. Because the heart has to exert a greater pressure to pump the blood around the body, it may become weakened. This can lead to complications later in life. The other twin, in contrast, receives less nutrients and in extreme cases this could lead to malformation of organs.

Despite the differences between monozygotic twins, the physical similarity between them is far greater than that observed between normal siblings and fraternal twins. This suggests that the environment has less impact than genetic composition on physical development. Intelligence, however, seems to be affected more by pre- and post-natal environments. The largest differences between identical twins have been shown to occur in areas of academic achievement and temperament.

Studies of identical twins reared apart have shown how significant the genes are to development. One set of twins, separated at birth and reared in different countries, both wore rubber bands around their wrists, sneezed loudly to get attention and clipped their moustaches in a particular way. Similar studies suggest that other traits such as leadership ability, imagination and vulnerability to stress are strongly influenced by heredity.

Other multiple births can also be identical. There can be identical triplets, quadruplets and quintuplets. Although these multiple births may be a result of a combination of dizygotes and monozygotes, one set of quintuplets (the Dionne girls) have identical DNA. The separation into the five embryonic discs must have occurred at different stages, since only two of the girls are mirror-image twins.

SUMMARY

Twins may be either dizygotic (two different ova are fertilised) or monozygotic (a single fertilised ovum separates into two sets of embryonic cells early in development). Because the combinations of genes are different in dizygotic twins, the two individuals will have different characteristics. Monozygotic twins, however, are clones having the same gene combinations and so largely exhibit identical characteristics. The differences seen in these twins will be associated with environmental influences. These twins will invariably share some of their extra-embryonic structures during pre-natal development.

There are three different categories of monozygotic twins, depending on the time lapse between fertilisation and the separation of the cells. Identical twins usually are formed in the first 7 days after conception. If the twinning occurs between the eighth and twelfth days of development, mirror-image twins usually result. From the thirteenth day of development separation is usually incomplete and the twins are co-joined.

Review questions

19.10 Distinguish between dizygotic and monozygotic twins.

19.11 Explain why monozygotic twins are commonly called identical twins.

19.12 Some monozygotic twins are mirror-image twins. Explain what this means and why they form such a small proportion of the twin population.

19.13 What is meant by the term 'co-joined twins'? Suggest a reason why these, but not mirror-image twins, are not completely separated.

19.14 Why is it dangerous to try to separate some co-joined twins?

19.3 Embryo anomalies

The development of the embryo can be affected by many factors. Case study 19.2 described how a variety of non-nutritive substances are able to pass from the maternal blood into the embryo and cause disruption to tissue and organ development. These are termed **congenital defects**. They occur only in the organs of that developing child and are not part of the genetic machinery. An individual with a congenital anomaly cannot pass the problem on to their children.

Other anomalies result from information carried by the genes. Individuals with a **genetic defect** may exhibit characteristics that only mildly affect their overall functioning to severe disfunction. In some cases the genetic information passed on to the embryo can disrupt metabolic pathways to such an extent that it is unable to develop correctly and a **miscarriage** can occur. The embryo is expelled from the mother's body. The effects of the gene have been lethal. Examples of inherited genetic diseases will be discussed in Chapter 20. Miscarriages can also occur as a result of congenital defects.

A third type of anomaly can result from changes to chromosomes that occur during meiosis—**chromosomal defects**.

19.3.1 Studying chromosomes—the karyotype

Each species has a set number of chromosomes. The genetic information carried on these chromosomes determines the characteristics of the species, therefore each member of a species has the same types of chromosomes. In the human, there are forty-six chromosomes. These include twenty-two pairs of homologous chromosomes, called **autosomes**. The structure of the other two chromosomes differs between males and females; these are therefore termed the **sex chromosomes**. In females the two sex chromosomes, the **X chromosomes**, are similar, whereas males have one X chromosome and a smaller **Y chromosome**. In other species, the number and types of sex chromosomes may be different.

A **karyotype** is a display of the total complement of a species' chromosomes. It is prepared using mitotic metaphase chromosomes. In humans a blood sample is usually taken and the white blood cells separated from the other constituents. Cells in the process of dividing are interrupted by the addition of colchicine. This drug prevents anaphase from occurring by interfering with the spindle microtubules. The addition of water causes the cells to rupture. Photographs of the ruptured cells are taken. These are enlarged and the chromosomes cut out and arranged in pairs. The position of the centromere, and thus the length of the 'arms' of the chromatids, is used as a determinant for the pairs. Certain anomalies, such as an extra chromosome or piece of chromosome, can then be detected.

19.3.2 Mistakes during meiosis

Several types of mistakes can occur during meiosis. During metaphase I, there is often exchange of pieces of chromatids between **homologs** (homologous chromosomes). A **deletion** can occur when a segment which has broken off is not replaced by the corresponding segment of the homolog. The resulting chromosome will therefore not have all of the genetic information it should. Sometimes the broken-off segment becomes incorporated into the homolog, which then has two sections of that piece of information: a **duplication** occurs. In other instances the broken-off segment becomes incorporated into a non-homologous chromosome: this is known as **translocation**. An **inversion** occurs when the broken-off segment re-attaches ‘back-to-front’. Depending on the size of the segment, and the genetic information it carries, these forms of misinformation can result in death of the developing embryo. (See Figure 21.12 on page 588.)

Occasionally, during meiosis, a pair of homologous chromosomes fails to separate. This process is termed **nondisjunction**. It results in some of the gametes having two of a particular chromosome, while other gametes do not have that chromosome.

This condition was first observed by a geneticist who was studing the inheritance of eye colour in the fruit fly, *Drosophila melanogaster*. Then, in 1959, it was discovered that the presence of an extra chromosome was associated with Down syndrome in humans. Since that time several other conditions have been found to result from nondisjunction.

Nondisjunction in human gametes

Nondisjunction can occur in autosomes and in sex chromosomes. If a male gamete with one missing autosome fertilises an ovum, the embryo will not develop. If there is an extra autosome present, the embryo may develop. The new individual will then have three of that chromosome in every body cell. In most cases, however, the fetus is spontaneously aborted (i.e. there is a miscarriage) early in pregnancy. It has been estimated that approximately 20 per cent of pregnancies result in miscarriage due to autosomal nondisjunction.

The extra autosome disrupts the normal control of the cell by the nucleus. Thus individuals with this characteristic always have widespread anomalies. Many die within a few months of birth. Of those who survive, most are mentally retarded and frequently have heart and other organ defects. Survival to maturity is rare and usually accompanied by sterility.

Down syndrome is the most familiar condition resulting from autosomal nondisjunction. Individuals have an extra chromosome in the pair labelled number 21. The condition is termed a syndrome since this nondisjunction results in a number of related disorders.

Usually Down syndrome results in:

- a short, stocky body with short neck
- mental retardation ranging from mild to severe in different individuals
- an enlarged tongue which produces speech defects
- a high probability of heart and other organ defects
- a high likelihood of developing a form of senility similar to Alzheimer’s disease in middle age.

The chances of having a Down syndrome child increase with the age of the mother. Up to the age of 30, there is only a 0.007 per cent likehood of this occurring. Over the age of 45, there is a 3.4 per cent chance of a female giving birth to a Down syndrome child. In about 5 per cent of the cases, however, the defective gamete is paternal.

Down syndrome can also result from translocation where sections of chromosome 21 have become attached to another chromosome. Functionally this is equivalent to an extra chromosome 21.

(a) (b)

Figure 19.16 (a) Karyotype and (b) features of a child with Down syndrome

Nondisjunction can also produce individuals with unusual combinations of sex chromosomes. Maleness in humans results from the presence of the Y chromosome. A normal male's sex chromosome complement is XY. Males with XXY, XXXY and XXXXY are usually sexually undeveloped and sterile.

Klinefelter syndrome has the XXY chromosome combination. These males:

- fail to develop normal sex characteristics
- are normally sterile
- may have very long arms and legs
- may have below-average intelligence.

The normal female has XX sex chromosomes. Women with only a single X chromosome (X–) show **Turner syndrome**, which is characterised by:

- failure of ovaries to develop
- undeveloped sex characteristics
- sterility
- 'shield' chest
- short stature
- some degree of mental retardation.

Some women have three X chromosomes (triple X syndrome). The symptoms of this condition vary from no distinguishing features to several of the following:

- tall stature
- delayed development of motor skills, language and/or puberty
- learning disabilities such as dyslexia
- infertility
- small head
- vertical skin folds that may cover the inner corners of the eyes.

19.3.3 Detecting embryo anomalies

Due to technological developments, the human species is able to control many of the environmental factors that affect other animals, such as food supply and protection. Pregnancies can be planned. Many difficulties in conception can be rectified through surgical or other medical procedures, including in-vitro fertilisation. Birth difficulties can be circumvented through caesarian section and premature babies can be brought to an artificial full term. Embryonic anomalies can be detected at an early stage of pregnancy, which may lead to safe termination. Many of these technologies have serious cultural and legal implications, however.

Techniques such as amniocentesis and ultrasound can be used to detect physical and genetic defects in the human fetus from about 4 months of development.

The position of the fetus is determined by **ultrasound**. High-frequency sound waves are passed through the uterus across the mother's abdomen. Reflected waves are picked up and transmitted to a video screen in the form of an image called a sonogram. The size of the fetus, beating of its heart and other movements, as well as general external physical development can be observed on the sonogram. **Fetoscopy** involves inserting a small, enlarging device (an **endoscope**) into the uterus, usually through an incision in the abdominal and uterine walls. Direct viewing of the fetus can be achieved with little disturbance.

While the sonogram is being observed, **amniocentesis** can be performed. A thin needle is inserted through the mother's abdominal and uterine walls into the amniotic cavity, and a sample of amniotic fluid is removed. This fluid contains living cells sloughed off from the fetal skin. The cells are cultured and induced to divide, and a karyotype can then be produced. The results may show whether the fetus has a chromosome anomaly. The parents then have the choice of whether or not to medically abort the fetus at an early stage. After 4 months of fetal development, however, the abortion could be both risky and traumatic for the mother.

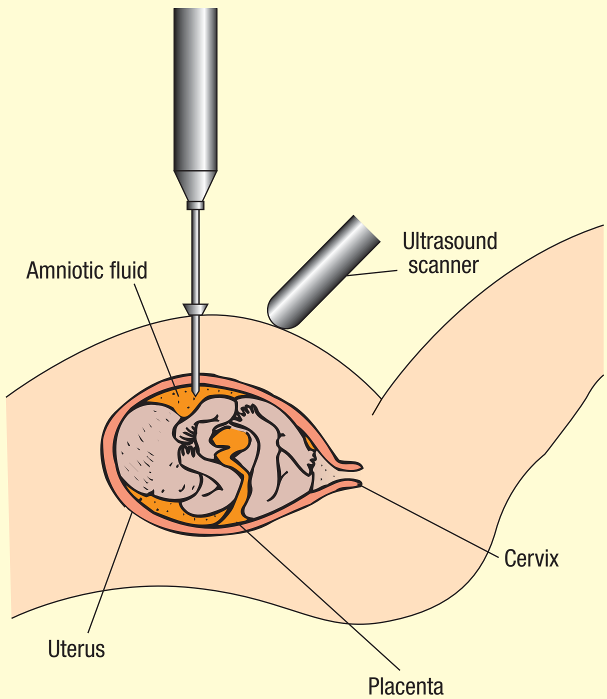


Figure 19.17 Removal of amniotic fluid during amniocentesis

Another method, called **chorionic villus sampling**, can be performed at a much earlier stage. A tiny piece of the chorion (genetically identical to the cells of the embryonic baby) is removed. The DNA from these cells is extracted and, by using **gene probes** (pieces of radioactively labelled DNA), several disorders can be identified.

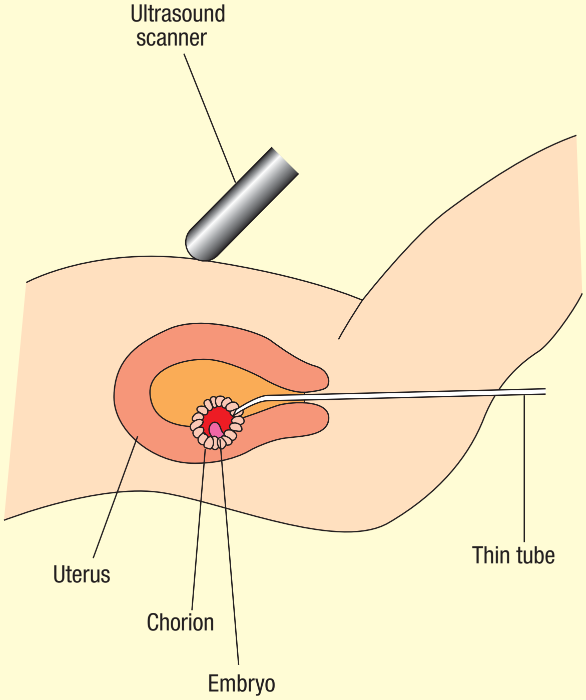


Figure 19.18 Chorionic villus sampling

Using this method, doctors in Adelaide have been able to identify the conditions cystic fibrosis and Huntington's chorea. Similar work in Sydney has provided diagnosis of muscular dystrophy and blood diseases such as haemophilia and thalassaemia. New probes are being developed for rare diseases such as neurofibromatosis (the affliction of the 'Elephant Man'), phenylketonuria, Alzheimer's disease and manic depression. Chromosomal abnormalities such as Down syndrome can also be detected.

SUMMARY

The karyotype of an individual shows the numbers and types of chromosomes.

Mistakes can occur during meiosis. Segments of chromosomes may be deleted, added, translocated or inverted. Nondisjunction occurs when homologous chromosomes fail to separate during metaphase I. Most cases of nondisjunction are lethal. Down syndrome results from nondisjunction (or translocation) of chromosome 21.

Nondisjunction of human sex chromosomes can lead to Klinefelter syndrome (XXY) or Turner syndrome (X–), each with characteristic symptoms, or triple X syndrome (XXX), which has variable symptoms.

Prenatal detection of abnormal fetal development can be made using ultrasound, amniocentesis and chorionic villus sampling. However, parents are then faced with the difficult decision of whether or not to abort the affected fetus. Many ethical and legal dilemmas are raised by abortion.

Review questions

19.15 What is a karyotype?

19.16 Distinguish between an autosome and a sex chromosome.

19.17 Explain what happens when (a) deletion, (b) duplication, (c) translocation and (d) non-disjunction occurs during meiosis. At what phase does each of these occur?

19.18 Most meiotic mistakes are lethal. Some, however, can result in abnormal offspring. List one autosomal nondisjunction and one sex chromosome nondisjunction in which the offspring survive. For each case give the chromosome involved in the aberration.

19.19 Distinguish between amniocentesis and chorionic villus sampling.

19.20 Why is it necessary to use ultrasound detection while performing the above techniques?

19.21 List some of the conditions which can be detected using prenatal screening.

19.22 Why is chorionic villus sampling considered a better alternative to amniocentesis?

19.4 Growth and development after birth

After birth in mammals, there is a period of time during which the young is under parental protection and is dependent on the mother for nutrition. The first milk produced consists mainly of colostrum, a chemical which is rich in antibodies and which protects the young until it is able to produce its own antibodies. Nutrition is the primary function of the milk that is produced subsequently, but it also contains antibodies.

The period of dependency varies from species to species but is longest in the human species. During this time the young mammal relies on the parents for food and protection. It is a time during which the young learn the skills of survival. Although good nutrition is required throughout the lifetime of an individual for good health and prevention of nutritional diseases, it is of particular importance during phases of active growth and development. Table 5.1 on page 104 lists the major human nutrients, their functions and the nutritional diseases associated with lack or inadequate supply of particular substances.

From birth to sexual maturity the young animal undergoes rapid growth. Factors which may affect survival, growth and development include:

- abiotic conditions, influencing food availability
- parasites
- disease
- predation.

A major developmental phase occurs as the young animal passes into adulthood. It is at this time that the final maturation of the reproductive system occurs.

In humans, there are two phases of active growth before adulthood. One occurs in the early childhood years and the other during adolescence. There is usually a slower growth rate between these two periods. The growth curve, therefore, resembles two sigmoid curves (see Figure 19.19).

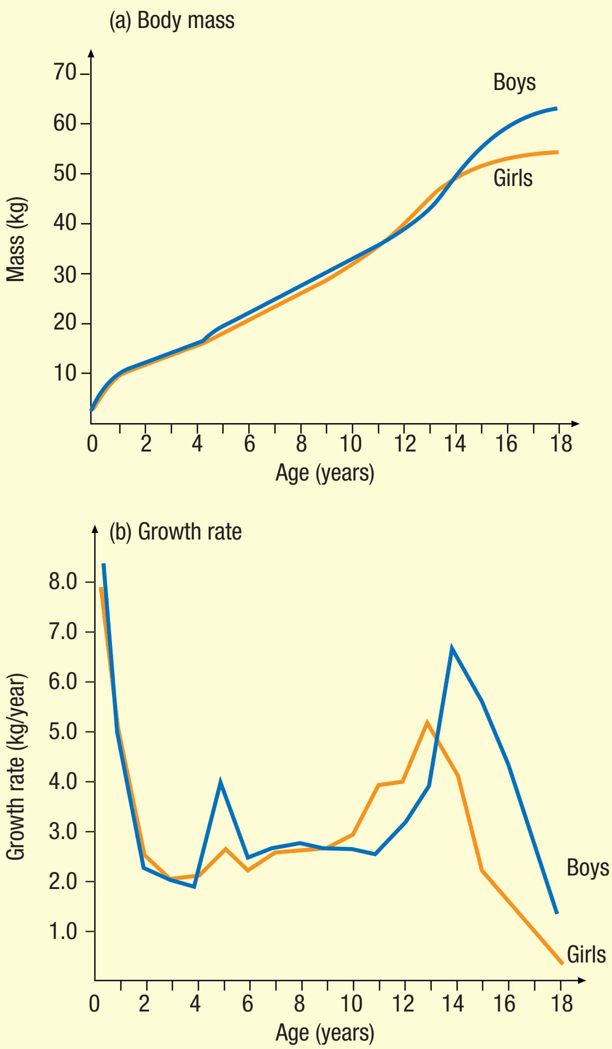


Figure 19.19 Human growth curves

Case study 19.3: What else is consumed with food?

Increased urbanisation has resulted in many changes to the ways that humans obtain food. No longer does every backyard have a henhouse, possibly a goat or cow, and almost certainly a vegetable patch and fruit trees. For the vast majority of people, all their food requirements come from the shops.

The processing of food has also changed dramatically. Fruit and vegetables are canned, frozen or used in the preparation of ready-to-eat meals. Meat is treated in a variety of ways. Processed food contains additives.

Not all additives are harmful. Food would be more susceptible to bacterial decay if no additives were used. If these were eliminated from the processing, the shelf-life of many products would be dramatically reduced, and there would be fewer convenience foods and spreads.

Some additives, however, are unnecessary and can produce side effects. Tartrazine, for example, is a commonly used orange food colouring, known to trigger hyperactivity and to have adverse effects on asthma sufferers. Monosodium glutamate, a flavour enhancer, can be a severe allergen to some people.

More significant, however, are side effects resulting from the large-scale use of pesticides. There is great economic pressure on growers to produce larger and more 'attractive' crops, and this can be done only by controlling pest organisms. A study of 177 Australian foodstuffs, reported by the *Sunday Mail* in early 1997, revealed only seventeen that were pesticide-free. Thirteen different pesticides were found in the other foods. Six foods were found to have levels of pesticide above the acceptable levels set by health authorities. In one of these, the pesticide level was twenty-five times the maximum residue limit. Some contained unauthorised chemicals such as dicloran, dieldrin, diphenylamine and fenthion. Although most food contained individual pesticides below the average accepted residue, no account was taken of the cumulative effects of different chemicals present. Apples, for example, were found to contain thirteen chemical residues which represented five different groups of pesticides. Human milk was found to contain DDE, DDT, dieldrin and hexachlorobenzene.

Pesticides may have a direct effect on the individual's metabolism; these effects were discussed in Chapter 10. More significantly, they can lead to disruption of hormone balances in humans and other animals. Included among these are dicofol, dieldrin, DDE and DDT, endosulfans, fervalerate, hexochlorobenzene, permathrin and vinclozolin, substances found to be in Australian foods. Although they may not be present at levels sufficient to bring about direct metabolic damage, many authorities believe they can still have an effect on the endocrine system in very low doses.

Some residues mimic the female sex hormone, oestrogen. These include:

- phthalates, which are derivatives of oil and natural gas, used in the production of resins, plastic packages (particularly 'cling films'), pharmaceuticals, dyes and insecticides
- alkylphenols, which are used in the production of detergents, agricultural chemicals and plastics
- synthetic oestrogen (DES), which was given to 5 million women between 1950 and 1980 to prevent miscarriage
- organochlorines, such as the pesticides DDE and DDT, which are still used in developing countries
- PCBs, used as insulating material.

Several heavy metals (cadmium, lead, mercury) are also believed to mimic oestrogen and other animal hormones. Oestrogen is fed to food animals (poultry, cattle and pigs) to stimulate their growth. All of these substances are capable of entering the food chain and finishing up on the human dinner plate. Many accumulate in the body and are subject to biological magnification.

Although rigorous scientific tests have not been imposed, it is hotly contended that oestrogen mimics are responsible for the general trend towards low sperm count in human males and declining populations of many long-lived animals, such as seals in Russia, bottlenose dolphins along the Atlantic coast of the USA and harbour seals in the North Sea.

One study indicates that between 1930 and 1990 the average human sperm count dropped from 113 million to 66 million per mL of semen. Eighteen per cent of men are below the subfertile level of 20 million sperm per mL of semen. One in six couples have infertility problems, and 40 per cent of these cases are attributed to low sperm count, or malformed or defective sperm too feeble to penetrate the egg.

Oestrogen mimics in the female interfere with her normal oestrogen secretions. This may have dramatic effects on embryological development if she is pregnant. It has been suggested that the mimics can modify development, and in particular sexual development. Observations of wildlife have shown an increasing trend towards feminisation in males and male behaviour by females. One colony of gulls ceased to breed, as females paired off and nested while the males ignored them. Some reports indicate that similar behaviour disruptions may be occurring in the human species.

In Britain, male fish (roach and rainbow trout) living in lagoons at sewage treatment works turned hermaphrodite and started growing eggs in their testes. Researchers isolated chemicals with oestrogenic activity from seven sewage works. They tested fish with extracts of these chemicals and found feminisation of the males occurred at levels comparable to those in sewage effluent. Although the contraceptive pill (ethinyl oestradiol) was originally blamed for the increase in effluent oestrogens, the scientists found that natural oestrogens were more likely the cause. The synthetic oestrogen was found only in small quantities in a few sewage works while natural forms were more abundant. The two most abundant human oestrogens (oestrone and 17ß-oestradiol) are bound to a protein when they are excreted. This reduces their oestrogenic activity. At some phase in the sewage treatment, however, the oestrogens are liberated from their protein and actively impact on the male fish downstream from treatment works.

19.4.1 From childhood to old age in humans

Male hormones, collectively termed androgens, are first produced in the early embryo. They determine the development of the male genitalia. After birth the androgens are secreted at a low level, then at about 10 years of age there is a huge surge of testosterone which initiates sperm production. This period is called **puberty**. The penis, testes and accessory organs enlarge. Secondary sex characteristics develop:

- Facial, underarm and pubic hair develops.
- Musculature increases.
- The shoulder bones increase in width.
- Fat becomes deposited in the abdomen.
- The larynx enlarges and vocal cords thicken, producing a deeper voice.

The androgens stimulate an increase in skeletal size and biosynthesis of proteins. Thus adolescence in boys is marked by a dramatic increase in growth.

Male puberty is often associated with increased body odour. This results from stimulation of sweat glands by androgens. The increased sweat production attracts bacteria, and bacterial decomposition of sweat causes a pungent odour. It has been suggested that the odour of fresh sweat acts as a pheromone sex attractant.

The onset of the first menstrual cycle marks puberty in the human female. The average age for puberty is 12.3 years, but the time of onset is very variable. It may occur as early as 9 years of age. Girls with a thin body type generally start puberty at a later age. Environmental factors, such as the quality and quantity of nutrients, physical activity and general health can all influence the time of pubertal changes.

Just before puberty there is an increase in the production of female sex hormones. This stimulates not only the final development of the reproductive structures but also secondary sex characteristics:

- enlargement of the breasts and hips
- increased activity of the sweat glands
- development of pubic and underarm hair
- deposition of fat around the hips.

In males and females the sex hormones may stimulate activity in the oil-secreting glands of the skin. Overactivity of these glands can result in acne.

The sudden surge of sex hormones in the system can initiate changes in behaviour. Males may become more aggressive and loud. They, like their mammalian relatives, challenge dominant males (fathers, older brothers, teachers) in their environment. Mood swings, between elation and depression, are common. This is particularly the case in females where increased progesterone just prior to menstruation can result in oversensitivity.

Adolescence is a time when the body completes its growth and development. It is a period during which the body adjusts to the changed hormonal balance associated with a sexually mature organism. During this time, the adolescent undergoes a series of behavioural changes in preparation for the responsibilities associated with rearing the next generation.

Final adult size is normally achieved by age 20. **Adulthood** is the longest period in the human life cycle. It is the reproductive phase.

With age, many cells begin to degenerate. This process is termed **senescence**, or cell aging. The time of onset, the type of cells affected and the extent of senescence vary from individual to individual.

Many degenerative processes are associated with decreased production of the sex hormones. At about 50 years of age women reach menopause. The ovaries no longer function and there is a decrease in oestrogen production. Oestrogen is associated with calcium metabolism. Although the ovaries are the principal site of production, oestrogen is also metabolised in fat tissues. Thin women, therefore, are more prone to bone degeneration (osteoporosis) than those with fat storage. Fat people, however, are more prone to cardiac disease. The ideal, therefore, is to have adequate fat supplies to maintain oestrogen production while not overloading the body. Osteoporosis is a condition where the bones become brittle and breakages take a long time to heal. Disrupted calcium metabolism may lead to the development of the 'widow's hump'—a curvature of the upper spine (see Figure 5.3 on page 103).

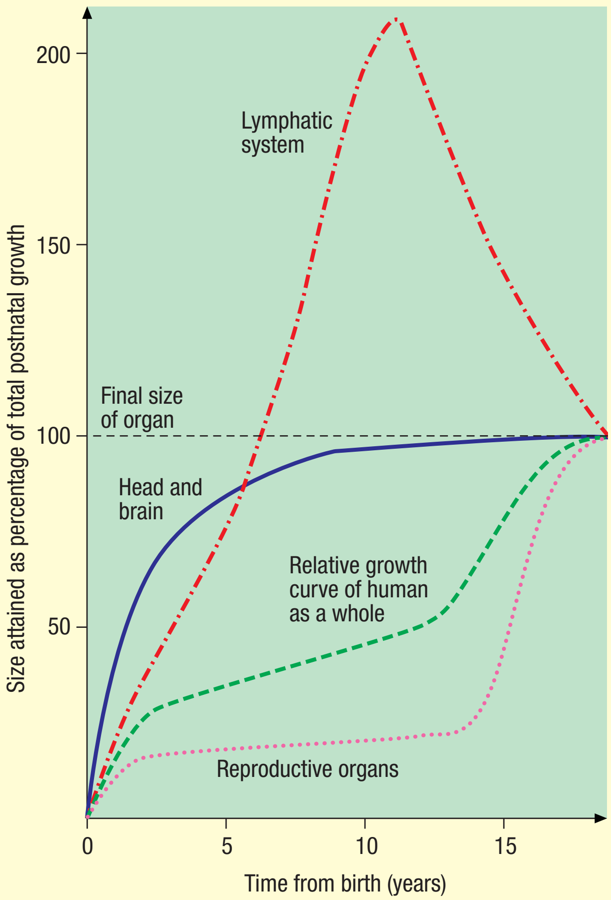


Figure 19.20 Growth curves of different tissues of the body, as a percentage of the 20-year-old mature size

Although males do not experience the rapid menopause of females, there is a gradual decline in levels of sex hormones. As they age, men experience muscle and bone deterioration.

Both males and females may be affected by various forms of **senility**, or decreased mental competence. Senility is usually associated with decreased oxygen supply to the brain. There is often a general decrease in muscle tone, which affects return of the blood to the heart, maintenance of arterial blood pressure and respiratory gas exchange.

Case study 19.4: Alzheimer's disease

Alzheimer's disease is a degenerative disease of the brain. Beginning as progressive memory loss, it ultimately leads to inability to think, speak or perform simple, basic tasks. This severe dementia usually results in the death of the individual between 3 and 10 years after the onset. The first symptoms of Alzheimer's disease usually occur at 40–50 years of age.

Three major changes to the brain, particularly in those areas involved in memory, are associated with this disease. There is an accumulation of tangled protein filaments in the cell bodies of the neurons, there are clusters of degenerated axon terminals surrounded with the protein amyloid, and amyloid accumulation adjacent to and within the walls of blood vessels. In addition there is loss of those neurons which secrete acetylcholine, particularly in the forebrain. Acetylcholine increases the level of activity in the cortical neurons.

It is not clear whether these changes in the brain are the cause of the disease or a result of it. Similarly, it is not known if it is the result of one condition or a series of related conditions.

The high levels of amyloid in diseased parts of the brain suggest that Alzheimer's disease may have a genetic basis. Considerable research has been undertaken to ascertain this possibility. A gene for the amyloid precursor has been located on chromosome 21. This is the chromosome associated with Down syndrome, and many people with this condition develop Alzheimer's disease. Further research is under way to determine if this protein is a normal or abnormal gene product.

It has also been suggested that environmental factors play a significant role in the development of the disease. It has been linked to high levels of aluminium in the diet. This metal is found in relatively high levels in soya beans. It is also possible that some aluminium is absorbed by food cooked in utensils made of this metal.

Other environmental factors which may induce this debilitating disease include toxic agents, infections and immunological responses to infection.

SUMMARY

Growth and development of the organism continues after birth. There is usually a very rapid growth up to sexual maturity.

In humans there are two major growth phases: one in early childhood and another at adolescence. Both phases of growth are dependent upon availability of adequate nutrient supplies. Adolescence is preceded by puberty, the stage at which the sex organs become mature. Major developmental and behavioural changes accompany maturation of the sex organs. Adulthood is the reproductive phase of the life cycle. It is followed by degenerative processes in old age which ultimately lead to death.

Review questions

19.23 List the stages of growth and development in the human after birth.

19.24 Describe the physical, physiological and behavioural changes which occur at puberty and adolescence:
(a) in the human male
(b) in the human female.

19.25 Define senescence. Describe some results of human senescence.

19.26 List ways in which oestrogen mimics in the body can alter population dynamics.

EXTENDING YOUR IDEAS

1. UB The following diagram contains at least three deliberate errors in the accuracy of the drawing and/or the labelling.
   Identify TWO errors and give a reason and a correction of the error. (Vas efferentia are sperm-collecting tubules.)

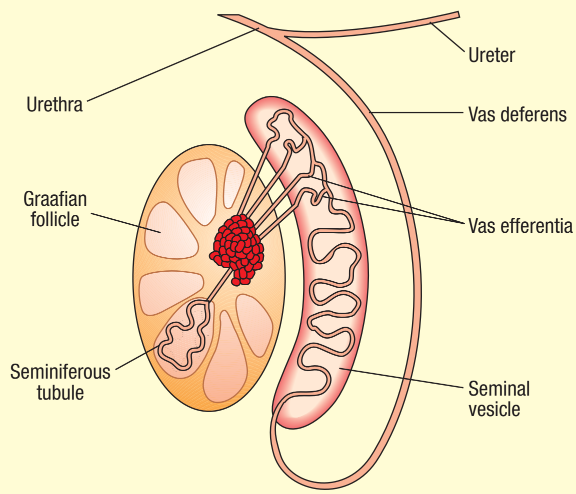


Figure 19.21

2. UB The secretion of LH is controlled by LH releasing factor (LRF), a small peptide produced in the hypothalamus. LRF has been synthesised in the laboratory.
   Figure 19.22 shows the effect of synthetic LRF on LH secretion in a healthy woman. Synthetic LRF was injected on either day 3 or day 11 of the menstrual cycle. The same dose of LRF was injected on each occasion.

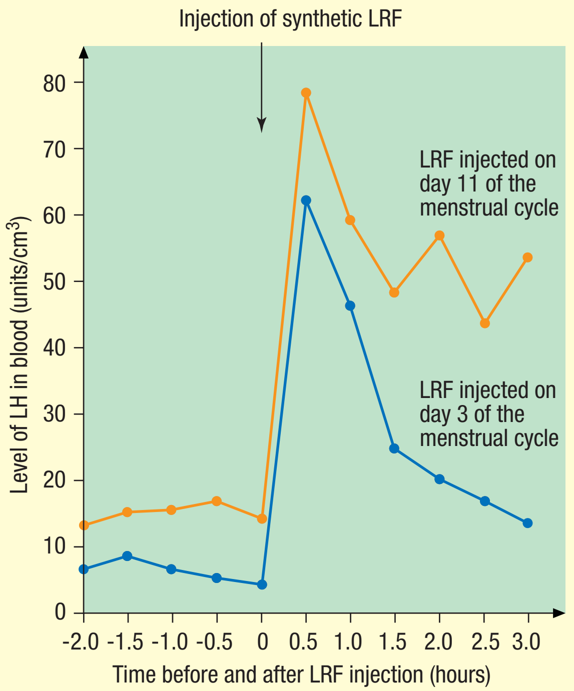


Figure 19.22

(a) Comment on the differences in response to synthetic LRF on days 3 and 11 of the menstrual cycle.

(b) Suggest one possible medical application of synthetic LRF.

LRF triggers LH secretion by binding to receptor molecules on the surface of LH-secreting cells. It has been suggested that synthesis of substances with a molecular structure similar, but not identical, to LRF may have applications for contraception.

(c) Explain the physiological basis of this suggestion.

In the hypothalamus, LRF is secreted directly into capillaries which join to form a short portal vein leading to the anterior pituitary. In the pituitary, this portal vein branches into another capillary network, supplying the cells which secrete LH. This system is illustrated in the simplified diagram Figure 19.23.

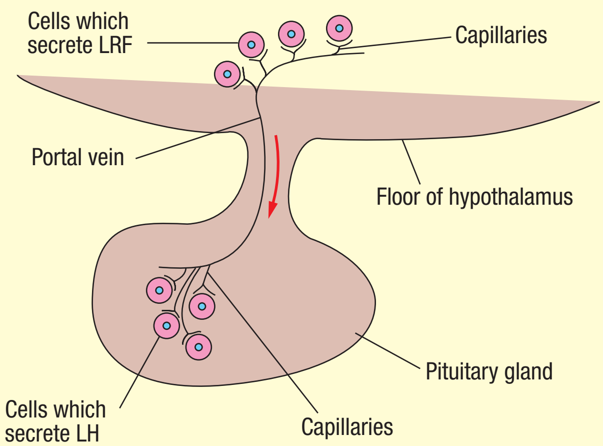


Figure 19.23

(d) How does the transport of LRF to its target organ differ from the transport of a typical hormone such as LH to its target organ?

(e) What advantages may be gained from the system described for the transport of LRF?

3. UB If a pregnant woman develops high blood pressure, particularly in the later stages of pregnancy, doctors often consider inducing the birth. Suggest why maternal high blood pressure is dangerous to the fetus.

4. UB Figure 19.24 shows changes in the mean diameters of follicles and corpora lutea in the ovary of a pig over a period of 40 days.

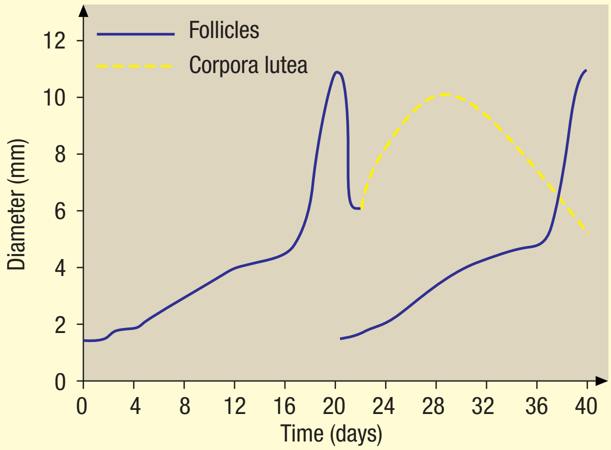


Figure 19.24

(a) Between which days is fertilisation most likely to occur? Explain your answer.

(b) In the cycle represented in the graph, fertilisation did not occur. Give two pieces of evidence from the graph to support this.

5. UB How would the effects of nondisjunction differ if it occurred at meiosis II rather than meiosis I?

6. UB Umbilical arteries carry deoxygenated blood and umbilical veins carry oxygenated blood. Discuss the significance of this.

7. UB A pregnant woman in her final trimester fell and broke her tailbone. The pregnancy was too far advanced for the consulting doctor to risk surgery to rectify the problem. Her pain was so extreme, however, that it was feared that this could induce premature labour. The woman was prescribed morphine to alleviate the symptoms as the best alternative at the time. A perfectly healthy baby was born at the correct time. He was, however, extremely unsettled. He cried constantly, would not feed properly and did not gain normal

weight. At 8 months of age, his behaviour changed. He became placid, fed voraciously and maintained very good weight gains. Explain the behaviours in the baby.

8. EBI Discuss the ethical, social and legal implications of aborting a fetus found to be suffering either a genetic or congenital anomaly. Present evidence for and against such an abortion and draw a conclusion from this evidence.

9. EBI In Case study 19.3, evidence was cited showing a decrease of approximately 50 per cent in the human sperm count between 1930 and 1990. An analysis of sixty-one sperm count studies, involving 14 947 men, was reported in medical literature over that time period. Most of the data prior to 1970 were from New York, where sperm counts were highest. Post-1970 data were from developing countries, where sperm counts were lower. Studies of 1351 sperm donors in Paris between 1973 and 1992 showed that the average sperm count had decreased by 33 per cent. American studies, however, have not revealed such a general trend. There was great variation in sperm counts from one year to the next and between different geographic regions. Recent studies from Scotland and Belgium also show declines, but those from France and from Finland do not indicate decreased sperm counts.

   Discuss whether these data support the hypothesis that decline in sperm count could be linked to rising levels of oestrogen-like compounds in the environment.

10. IB In a recent study of the menstrual cycle, a Canadian researcher performed daily ultrasound scans on sixty-three women who had normal menstrual cycles over a period of 6 weeks. This allowed him to measure the diameter of every follicle in the ovary and their waves of growth. Contrary to prior belief, they found that up to twenty Graafian follicles develop prior to ovulation, but that generally one is larger and as it ruptures to release the ovum the others degenerate. They also found that all of the women had two growth waves in a cycle and half of them had three. Regardless of the number of growth waves, however, the actual ovulation differed between the women. Fifty of the women ovulated once, seven did not ovulate and six ovulated twice over a month and on separate days. This would explain why 10 per cent of conceptions are non-identical twins. It has been suggested that those women who have three follicular growth waves in a cycle would run out of primary follicles at a faster rate than women who have two waves. This would therefore explain why the onset of menopause is earlier in some women than others.

    (a) Critically evaluate the experimental protocol in this study.

    (b) Design an experimental procedure to determine whether the number of follicular waves per cycle is related to time of menopause and if this is an inherited characteristic.

UNIT 7

Genetics

Genetics is the study of the inheritance of characteristics from one generation to the next. Inheritance of some characteristics involves a single gene. Sometimes, different expressions of this gene may be due to a simple dominant–recessive relationship. In other cases this is not so clear-cut. Many characteristics, although primarily controlled by a single gene, may be modified or masked by other genes. Other characteristics are determined by the combined actions of several genes. Genes play a crucial role in the life of organisms. Through determining the types and timing of protein production, genes control physical features and all metabolic reactions within the body. The quantitative nature of this topic highlights the predictability of some biological systems.

Genes are sequences of DNA nucleotides. DNA is the major molecule comprising the chromosomes. During the processes of DNA replication and formation of mRNA (the transcription phase of protein synthesis), errors in the genetic code can occur. These errors, or mutations, can have a range of effects on either the individual organism or the species.

Key concepts

- A variety of mechanisms results in continual change at all levels of the natural world.
- There are mechanisms by which characteristics of individuals in one generation are passed on to the next generation.

Key ideas

- Malfunctioning in one system or part of a system may affect the whole organism.
- In most organisms coded instructions within the DNA molecule account for their inherited characteristics.
- During reproduction DNA is passed from parent(s) to offspring.

20 THE INHERITANCE OF CHARACTERISTICS

20.1 THE WORK OF GREGOR MENDEL

Genetics is the study of the inheritance of traits from parents to offspring. Although previous attempts had been made to understand the inheritance of characteristics, a now-famous Austrian monk called Gregor Mendel (1822–84), solved the fundamental problems with his research on the garden pea (*Pisum sativum*). He presented his findings at a conference in 1865 and published it in the following year. The scientific community at the time, however, did not understand his work and rejected it. It was not until 1900, sixteen years after his death, that its true significance was appreciated.

The success of Mendel's work can be attributed to several factors:

- He chose to investigate garden peas, which:
  (a) were readily available and easily cultivated
  (b) are found in different varieties with clearly different traits for each characteristic
  (c) are self-pollinating and thus pure strains can be bred
  (d) allow different strains to be deliberately cross-pollinated
  (e) can produce a large number of offspring in a short time
  (f) can produce several generations in a few growing seasons.
- He conducted carefully controlled experiments.
- He restricted his study to a few characteristics.
- By chance he selected characteristics which were inherited, or behaved as though they were, on different chromosomes.
- He collected a vast amount of data which gave statistically reliable results.

Trait	Dominant	Recessive
Seed shape	smooth	wrinkled
Seed coat	coloured	white
Pod shape	smooth	wrinkled
Pod colour	green	yellow
Seed colour	yellow	green
Flower position	axial	terminal
Flower colour	red	white
Stem length	tall	dwarf

Figure 20.1 Traits in peas studied by Mendel

20.1.1 Monohybrid cross

Mendel started with thirty-two different types of pea plants, which he studied for 2 years before he began his experiments. He finally selected seven which had conspicuously different traits in different types of plants. One variety, for example, always produced yellow seeds, while another variety always produced green ones. He then began his experiments by taking the pollen from one strain and artificially pollinating the strain with the alternative trait, after first removing the anthers to prevent self-pollination.

For example, he crossed a smooth-seed pea plant with a wrinkled pea plant. In every case all of the offspring in the first (filial) generation (F_1) displayed only one of the two possible traits. Thus all of the progeny of the cross between smooth-seeded plants and wrinkled-seeded plants were smooth-seeded. He termed the trait which always showed up in the offspring the **dominant trait**, and that which disappeared the **recessive trait**. Since the progeny were a cross between two pure-breeding individuals (i.e. if wrinkled-seeded plants are allowed to self-pollinate, they always produce wrinkle seed), the offspring are termed **hybrids**.

When Mendel grew the hybrid seeds and allowed the plants to self-pollinate, he found that some of the second (F_2) generation displayed the recessive trait. The proportion of recessives in the second generation, moreover, was always approximately one-quarter of the total number. In other words, the ratio of plants showing the dominant trait to those showing the recessive trait was 3:1.

Mendel saw that the appearance and disappearance of traits and their constant proportions could be explained only if hereditary factors were always determined by discrete factors which occur in the offspring as pairs, one inherited from each parent. These are separated again when the sex cells are formed, producing two types of gametes with one factor of the pair in each. This hypothesis is known as Mendel's first law or the **principle of segregation**.

The two factors in a pair may be **homozygous** (the same) for either the dominant or the recessive trait. The self-pollinating plant breeds true. Alternatively, the two factors may be **heterozygous** (different). A hybrid for a characteristic is always heterozygous.

Alternative expressions of the gene for a particular characteristic are known as **alleles**. Thus

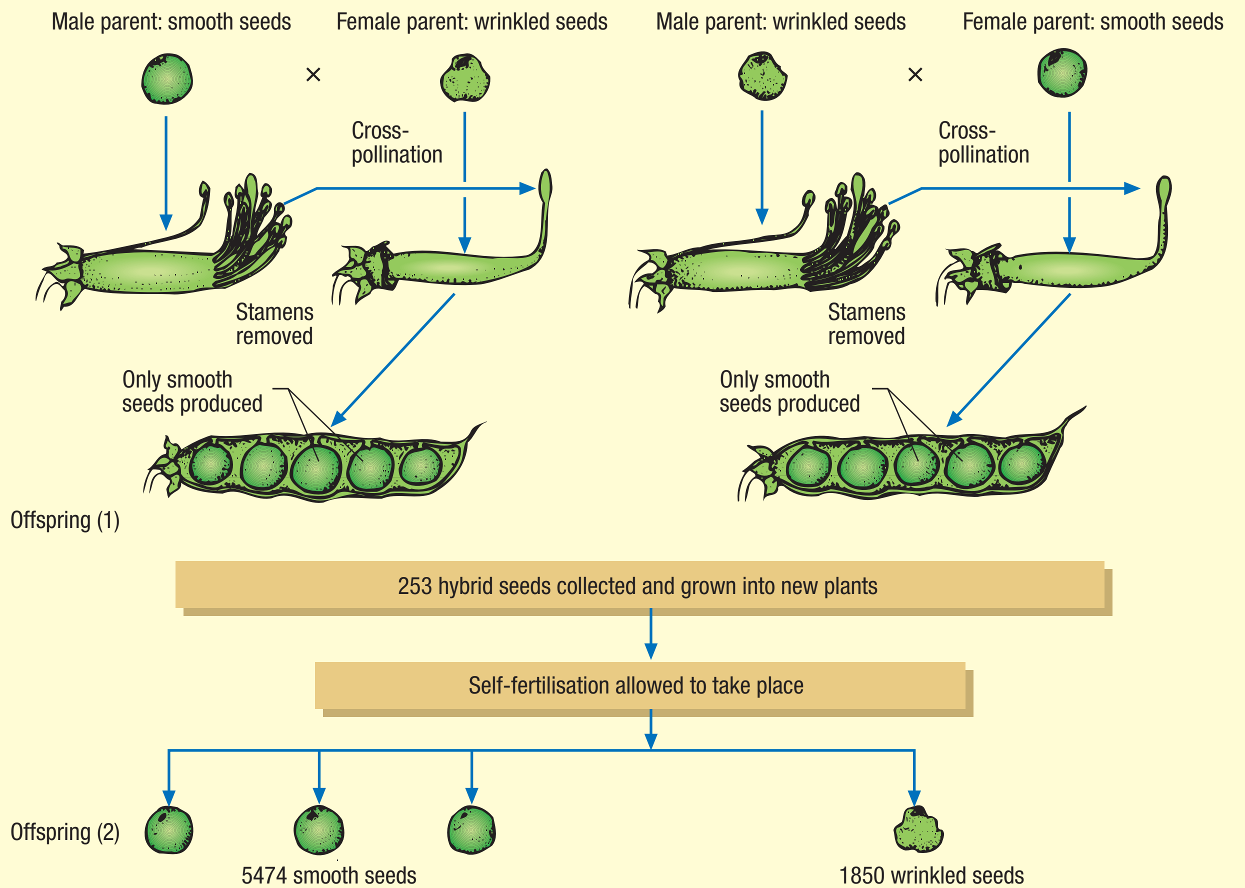


Figure 20.2 Summary of one of Mendel's experiments

the two alleles for seed shape in the pea are the smooth allele and the wrinkled allele. When the two alleles are present, one of them, the dominant, masks out the effects of its alternative recessive expression and all heterozygous individuals display only the dominant trait. Thus the **law of dominance** states that when homozygous parents with contrasting expressions of a given trait are crossed, only one expression, the dominant allele, will be seen in the offspring.

When the inheritance of one pair of contrasting alleles is studied, it is said to be a **monohybrid cross**. The dominant allele for any particular characteristic is always represented by a capital letter, and the recessive allele is represented by the same letter in the lower case. Thus a plant homozygous for smooth seeds would be represented as *SS* and a plant homozygous for wrinkled seeds (the alternative expression for seed shape) would be represented as *ss*. When the gametes are formed, only one of each possible allele will be present.

A plant homozygous for smooth seeds can produce only *S* gametes, whereas a plant homozygous for wrinkled seeds can produce only *s* gametes. Obviously a cross between such plants will result in all of the offspring being heterozygous *Ss*. If such a first-generation plant is allowed to self-pollinate, the cross will be between two heterozygotes or hybrids. When the gametes of such plants are formed there are two possible types for both the male and female gametes: a *S* gamete and a *s* gamete. This F_1 cross can be demonstrated with a Punnett square:

Possible **female** gametes

Possible **male** gametes		***S***	***s***	
	S	***SS***	***Ss***	Possible types of offspring
	s	***Ss***	***ss***	

It can be seen that three out of the four possible types of offspring will carry the dominant allele and thus display the dominant trait, and one out of the four possible offspring is homozygous for the recessive allele and shows the recessive trait. In terms of **genotype** (= alleles) the ratio of possible offspring is:

1 homozygous dominant : 2 heterozygous : 1 homozygous recessive.

In **phenotype** (= actual appearance) the ratio of possible offspring is:

3 dominant : 1 recessive

that is,

3 smooth seeds : 1 wrinkled seed.

This phenotypic ratio resulting from the cross between two heterozygotes for a single trait is called the **monohybrid ratio**. Note that in the Punnett square the term 'possible offspring' is used. Although there is an equal chance that half of the gametes produced from a heterozygote will be *S* and half will be *s*, the actual gametes which fuse in fertilisation are completely random. If only a small number of fertilisations, and thus offspring, are examined, it is possible that they could all be the same. It is only by looking at vast numbers of offspring from a particular cross that such a ratio holds true.

20.1.2 Dihybrid cross

In a second series of experiments, Mendel studied crosses between pea plants that differed simultaneously in two characteristics: for example, a pure-breeding plant that had seeds which were smooth and yellow (homozygous for both the smooth and the yellow trait) and a pure-breeding plant that had seeds which were wrinkled and green (homozygous for both the wrinkled and the green trait). The parent cross would be represented as:

SS YY × ***ss yy***

smooth and yellow   wrinkled and green.

Since both parents are homozygous for each characteristic, each can form only one type of gamete:

S Y gametes × ***s y*** gametes

and all of the offspring will be heterozygous for both traits:

Ss Yy

although they will show the dominant phenotype for both (i.e. smooth and yellow).

When Mendel allowed the F_1 generation to self-pollinate, he found that the F_2 generation displayed the following ratio of phenotypes:

9 smooth yellow : 3 smooth green : 3 wrinkled yellow : 1 wrinkled green

This ratio is known as the **dihybrid ratio**.

These results suggested that, in gamete formation, each of the types of alleles behaved as if they were completely independent of each other. Thus the allele for green seeds sorts independently of the allele for wrinkled seed. Mendel's **law of**

independent assortment states that each allele is an independent unit that is inherited on its own.

The dihybrid cross *Ss Yy* × *Ss Yy* can be illustrated in a **Punnett square**:

Possible types of female gametes (columns); possible types of male gamete (rows); possible offspring (cells)

	S Y	*S y*	*s Y*	*s y*
S Y	***SS YY*** smooth & yellow	***SS Yy*** smooth & yellow	***Ss YY*** smooth & yellow	***Ss Yy*** smooth & yellow
S y	***SS Yy*** smooth & yellow	***SS yy*** smooth & green	***Ss Yy*** smooth & yellow	***Ss yy*** smooth & green
s Y	***Ss YY*** smooth & yellow	***Ss Yy*** smooth & yellow	***ss YY*** wrinkled & yellow	***ss Yy*** wrinkled & yellow
s y	***Ss Yy*** smooth & yellow	***Ss yy*** smooth & green	***ss Yy*** wrinkled & yellow	***ss yy*** wrinkled & green

1 *SS YY* : 2 *SS Yy* : 2 *Ss YY* : 4 *Ss Yy* = 9 smooth and yellow

1 *SS yy* : 2 *Ss yy* = 3 smooth and green

1 *ss YY* : 2 *ss Yy* = 3 wrinkled and yellow

1 *ss yy* = 1 wrinkled and green

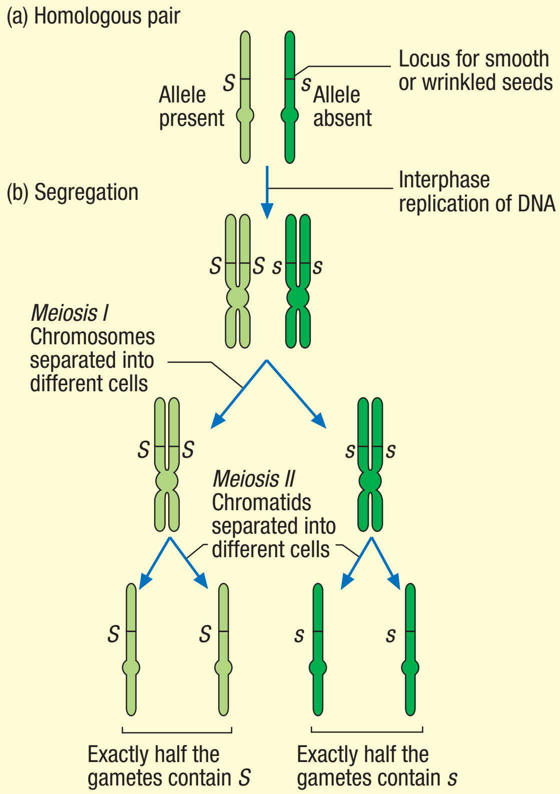


Figure 20.3 Chromosome explanation of segregation

20.1.3 Genes and chromosomes

Mendel knew nothing about chromosomes, genes or DNA, but modern evidence has shown that inherited traits are controlled by pieces of DNA called **genes**. The gene for a particular characteristic is always found in the same position on its DNA strand. This is called the **locus** (plural *loci*). Chromosomes are strands of DNA embedded in a protein matrix. Each strand of DNA, and thus each chromosome, will contain many genes. The chromosomes normally occur in homologous pairs, each member of the pair containing information about specific characteristics. The gene conveys information about a characteristic, such as seed colour. The exact specification of the characteristic or trait is termed the allele. The allele for seed colour could specify green or it could specify yellow.

During gamete formation the homologous pairs of chromosomes separate, with one member of the pair going to one cell and the other going to the second cell formed during meiosis I. If more than one gene is being examined and they are situated on different chromosomes, the way in which the alleles segregate will be completely random. Each pair of chromosomes acts independently.

The phenotype most commonly encountered for a characteristic is called the **wild type**. This may be either the dominant or recessive phenotype, depending on its significant adaptive advantage in any particular set of environmental conditions.

Many characteristics in humans are also governed by simple 'Mendelian' traits.

Table 20.1 Examples of possible Mendelian inheritance in humans

Dominant	Recessive
presence of dimples	absence of dimples
ability to roll tongue	inability to roll tongue
ability to fold tongue	inability to fold tongue
free earlobes	attached earlobes
long ears	short ears
wide ears	narrow ears
prominent convex nose	moderate straight nose
thick lips	thin lips
long eyelashes	short eyelashes
brown eyes	blue eyes
wide/large eyes	narrow/small eyes

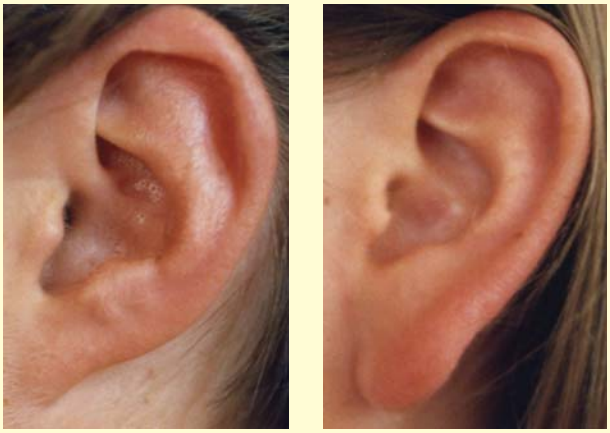


Figure 20.4 Attached and free earlobes: example of a possible dominant–recessive trait in humans

20.1.4 Laws of probability

Mendel's laws are based upon mathematical principles known as the laws of probability. One of these laws is the **product rule**, which states that:

The chance of two independent events occurring together is equal to the chance of one event occurring alone multiplied by the chance of the other event occurring alone.

Consider a disc that has two sides, one of which is black and one of which is white. The chance that the black side will land face up if the disc is tossed is equal to the chance that the white side will land face up. There are two possibilities and each has an equal chance of occurring: the chance of each is 1 in 2 or ½. If two such discs are tossed simultaneously, they represent two independent events occurring together. The outcome of one disc is not dependent upon the outcome of the other disc. Thus the chance of:

- both discs showing black is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$
- the first disc showing black and second showing white is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$
- the first disc showing white and second showing black is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$
- both discs showing white is $\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$

If the discs are thrown only a couple of times, these results will not necessarily occur. The more times they are thrown, the closer the results will be to the predicted outcome.

Predictions of a particular allele combination occurring in offspring can be made using this rule, provided it is assumed that gametes are fertilised at random. Thus the probability of a homozygous yellow-seeded plant being produced from two heterozygotes for this trait can be predicted:

½	×	½	=	¼
(chance of *Y* male gamete)		(chance of *Y* female gamete)		(chance of *YY* offspring)

The probability of occurrence of each of the possible types of offspring from this cross can be calculated from the equation $(\frac{1}{2}Y + \frac{1}{2}y) \times (\frac{1}{2}Y + \frac{1}{2}y)$:

$$(\tfrac{1}{2}Y + \tfrac{1}{2}y) \times (\tfrac{1}{2}Y + \tfrac{1}{2}y) = \tfrac{1}{4}YY + \tfrac{1}{4}Yy + \tfrac{1}{4}Yy + \tfrac{1}{4}yy$$

$$= \text{Genotypes} \quad \tfrac{1}{4}YY \; + \; \tfrac{1}{2}Yy \; + \; \tfrac{1}{4}yy$$

$$= \text{Phenotypes} \quad \tfrac{3}{4}\text{ yellow} : \tfrac{1}{4}\text{ green}$$

$$= \text{Ratio} \quad 3 \text{ yellow} : 1 \text{ green.}$$

The Punnett square calculation of possible outcomes is based on the product rule. The advantage of using the Punnett square method is that simple errors in mathematical calculations do not occur.

20.1.5 Test cross

It is clear which individuals are homozygous recessive. However, it is not possible to tell from appearances which individuals in the F_2 generation are homozygous dominant and which are heterozygous. In the monohybrid cross above, yellow-seeded plants may have the genotype *YY* or *Yy*. In a dihybrid cross the possible genotypes are even more numerous. For example, a smooth, yellow-seeded plant can have the following genotypes:

SS YY, *SS Yy*, *Ss YY*, or *Ss Yy*.

In such cases a **test cross** or back cross can be used to determine the genotype.

A test cross involves crossing organisms of unknown genotype, but dominant phenotype, with individuals which are homozygous recessive for the trait(s) under examination.

The homozygous recessive trait is used because this is the only situation in which the recessive trait will show in the phenotype of offspring.

Example 1

With a smooth-seeded plant, test crosses will yield the following results.

If the plant is *SS*: test cross *SS* × *ss*

	S
s	***Ss***

all offspring will produce smooth seeds.

If the plant is *Ss*: test cross *Ss* × *ss*

	S	***s***
s	***Ss***	***ss***

half the offspring will produce smooth seeds and half will produce wrinkled seeds.

Example 2

Using the example of smooth, yellow-seeded plants, test crosses will yield the following results.

If the plants are *SS YY*: test cross *SS YY* × *ss yy*

	S Y
sy	*Ss Yy*

all offspring will be smooth, yellow.

If the plants are *Ss YY*: test cross *Ss YY* × *ss yy*

	S Y	*s Y*
sy	*Ss Yy*	*ss Yy*

half the offspring will be smooth yellow and half offspring will be wrinkled yellow.

If the seeds are *SS Yy*: test cross *SS Yy* × *ss yy*

	S Y	*S y*
sy	*Ss Yy*	*Ss yy*

If the seeds are *Ss Yy*: test cross *Ss Yy* × *ss yy*

	S Y	*S y*	*s Y*	*s y*
sy	*Ss Yy*	*Ss yy*	*ss Yy*	*ss yy*

the offspring will be:
¼ smooth yellow : ¼ smooth green : ¼ wrinkled yellow : ¼ wrinkled green.

The types of offspring produced from such a test cross, therefore, can be used to determine the genotype of the unknown dominant phenotype.

SUMMARY

Mendelian genetics describes those patterns of inheritance of a characteristic which are controlled by a single gene displaying dominant and recessive traits. Each gene:

- is a segment of DNA
- specifies a characteristic (e.g. seed colour)
- has two or more alternative alleles (e.g. yellow seeds or green seeds).

The principle of segregation states that during gamete formation, each haploid gamete carries only one allele for a characteristic. In sexual reproduction, fertilisation restores the diploid condition so that each individual has two alleles for a particular characteristic.

In the homozygous condition both alleles are the same. In the heterozygous condition the alleles for the characteristic are different. A dominant allele masks the effects of a recessive allele in the heterozygote or hybrid (law of dominance).

The genotype specifies the actual alleles present for a particular characteristic. The trait for the characteristic that is displayed in the individual is the phenotype. A test cross (breeding with a recessive phenotype) can determine if a dominant phenotype is homozygous or heterozygous.

A monohybrid cross results from two individuals which are heterozygous for a single characteristic. Provided adequate offspring result, the phenotypic ratio of 3 dominant : 1 recessive is achieved. This is known as the monohybrid ratio. A dihybrid cross (a cross between two individuals which are heterozygous for both of two characteristics) results in the dihybrid ratio of 9 (both phenotypes dominant) : 3 (one phenotype dominant) : 3 (other phenotype dominant) : 1 (both phenotypes recessive). Each allele is an independent unit that is inherited on its own (law of independent assortment).

The probability, or chance, of the expression of a particular trait can be determined using the product rule or a Punnett square.

? Review questions

20.1 Define the following terms:

(a) allele
(b) gene
(c) genotype
(d) phenotype
(e) monohybrid cross
(f) dihybrid cross
(g) hybrid
(h) pure breeding
(i) heterozygous
(j) homozygous.

20.2 State Mendel's three laws. On what basis did Mendel form his three laws?

20.3 What factors contributed to the success of Mendel's experiments?

20.4 Explain Mendel's laws of segregation and independent assortment in terms of meiosis.

20.5 What is the product rule?

20.6 What is a Punnett square? Illustrate your answer by showing how you would determine the expected offspring of a cross between a heterozygous tall-stemmed pea plant and a dwarf-stemmed pea plant.

20.7 In pea plants, tallness is dominant to shortness and purple flower colour is dominant to white. If two heterozygous tall purple pea plants were crossed, what is the expected ratio of the offspring?

20.8 In guinea pigs, black (*B*) is dominant to white (*b*) and rough coat (*R*) is dominant to smooth coat (*r*). A black, rough-coated male guinea pig was crossed with a white, smooth-coated female. Several litters from the pair resulted in offspring ¼ of which had black smooth coats, ¼ white smooth, ¼ white rough and ¼ black rough. What are the probable genotypes of the parents?

20.9 A homozygous rough black guinea pig is mated with a smooth white one.

(a) What will the F_1 look like?

(b) What phenotypes would you expect in the F_2 and in what proportion?

(c) Predict the ratios of phenotypes in the offspring of the following crosses:

(i) *Rr Bb* x *rr bb*

(ii) *Rr bb* x *Rr Bb*

(iii) *Rr bb* x *rr BB*

20.10 Suppose you were given a pure-breeding female guinea pig with rough, black fur and a male with smooth, white fur.

(a) How could you produce a strain of pure-breeding smooth, white-furred guinea pigs?

(b) Could you produce a strain of pure-breeding rough, black-furred guinea pigs? Explain.

20.2 Inheritance not involving simple Mendelian genetics

Further studies have shown that not all traits are inherited as a straightforward dominant–recessive involving two alternative expressions of a gene. Few inherited characteristics are controlled by a single gene. Even when only one principal gene is involved, its expression may be influenced to some extent by countless other genes.

Human eye colour is generally regarded as controlled by one gene with two alleles: brown (*B*) which is dominant to blue (*b*). A heterozygote (*Bb*) will be brown-eyed. Blue-eyed people lack melanin pigment in the front layer of the iris. The blue colouration is an effect of the black pigment on the back of the iris as it is seen through the semi-opaque front layer. Brown-eyed people have branching pigment cells containing melanin in the front layer of the iris.

Eye colour, however, exhibits endless variations in hue. It appears that other genes, **modifier genes**, are involved. They may influence the amount of pigment in the iris, the tone of the pigment (which may be light yellow, dark brown etc.) or the distribution of the pigment (e.g. even, scattered or forming a definite pattern such as a ring around the outer iris).

The expression of a simple dominant–recessive gene may also be greatly influenced by the environment in which the organism is reared. Thus a genetically tall plant growing in a rocky, nutrient-depleted soil will not attain its genetic potential. Hydrangeas have flowers which can be blue, pink or white. Blue flowers develop if the plant is grown in an acid soil but white or pink flowers develop if the soil is alkaline.

In some cases, the pattern of inheritance involves mechanisms which do not follow a simple dominant–recessive pattern.

20.2.1 Codominance and intermediate dominance

In **codominance** each allele expresses itself equally in the phenotype. In shorthorn cattle a codominance between the alleles for red-coloured hair and white-coloured hair occurs. A heterozygote ($C^R\ C^W$) will exhibit a roan colour—some of the hairs being red and some white.

Sometimes heterozygous alleles result in a phenotype in between the two traits. Some flowers, such as the snapdragon, have an allele for red flowers (R_1) and an allele for white flowers (R_2). In the heterozygous condition ($R_1\ R_2$), the flowers are pink: that is, they are intermediate between red and white.

If two pink-flowered plants are crossed:

	R_1	R_2
R_1	$R_1 R_1$ red	$R_2 R_2$ pink
R_2	$R_1 R_2$ pink	$R_2 R_2$ white

the offspring will be:

¼ red ($R_1\ R_1$) : ½ pink ($R_1\ R_2$) : ¼ white ($R_2\ R_2$)

Although neither allele is dominant over the other, one of the alleles has a stronger influence than the other. The phenotype is an intermediate between that of complete dominance and co-dominance. This situation is termed **intermediate dominance**. Other terms used to describe this type of inheritance are **partial dominance** or **incomplete**

dominance. There are many blends of intermediate dominance, and thus a wide range of intermediate varieties between two extremes.

Figure 20.5 Intermediate dominance between red and white flowers

20.2.2 Multiple alleles

Many characteristics are governed by more than two alleles, in which case inheritance is said to be controlled by **multiple alleles**. Although more than two alleles may control the characteristic, however, there are only ever two present in an individual, one allele on each of the pair of homologous chromosomes.

Human ABO blood groups, for example, are governed by the three alleles I^A, I^B and i. Alleles I^A and I^B are both dominant to i but I^A and I^B are codominant. As a result there are four possible phenotypic expressions of human blood type:

Phenotype	Genotype
A	I^AI^A or I^Ai
B	I^BI^B or I^Bi
AB	I^AI^B
O	ii

In a situation where the parents are AO and BO respectively, there are four possible genotypes of the offspring:

	I^A	i
I^B	I^AI^B	I^Bi
i	I^Ai	ii

Thus there is an equal chance that the phenotypes of the offspring would be A, B, AB or O. Note that the offspring can exhibit blood types not shown by either parent (AB and O).

Blood may be donated from one person to another provided it is compatible. This depends upon the presence of certain antigens and antibodies. Blood cell antigens are specific proteins which are found on the surface of the red blood cells. There are two types of antigens, A and B. An individual may contain one or both of these depending upon the genotype. Thus a type A person

Table 20.2 Compatibility of human blood groups

Genotype	Antigens	Blood group	Antibodies	Can donate to:	Can receive from:
I^AI^A or I^Ai	A	**A**	anti-b	A and AB	O and A
I^BI^B or I^Bi	B	**B**	anti-a	B and AB	O and B
I^AI^B	A and B	**AB**	none	AB	O, A, AB, B
ii	none	**O**	anti-a and anti-b	O, A, AB, B	O

would have A antigens, a type B person would have B antigens and a type AB person would have both A and B antigens. Type O does not produce an antigen. Antibodies are proteins which are present in the plasma. A type A person has antibody b (anti-b); a type B person has antibody a (anti-a); and a type O person has antibodies a and b (anti-a and anti-b).

Should a type A person be given a transfusion of type B blood, the presence of the B antigen would act as a foreign body in the recipient and stimulate the further production of anti-b in the plasma. The antibody has a high affinity for its antigen and as a result an antigen–antibody reaction occurs which destroys the foreign red blood cells. This reaction is observed as clumping of the red blood cells together, a process known as **agglutination**.

Since type O can donate to all other blood groups it is known as the **universal donor**. Although type O blood contains both antibodies a and b, when transfused into a recipient they produce very little agglutination due to their dilution by the host's blood. Since type AB can receive from all blood groups, it is known as the **universal recipient**.

Other factors are also present in blood which will affect the compatibility of transfusions. The most important is the rhesus (Rh) factor. If present in the blood, the type is indicated as + (positive); - (negative) indicates its absence. Rh^+ is dominant to Rh^-. If Rh^+ blood is given to a Rh^- person, antibodies against the + factor can form and agglutination occurs. This can cause problems in pregnancy if the fetus has inherited the rhesus factor from the father and the mother is negative. If any fetal blood cells or fragments pass across the placenta into the maternal circulation, antibodies can be formed, and may pass back across the placenta into the fetal circulation. The fetus' blood would become foreign material to the antibodies and anaemia or death could result from agglutination. Rh incompatibility is rarely a problem in the first pregnancy but with each pregnancy the amount of anitbodies increases. A chemical has now been developed which prevents the mother's immune system from recognising the + factor in the fetus' blood. This chemical is administered shortly after she delivers an Rh^+ child and so prevents build-up of the antibodies.

Coat colour in rabbits is determined by the combination of two of four different alleles. These four alleles form a dominance series. Full coat (C^F) is dominant to chinchilla (C^{CH}), which is dominant to Himalayan (C^H), which in turn is dominant to albino (C^A). Thus an albino rabbit must be C^AC^A, whereas a full coat rabbit may be C^FC^F, C^FC^{CH}, C^FC^H or C^FC^A.

20.2.3 Continuous variation

When a population is observed, a gradation of expression for many characteristics can be seen. Many people are not either tall or short; many mice are not either fat or thin. There are many variations between the two extremes. These situations are explained by **multiple gene inheritance** (or **polygenes**), where two or more pairs of genes control a single trait. Each gene pair works according to the laws of dominance and segregation. The organism's phenotype depends on the combined effect.

The cob or ear length of corn is an example of **continuous variation**. It is believed that two pairs of genes are responsible, with the dominant allele of each contributing towards length and the recessive allele not adding any length. The shortest possible length would be represented by the double recessive condition (*aa bb*). Each dominant allele adds another length dimension so that the longest possible ear has the genotype *AA BB*. A cross between *AA BB* and *aa bb* parents results in F_1 offspring which are *Aa Bb* and intermediate in length. If these offspring are interbred, a broad range of genotypes and phenotypes result (see Punnett square below).

Aa Bb* × *Aa Bb

	A B	***A b***	***a B***	***a b***
AB	***AA BB*** longest	***AA Bb*** long	***Aa BB*** long	***Aa Bb*** medium
Ab	***AA Bb*** long	***AA bb*** medium	***Aa Bb*** medium	***Aa bb*** short
a B	***Aa BB*** long	***Aa Bb*** medium	***aa BB*** medium	***aa Bb*** short
a b	***Aa Bb*** medium	***Aa bb*** short	***aa Bb*** short	***aa bb*** shortest

Genotypic ratio:

$\frac{1}{16}$ *AA BB* : $\frac{1}{8}$ *AA Bb* : $\frac{1}{8}$ *Aa BB* : $\frac{1}{4}$ *Aa Bb* : $\frac{1}{16}$ *AA bb* : $\frac{1}{16}$ *aa BB* : $\frac{1}{8}$ *Aa bb* : $\frac{1}{8}$ *aa Bb* : $\frac{1}{16}$ *aa bb*.

Phenotypic ratio:

$\frac{1}{16}$ longest : $\frac{1}{4}$ long : $\frac{3}{8}$ medium : $\frac{1}{4}$ short : $\frac{1}{16}$ shortest.

This can be represented graphically, as shown in Figure 20.6.

Human height is believed to be controlled by four pairs of genes and skin colour by up to seven pairs. Figure 20.7 shows the variations that can occur if two pairs of genes determine human skin colour (i.e. production of the pigment melanin).

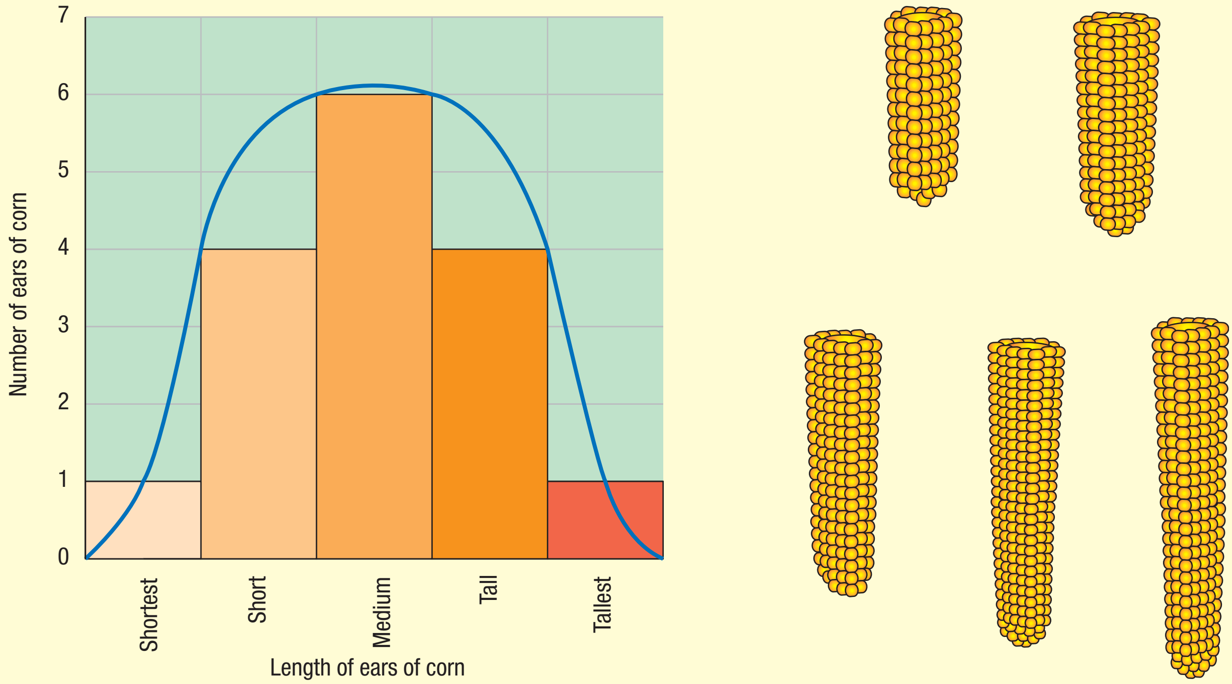


Figure 20.6 Distribution of cob lengths of corn (*Zea mays*)

Figure 20.7 Possible human skin colours produced if melanin production is controlled by two pairs of genes. The dominant allele of each gene contributes to melanin production, while the recessive allele does not.

COMPLEMENTARY GENES are genes that can only be expressed in the presence of the dominant allele of the other gene; therefore, both genes must have at least one dominant allele present in the genotype for the final end product to be expressed in the phenotype.

Flower colour in petunias: Colourless precursor substance is converted by the enzyme *C* into a colourless intermediate substance. A second enzyme, *P*, converts this colourless intermediate substance into a purple pigment.

	Gene *C* produces enzyme *C*		Gene *P* produces enzyme *P*
	Colourless precursor substance	**Colourless intermediate substance**	**Purple pigment (end product)**
	ccPP *ccPp* *ccpp*	*CCpp* *Ccpp*	*CCPP* *CcPP* *CCPp* *CcPp*
	Homozygous recessive form of gene *C* cannot produce enzyme *C* so the intermediate substance cannot be produced.	If one allele of gene *C* is the dominant form then the intermediate substance can be formed but if gene *P* is the homozygous recessive form then it cannot produce enzyme *P*, so the purple pigment cannot be produced.	If there is one dominant allele of both gene *C* and gene *P* then the end product of a purple pigment can be expressed.
	White flowers	White flowers	Purple flowers

Phenotypic ratio: 9 7

SUPPLEMENTARY GENES are genes that have an effect in determining whether another gene will be fully expressed.

Coat colour in labradors: Gene B controls the production of melanin—a black pigment in hair. Gene D controls the dispersion and deposition of this pigment into the hair.

No pigment produces	**Pigment produced but not deposited**	**Pigment produced and deposited**
bbDD *bbDd* *bbdd*	*BBdd* *Bbdd*	*BBDD* *BbDD* *BBDd* *BbDD*
Homozygous recessive form of gene *B* cannot produce melanin; therefore, the labrador is yellow in colour. This colour will range from almost white through yellow to a copper colour, due to the other genetic influences.	If one allele of gene *B* is the dominant form then the pigment can be produced but is not deposited in the hair if gene *D* is present as one dominant allele.	If there is one dominant allele of both gene *B* and gene *D* then the pigment can be produced and also deposited.
Yellow labrador	Brown labrador	Black labrador

Phenotypic ratio: 9 3 4

Figure 20.8 How genes interact

COLLABORATIVE GENES are genes that influence the same characteristic (trait) and produce an phenotype that would not be possible if either gene were to act independently.

Comb shape in domestic poultry: Gene *R* controls the production of the rose comb. Gene *P* controls the production of the pea comb.

Walnut comb

RRPP
RrPP
RRPp
RrPp

The presence of one dominant allele of both gene *R* and gene *P* causes a walnut comb.

Rose comb

RRpp
Rrpp

The presence of one dominant allele of gene *R* and the homozygous recessive form of gene *P* causes a rose comb.

Pea comb

rrPP
rrPp

The presence of one dominant allele of gene *P* and the homozygous recessive form of gene *R* causes a rose comb.

Single comb

rrpp

The presence of the homozygous recessive form of both gene *R* and gene *P* causes a single comb.

Phenotypic ratio: 9 3 3 1

DUPLICATE GENES are genes that have a copy of the gene at a different locus and both influence the same characteristic (trait). The presence of one dominant allele of either gene will produce a chicken with feathers on its legs. They both produce the same phenotype but the ratios are greatly changed.

Leg feathers in chickens: Both genes F and G (the duplicate gene at a different locus) control the production of feathers on the legs of chicken.

Feathers present on legs

The presence of either gene *F* or *G* in the dominant allele form will cause the presence of feathers on the legs of chickens.

FFGG
FFGg
FFgg
ffGG
FfGG
FfGg
Ffgg
ffGg

Legs featherless

For the chicken to have featherless legs the homozygous recessive genotype for both gene *F* and gene *G* must be present.

ffgg

Phenotypic ratio: 15 1

INHIBITOR GENES are genes in which one totally inhibits (stops) the expression of another gene.

The colour of squash: Gene *Y* controls the production of the green-coloured pigment to a yellow-coloured pigment. Gene A stops the production of the green pigment.

White skin colour

AAYY
AAYy
AaYY
AaYY
AaYy
AAyy
Aayy

The dominant form of gene A prevents the production of the green-coloured pigment so all the squash with at least one A allele will have white skins.

White-coloured squash (A---)

Yellow skin colour

aaYY
aaYy

The dominant form of gene Y causes green pigment to be converted to the yellow pigment but this must be coupled with the homozygous recessive genotype of gene A.

Yellow-coloured squash (aaY-)

Green skin colour

aayy

If both genes A and Y are present in the homozygous recessive form, then the squash skin will be green.

Green-coloured squash (aayy)

Phenotypic ratio: 12 3 3

Case study 20.1: Gene interactions

Sometimes two or more different genes interact in determining the phenotypic expression of a characteristic. These are termed **gene complexes**.

In fruit flies, two different genes interact in developing eye colour: *Bw* (producing red pigments) and *St* (producing brown pigments). The wild-type fruit fly has red-brown eyes and at least one dominant allele for each gene (*BwBw StSt, Bwbw StSt, BwBw Stst* or *Bwbw Stst*). A brown-eyed fruit fly cannot produce red pigment and has the genotype *bwbw StSt* or *bwbw Stst*. A red-eyed fruit fly is homozygous recessive *st* and either homozygous or heterozygous for *Bw*. An albino fruit fly is homozygous recessive for both genes: it cannot produce either red or brown eye pigments.

Figure 20.8 shows a number of examples of how genes interact.

In other situations, **epistasis** (= *standing upon*), the phenotypic expression of one gene is masked by another gene.

Epistasis is significant in coding for enzymes in biochemical pathways. The condition **phenylketonuria** (**PKU**) results from a recessive allele preventing the formation of the enzyme that normally brings about the breakdown of phenylalanine to tyrosine in humans. Even though enzymes for subsequent reactions in the metabolic pathway are present, they cannot exert their effect; they are masked, since tyrosine is not formed. As a result phenylalanine is converted to phenylpyruvic acid, which causes severe mental retardation. The phenylpyruvic acid is ultimately excreted in the urine, so tests can easily be done to detect PKU. Treatment involves a special diet from infancy to diminish the formation of phenylalanine.

SUMMARY

Not all characteristics are controlled by a single gene or by a simple dominant–recessive relationship. Modifier genes and interactions between different genes may determine the expression of a particular characteristic.

Some alleles display codominance, where each allele is expressed equally in heterozygotes. Intermediate dominance may occur, in which case one of the alleles exerts a stronger influence, resulting in a 'blend' of the expression of two alleles in the heterozygote.

Some genes have more than two alleles. In multiple-allele situations, however, each individual inherits only two alleles. The number of traits possible in this form of inheritance is greater than in the normal two-allele form. Human ABO blood groups are an example.

Multiple-gene inheritance refers to the determination of a characteristic by more than one gene. This leads to a variety of phenotypes for this characteristic (e.g. human height).

Review questions

20.11 Define the following terms:
(a) continuous variation
(b) partial dominance
(c) codominance
(d) modifier gene
(e) multiple alleles
(f) universal donor
(g) universal recipient.

20.12 In snapdragons, tallness (*T*) is dominant to dwarfness (*t*) and red flower colour (R^1) shows intermediate dominance to white flowers (R^2). The hybrid condition results in tall plants with pink flowers.

A dwarf red snapdragon is crossed with a plant pure-breeding for tallness and white flowers.
(a) Determine the expected proportions of genotypes and phenotypes in the offspring.
(b) What are the probable genotypes of the parents?

20.13 When red shorthorn cattle are mated with white shorthorns, all of the offspring are roan (a combination of red and white). When two red cattle are mated they produce only red offspring. When two white cattle are mated they produce only white offspring. When two roans are mated, half of the offspring are roan, a quarter are red and a quarter white.
(a) Explain this phenomenon.
(b) Of 300 calves from matings between roan cattle, how many would be roan?
(c) What genotypes must the parents of a red calf have?

20.14 If the litter resulting from the mating of two short-tailed cats contains three kittens without tails, two with long tails and six with short tails, what would be the simplest way of explaining the inheritance of tail lengths in these cats? Show genotypes.

20.15 If a man with blood type B, one of whose parents had blood type O, marries a woman with blood type AB, what will be the theoretical percentage of their children with blood type B?

> ? **20.16** Both Mrs Middleduck and Mrs Spiros had babies the same day in the same hospital. Mrs Middleduck took home a baby girl, whom she named Jemima. Mrs Spiros took home a baby girl, whom she named Letitia. Mrs Spiros began to suspect, however, that her child had been accidentally switched with the Middleduck baby in the nursery. Blood tests were made, and Mr Middleduck was found to be type A, Mrs Middleduck type B, Mr Spiros type A, Mrs Spiros type A, Jemima type O and Letitia type B.
>
> Has a mishap occurred? Explain your answer.

20.3 Sex determination

Studies of the inheritance of eye colour in the fruit fly, *Drosophila melanogaster*, by American geneticist TH Morgan in 1910 led to the discovery of chromosomes specifically involved in determination of the sex of the individual. Female flies were discovered to have four pairs of homologous chromosomes but the males had three homologous pairs plus one pair of two different chromosomes. One of these chromosomes is similar to the fourth pair of the female and is called the X chromosome. The other chromosome, which has a different shape, is called the Y chromosome. In the fruit fly the fourth pair of chromosomes are the sex chromosomes. The female has two X chromosomes and the male has one X and one Y chromosome. The other chromosomes are called the autosomes. Thus both the male and female fruit fly have three pairs of autosomes and one pair of sex chromosomes. All of the gametes of the female must have an X chromosome. Although they differ, the sex chromosomes of the male act as a homologous pair during meiosis. Thus half the male gametes will contain an X chromosome and half will contain a Y chromosome.

Such a pattern of sex determination is evident in many species, including humans, who have twenty-two pairs of autosomes and one pair of sex chromosomes. Unlike fruit flies, where the number of X chromosomes determines the sex, in humans a Y chromosome must be present in the zygote for an offspring to develop into a male. In the absence of

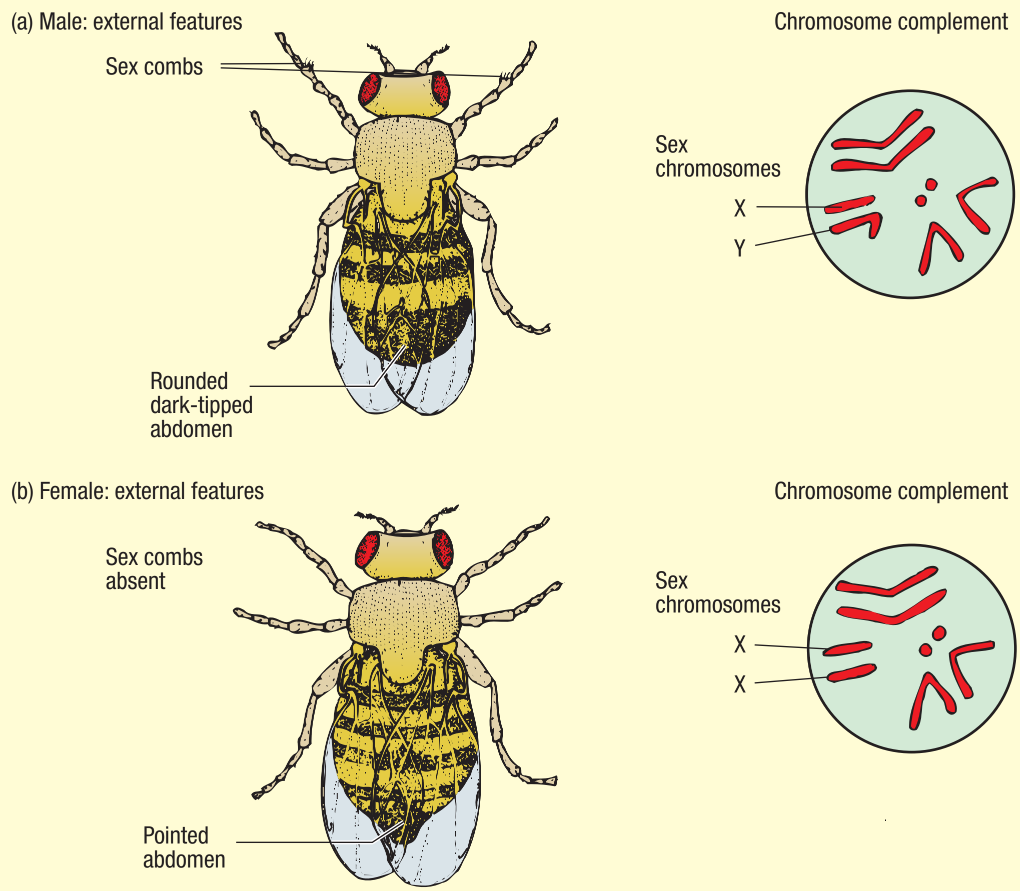


Figure 20.9 Male and female *Drosophila melanogaster*

the Y chromosome, an offspring develops into a female. Thus the Y chromosome carries genes which switch on male determination.

The pattern is, however, different in some organisms. In grasshoppers, for example, there is no Y chromosome. Females have two X chromosomes and males have only one X chromosome. In birds, most reptiles, some fish and all butterflies the male is XX and the female is XY.

20.3.1 Sex-linked inheritance

Genes which are found on the X chromosome are termed **sex-linked genes**. An equivalent allele is not carried on the Y chromosome.

The normal eye colour in fruit flies is red and is dominant to white eye. If a white-eyed individual is crossed with a pure-breeding red-eyed fly, all the offspring are red-eyed. When a male and female from this cross are mated, only males exhibit the white eye trait. If this gene was autosomal, an equal number of males and females would be white-eyed.

In male offspring, the X chromosome must come from the mother and the Y chromosome must come from the father. Since there can be no mediating allele from the father, a male inheriting a recessive allele from the mother must exhibit the recessive trait. A heterozygous female for a sex-linked recessive gene is called a **carrier**.

In humans red–green colour blindness and haemophilia are two examples of inherited, recessive sex-linked diseases. **Colour blindness** in humans is caused by a defect in the pigments in the retina of the eye that are sensitive to red and green light. These two colours, therefore, cannot be distinguished.

Haemophilia is a group of disorders in which the blood does not clot normally. Blood clotting (as discussed in Chapter 18) involves a series of chemical reactions in which each reaction depends upon a specific protein factor in the blood. The most common form of haemophilia results from the absence of one of these proteins. The gene for this protein is carried on the X chromosome. Haemophiliacs may bleed to death with even minor injuries. It is unlikely that a haemophiliac female would have children since the onset of menstruation at puberty is often fatal. A hysterectomy—the surgical removal

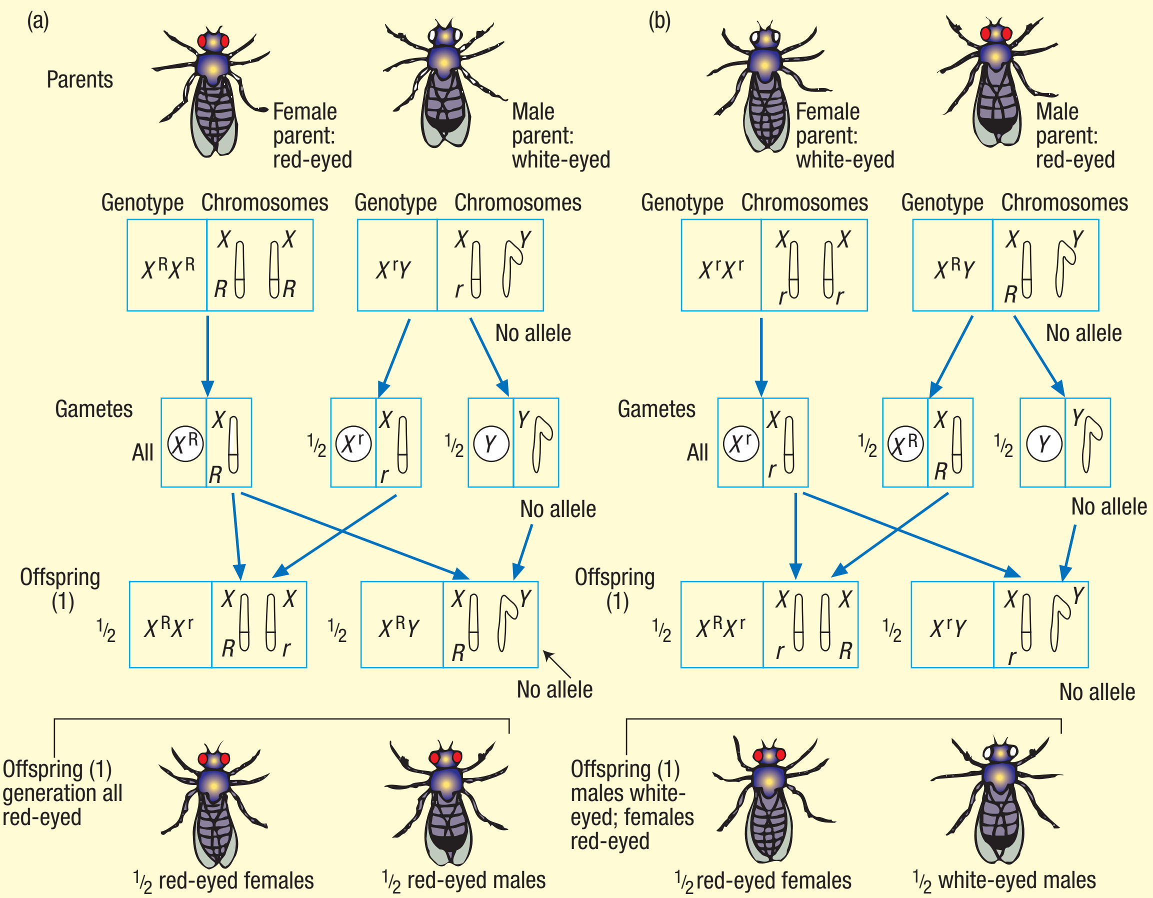


Figure 20.10 Sex-linked genes in *Drosophila*

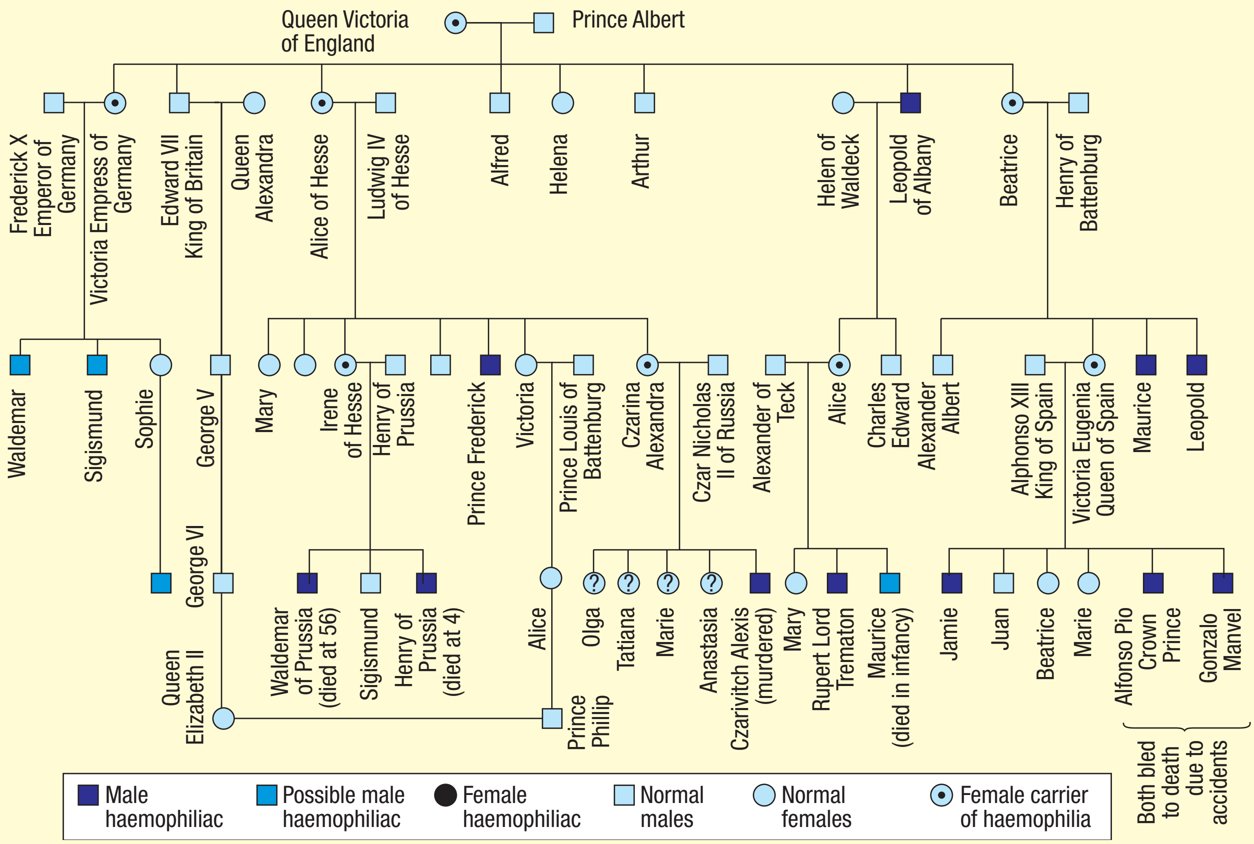


Figure 20.11 Queen Victoria's lineage

of the uterus—is commonly performed on prepubertal girls displaying haemophilia. The disease, therefore, is rare. Extraction of the missing protein factor from donor blood can be administered to haemophiliacs, permitting them to lead near-normal lives. This treatment does not prevent the haemophilia allele passing on to the offspring.

A classical example of haemophilia is that of the British royal family. Neither Queen Victoria nor Prince Albert had the disease but their descendants did, indicating that Queen Victoria was a carrier. Since none of Queen Victoria's predecessors were known to exhibit the disease, it has been hypothesised that this recessive allele arose in her by mutation of the dominant form. The prevalence of the disease among members of European royal families is related to the high incidence of close intermarriages. In the general population, the choice of marriage partners is not so restricted and thus the incidence of haemophilia is much lower.

Family trees or pedigrees are often used to determine whether an allele is dominant or recessive, or whether it is autosomal or sex-linked. In such a family tree, the female is always represented as a circle and the male as a square. The expression of the trait is indicated by shading. If only males exhibit the trait, this strongly suggests that it is sex-linked. If a son displays the trait but not the mother, it is recessive. If both males and females show the trait in approximately equal ratios, it is most likely to be an autosomal gene.

In the family pedigree shown in Figure 20.12, on page 566, both males and females show night blindness. Further, female 1, who is night blind, has sons who have normal vision. Therefore night blindness is inherited autosomally. Since offspring 18, from a cross between two individuals with night blindness, is normal, the allele for night blindness is dominant. The possible genotypes can then be determined:

1. *Nn*	8. *nn*	15. *Nn* or *NN*
2. *nn*	9. *nn*	16. *Nn* or *NN*
3. *nn*	10. *Nn*	17. *Nn* or *NN*
4. *nn*	11. *nn*	18. *nn*
5. *Nn*	12. *nn*	19. *Nn*
6. *Nn*	13. *nn*	
7. *nn*	14. *nn*	

Although females carry two alleles for sex-linked genes, it has been found that in most interphase

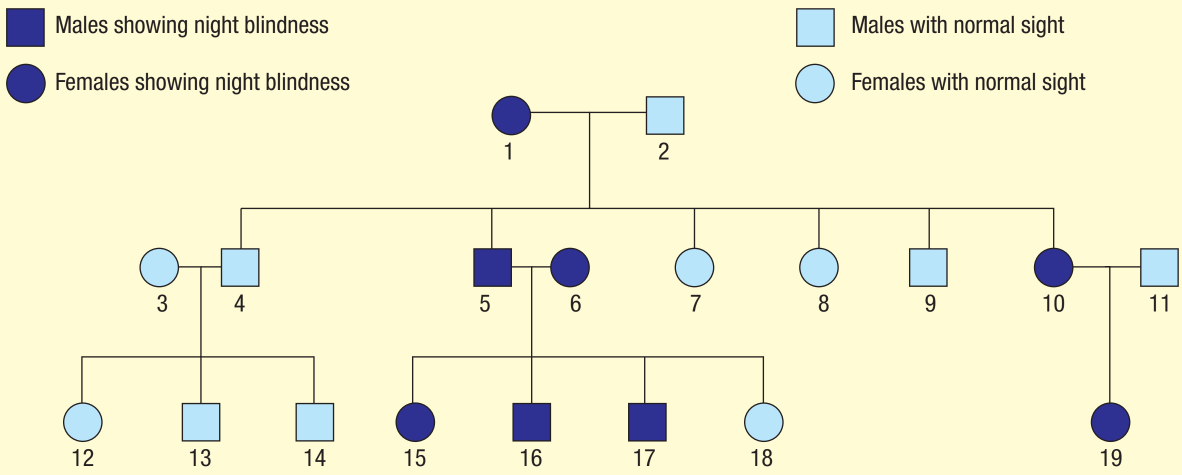


Figure 20.12 Family pedigree showing the inheritance of night blindness

somatic cells one of the X chromosomes condenses out into a tiny dark object called a **Barr body**. The presence or absence of these Barr bodies is used in true or genetic sex determination of, for example, international athletes. The genes on this condensed X chromosome are inactivated so that in a normally functioning female cell there is only one dose of each sex-linked gene. Barr body formation is therefore a process of **X inactivation**.

Since the condensation is purely random, in the total body approximately half of the cells will contain one X chromosome and half will contain the other. Females, therefore, can be considered to be genetic mosaics for sex-linked genes. It appears that for the majority of characteristics, as long as half of the cells are normal in a heterozygous female, she will show the normal phenotype. Thus a woman heterozygous for colour blindness will show normal vision.

One characteristic which does not follow this rule is that of coat colour in cats. The colours orange and black in cats are sex-linked and codominant. An orange female mated with a black male will produce male offspring that are all orange, and female offspring will all be tortoiseshell—a mixture of black and orange fur colour. Those female hair follicle cells with an active black X chromosome will produce black hairs, and those with an active orange X chromosome will produce orange hairs. The mixture of black and orange hairs creates the tortoiseshell condition. Thus tortoiseshell can be found only in females. If a tortoiseshell female is mated with a black male, the progeny will be black or tortoiseshell females and orange or black males.

	X^O	X^B	
X^B	$X^O X^B$ *tortoise-shell*	$X^B X^B$ *black*	Female offspring
Y	$X^O Y$ *orange*	$X^B Y$ *black*	Male offspring

20.3.2 Holandric genes

Holandric genes are those carried on the Y chromosome, although there appear to be very few of them. Such genes include the male sex determiners in humans. Phenotypic traits controlled by these genes are found only in males. Although it is not fully proven, it appears that the occurrence of human hairy pinnae, a tuft of hair sprouting from the ear rim, is probably due to a holandric gene. This condition is common in isolated parts of India.

20.3.3 Sex-limited and sex-influenced traits

Many traits associated with the sex of the individual are autosomal. Examples include the development of the sex organs such as the penis and vagina, distribution of body hair, size of the breasts and pitch of the voice. The sex of the individual, through hormonal action, determines whether or not the particular autosomal gene will be inhibited or activated. High levels of testosterone production in males results in the development of the male sex organs and secondary male characteristics; these are absent in females, whose testosterone production is low. These traits are said to be **sex-limited** since their phenotypic expression differs in the two sexes.

Pattern baldness is an autosomal allele which is also influenced by the sex of the individual. The presence of Y chromosome genes may cause this condition to be expressed, whereas absence of the Y chromosome inhibits its expression. Pattern baldness is a **sex-influenced** trait. It is a recessive trait in females but dominant in males. (See Figure 20.13.)

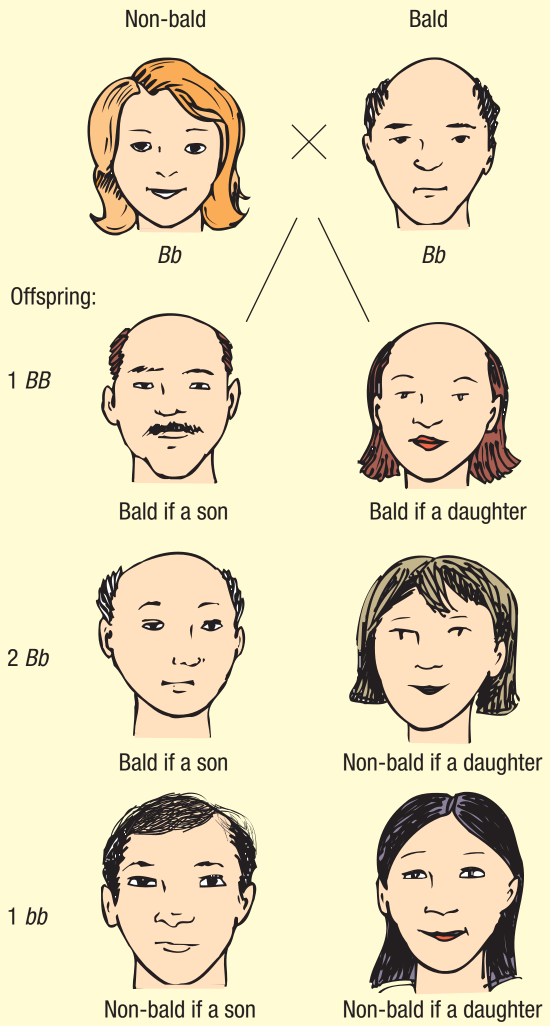


Figure 20.13 Inheritance of pattern baldness in humans

SUMMARY

The sex of an individual is determined by specific sex chromosomes. All other chromosomes are termed autosomes. In the human, and in some other species, the female has two X chromosomes and the male has an X and a Y chromosome.

Genes carried on the X chromosome are termed sex-linked. A recessive allele in an XY individual must be expressed in the phenotype since the Y chromosome does not carry a corresponding allele.

Pedigree studies are useful in determining whether a particular allele is sex-linked or autosomal.

In each cell of the female, one of the X chromosomes is inactivated and forms a Barr body. As long as half the body cells in the human have the active X chromosome carrying the 'normal' allele for most sex-linked characteristics, that trait will be expressed. In other situations the allele carried in each cell will be expressed (e.g. tortoiseshell coat colour in cats).

Alleles carried on the Y chromosome are termed holandric. In humans, it carries male-determining genes and may also carry the gene for hairy pinnae.

The expression of some autosomal genes is affected by the sex of the individual. Sex-limited genes will be either inhibited or stimulated by the presence of male or female hormones (e.g. secondary sex characteristics). Sex-influenced traits (e.g. pattern baldness) will be expressed as dominant or recessive, depending on the sex of the individual.

? Review questions

20.17 Define the following terms:

(a) Barr body
(b) carrier
(c) holandric
(d) sex-influenced
(e) sex-limited
(f) sex-linked
(g) X-inactivation.

20.18 Red–green colour blindness is inherited as a sex-linked recessive trait. A couple was surprised to learn that one of their sons was colour blind since neither of the parents showed this trait.

(a) Explain how this could have occurred.
(b) From which of the boy's grandparents could this allele have come, if none of them showed the trait?

20.19 A blue-eyed man, both of whose parents were brown-eyed, marries a brown-eyed woman whose father was blue-eyed and mother was brown-eyed. The man and woman have a blue-eyed son.

Draw up a family tree for this family, marking in the genotypes and phenotypes for all individuals.

20.20 A tortoiseshell cat (genotype $X^O X^B$) is mated with an orange cat ($X^O Y$). What genotypes and phenotypes would you expect among the offspring?

20.21 Suppose that, in the cat crosses described in question 20.20, the female had long hair and the male had short hair. The gene for hair length is autosomal and shows intermediate dominance (*L S* giving medium-length hair). How many different phenotypes would you expect, and in what proportion?

20.22 Haemophilia is a sex-linked recessive gene in humans. If a father and son are both haemophiliacs, but the mother is normal, what is the genotype of the mother?

20.23 In the above family, would you expect any of the daughters to be haemophiliac?

20.24 Humans vary in their ability to taste the chemical PTC. In the pedigree shown in Figure 20.14, shaded individuals lack the ability to 'taste'. (Squares = males.)

(a) Is 'tasting' a dominant or recessive characteristic? Why?

(b) Is it sex-linked? Why?

(c) Fill in the genotypes as far as possible.

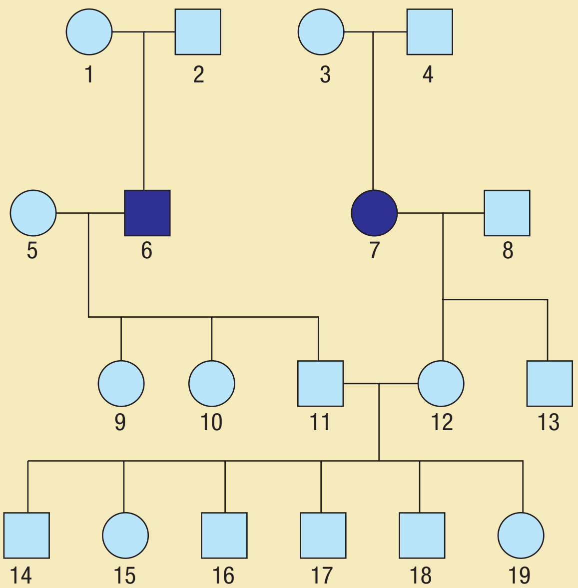


Figure 20.14

20.4 Linked genes

20.4.1 Gene linkage

The total number of genes in a cell is far greater than the number of chromosomes. Each chromosome, therefore, contains many genes, each of which determines a particular characteristic. Genes found on the same chromosome are said to be linked and the phenomenon is known as **gene linkage**.

Mendel found that in a dihybrid cross between, for example, smooth, yellow-seeded plants heterozygous for both traits, their offspring showed a 9:3:3:1 phenotypic ratio. The alleles for each trait assorted independently. Had these genes been on the same chromosome, the results would have been different. When genes are linked, this is represented by a line.

Thus

$$\frac{S\,Y}{s\,y}$$

indicates that the *S* and *Y* alleles are on the same chromosome and *s* and *y* alleles are on the homologous chromosome.

Thus from the following cross:

$$\frac{S\,Y}{S\,Y} \times \frac{s\,y}{s\,y}$$

all of the offspring are:

$$\frac{S\,Y}{s\,y}$$

S and *Y* are both inherited on the same chromosome from one parent and *s* and *y* are both inherited on the same chromosome from the other parent.

Should $\frac{S\,Y}{s\,y}$ individuals be allowed to self-pollinate, the variety of types of gametes is reduced.

The dihybrid ratio does not hold true. The probable ratio of offspring is 3 smooth yellow-seeded to 1 wrinkled green. There is no independent assortment of the alleles. Thus gene linkage reduces the chances for genetic recombination and variety among offspring. Since Mendel's experiment exhibited the dihybrid ratio, these alleles must have been on different chromosomes in order to achieve independent assortment.

20.4.2 Crossing-over

Crossing-over is an exchange of segments of chromosome between homologous chromatids during meiosis I. It may occur at one or more places along the chromosome.

During prophase I the homologous chromosomes pair and the four chromatids lie side by side. They are positioned so that the alleles of one chromosome are beside alleles for the same trait on the other chromosome. Adjacent segments of chromatids from the homologous chromosomes break off and rejoin with the partner chromatid. By the end of metaphase I this process is completed so that segments of one chromatid from each of the homologous chromosomes may have interchanged.

Separation of the homologous chromosomes in meiosis I and subsequent separation of the chromatids in meiosis II may result in four possible allele arrangements in the gametes—two similar to each of the original chromosomes, and two which will be different combinations of the two original chromosomes.

Crossing-over has survival value for the individual since some of the gametes have combinations of linked genes that are different from the parental combination. These gametes are called **recombination gametes**. Offspring can be produced with genotypes different from those of the parents.

In sweet peas, for example, the allele for purple flower is dominant over red flower, and the allele for long pollen is dominant over round pollen. The genes for flower colour and pollen shape are linked on the same chromosome. If a sweet pea pure-breeding for purple flowers and long pollen is crossed with one with red flowers and round pollen, all of the offspring will have purple flowers and long pollen. Each plant can produce only one type of gamete: $\underline{P\ L}$ (i.e. both found on the same chromosome) and $\underline{p\ l}$ respectively. Thus on fertilisation all of the offspring have the genotype $\frac{P\ L}{p\ l}$ and the phenotype purple flowers with long pollen.

$$\frac{P\ L}{P\ L} \times \frac{p\ l}{p\ l}$$

$$\frac{P\ L}{p\ l}$$

where $\underline{P\ L}$ or $\underline{p\ l}$ represents the alleles found on one chromosome.

If these offspring are interbred, then the situation changes if crossing-over occurs between the locations of these alleles:

$$\frac{P\ L}{p\ l} \times \frac{P\ L}{p\ l}$$

	$\underline{P\ L}$	$\underline{p\ l}$	$\underline{P\ l}$	$\underline{p\ L}$
$\underline{P\ L}$	$\frac{P\ L}{P\ L}$	$\frac{P\ L}{p\ l}$	$\frac{P\ L}{P\ l}$	$\frac{P\ L}{p\ L}$
$\underline{p\ l}$	$\frac{P\ L}{p\ l}$	$\frac{p\ l}{p\ l}$	$\frac{P\ l}{p\ l}$	$\frac{p\ l}{p\ L}$
$\underline{P\ l}$	$\frac{P\ L}{P\ l}$	$\frac{P\ l}{p\ l}$	$\frac{P\ l}{P\ l}$	$\frac{P\ l}{p\ L}$
$\underline{p\ L}$	$\frac{P\ L}{p\ L}$	$\frac{p\ L}{p\ l}$	$\frac{P\ l}{p\ L}$	$\frac{p\ L}{p\ L}$

In this case, the $\underline{P\ l}$ and $\underline{p\ L}$ gametes are recombinant gametes resulting from the crossing-over of the chromatids during meiosis I.

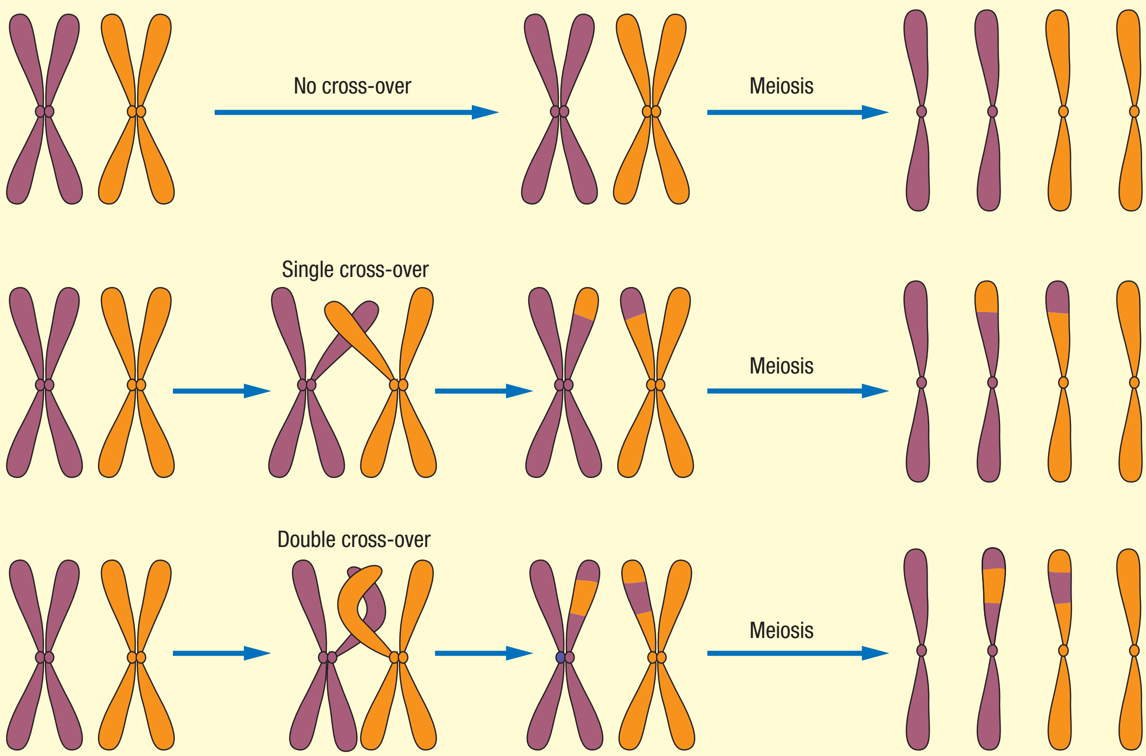


Figure 20.15 The differences in genetic make-up of gametes produced with non-cross-over, a single cross-over and two cross-overs

Offspring genotypes:

$1\ \frac{P\,L}{P\,L} : 2\ \frac{P\,L}{p\,l} : 2\ \frac{P\,L}{P\,l} : 2\ \frac{P\,L}{p\,L} : 2\ \frac{P\,l}{p\,l} : 1\ \frac{P\,l}{P\,l}$

$2\ \frac{P\,l}{p\,L} : 2\ \frac{p\,L}{p\,l} : 1\ \frac{p\,L}{p\,L} : 1\ \frac{p\,l}{p\,l}$.

Offspring phenotypes: 9 purple, long : 3 purple, round : 3 red, long : 1 red, round.

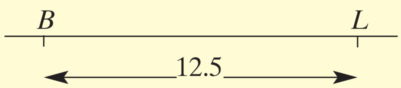
This situation assumes that there is an equal chance that a recombinant gamete will be produced as an 'original'. In reality this is not the case. The closer two gene loci are on the chromosome, the less likely it will be that crossing-over occurs between them.

This can be likened to tearing a strip of paper. If two points are widely separated on the paper, it is easy to make a tear between the points. As the points are made closer and closer, the harder it becomes to tear between them. Thus there is a greater probability of recombination occurring if the genes are situated a wide distance apart. Even if the gene loci are at opposite ends of chromosome, the greatest proportion of recombinant gametes is 50 per cent. This is because only one chromatid of each homologous chromosome takes part in the crossing-over. The other chromatid remains as an 'original'.

20.4.3 Chromosome mapping

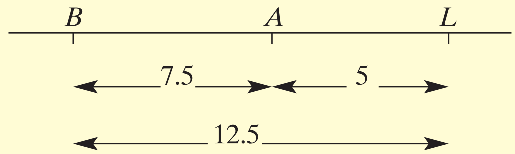
If we assume that there is an equal probability that a breakage will occur at any point along the chromatid, then the further apart two linked genes are, the more frequently will breakage occur between them; this is because there are more points between them at which a breakage can occur. Thus the frequency of crossing-over between linked genes will be directly proportional to the distance between them. The percentage of crossing-over can therefore be used to determine the relative distances between gene loci. **Chromosome maps** of the gene loci on the chromosomes can be determined from this information.

By convention, one unit of map distance on a chromosome is the distance within which crossing-over occurs 1 per cent of the time. If, for example, two out of sixteen offspring are recombinant products of crossing-over of *B* and *L* alleles, this represents 12.5 per cent; *B* and *L* are therefore 12.5 map units apart. This could be represented as:

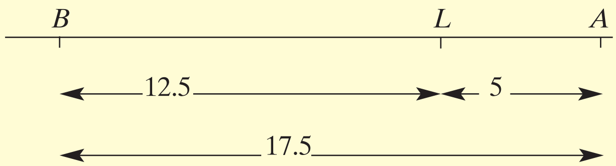


Suppose another allele, *A*, is linked to the same chromosome and is found, from analysis of recombinant offspring, to cross over with *L* 5 per cent of the time. It is not possible to determine from this information exactly where *A* would be on the chromosome. It could lie either 5 units to the left of *L* on the above map or 5 units to the right. The locus can be determined only by observing the frequency of recombinants between *A* and *B*.

If the frequency is 7.5 per cent, then *A* must lie between *B* and *L*:



If the frequency was 17.5 per cent, then the map would be:



When the gene loci are known, it is possible to determine the proportions of offspring with specific phenotypes from a specific cross.

In *Drosophila*, for example, the allele for vermilion eye (*r*) is 10 units away from the allele for cut wings (*c*). What proportion of the offspring will display vermilion eye and normal wings from the following cross?

$$\frac{R\,C}{r\,c} \times \frac{r\,c}{r\,c}$$

From the data, crossing-over occurs between the two types of alleles 10 per cent of the time. Thus the types and frequencies of the gametes are:

Parent 1: 45 <u>*R C*</u> : 45 <u>*r c*</u> : 5 <u>*R c*</u> : 5 <u>*r C*</u>

Parent 2: all <u>*r c*</u>

	45 *R C*	**45 *r c***	**5 *R c***	**5 *r C***
1 *r c*	**45** $\frac{R\,C}{r\,c}$	**45** $\frac{r\,c}{r\,c}$	**5** $\frac{R\,c}{r\,c}$	**5** $\frac{r\,C}{r\,c}$

Thus 5 per cent of the offspring will have vermilion eyes and normal wings.

SUMMARY

Many genes are carried on the same chromosome and must be inherited together. The *law of independent assortment* does not hold in these cases. Crossing-over involves exchange of segments of adjacent chromatids of a tetrad during meiosis. This results in recombinant gametes and thus increased genetic variability.

The closer two genes are located on a chromosome, the less probable it is that crossing-over will occur between them. Studies of the proportion of recombinations of linked genes have allowed geneticists to map their loci (locations) on the chromosome.

? Review questions

20.25 Define and exemplify the following terms:
- (a) chromosome map
- (b) crossing over
- (c) gene linkage
- (d) recombination gametes.

20.26 If the proportion of recombinations among the offspring of a cross involving two gene pairs was always 0, what can you conclude about their relative positions on the chromosomes?

20.27 Why is the proportion of recombinants never more than about 50 per cent?

20.5 Human genetic diseases

Humans inherit traits in similar ways to other organisms, and in some cases alleles cause specific conditions which constitute a **genetic disease**. One of the alleles for a specific characteristic may be harmful or even lethal. A **lethal gene** causes death at some stage of the development of the individual if it is expressed. Usually harmful and lethal alleles are recessive. Some genetic diseases are caused by the presence of certain alleles, while others result from abnormal mechanisms in the inheritance of chromosomes, such as the nondisjunction that produces Down syndrome.

20.5.1 Examples of human genetic diseases

Sickle-cell anaemia is a recessive gene which, in the homozygous condition, causes red blood cells to take on an abnormal sickle shape. This condition was discussed in Case study 12.2. The allele for sickle-cell anaemia remains prevalent in some areas of the world, such as Africa and southern Italy. In these areas it has been found that carriers (heterozygotes) are resistant to malaria which attacks the homozygous normal individuals. Thus there is genetic advantage in maintenance of the allele in the population in malaria-infested localities.

Galactosemia is a disease resulting from the absence of the enzyme which converts galactose, a constituent of milk sugar, to glucose. It is caused by a recessive allele. The build-up of galactose brings about another reaction, one of the products of which causes damage to the nervous system. This damage can cause early death. The condition can be detected and the disease prevented if the individual maintains a galactose-free diet from an early age.

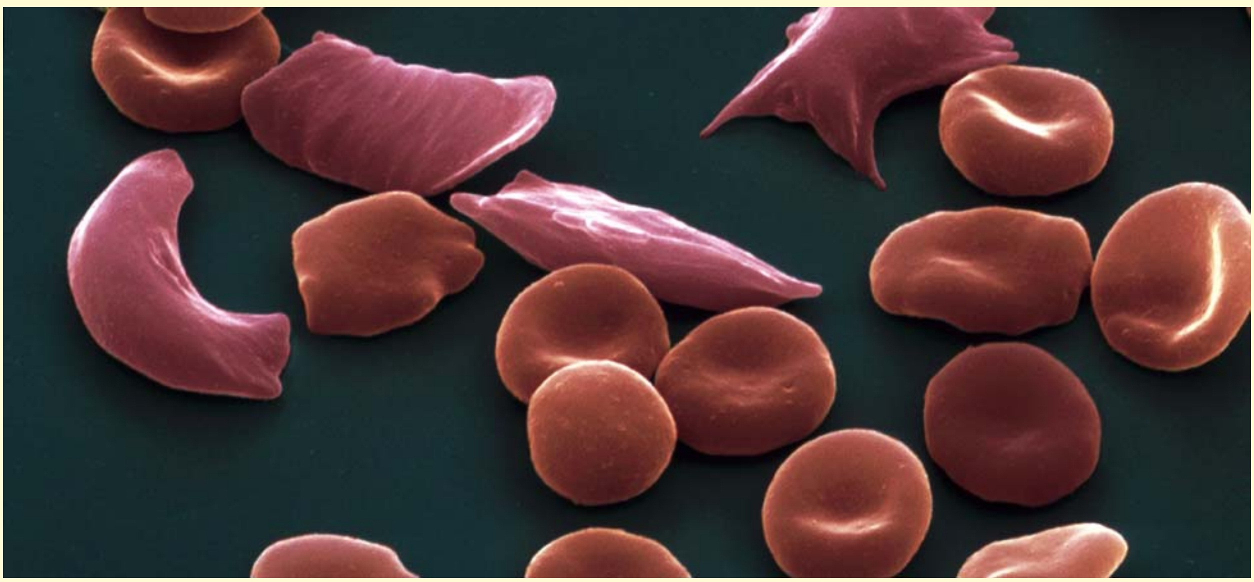


Figure 20.16 Normal red blood cells (rounded) contrast with red blood cells distorted by sickle-cell anaemia (pink)

Tay-Sachs disease is caused by another recessive allele. An individual displaying this disease does not have the enzyme which breaks down a specific fat. Accumulation of this fat affects the nervous system and, with time, the individual loses the ability to move. Death usually occurs by the age of two or three.

Each biochemical pathway involves many enzymes. The absence of any one of these enzymes disrupts the pathway and, as seen in the two previous examples, may lead to disease. Different effects may result from lack of specific enzymes within a single biochemical pathway. The pathway for the breakdown of phenylalanine, for example, may result in PKU (Case study 20.1). If another enzyme is missing, the urine becomes jet black in a condition known as **alkaptonuria**. The absence of yet another enzyme blocks the synthesis of the brown pigment melanin and the individual displays **albinism—**there is no pigmentation in skin, hair and eyes.

Diabetes mellitus has been dubbed the geneticist's nightmare. People affected by this condition are unable to produce and/or secrete enough insulin, and thus cannot convert excess blood sugar to glycogen, a form in which it can be stored. The disease is believed to be caused by several recessive genes, in which factors such as age, weight, sex and diet of the individual can determine the onset of the disease. Constant monitoring of the blood sugar (via a blood or urine test) and injection of an appropriate amount of insulin can control this disease.

Fragile X syndrome results from repeated duplication of three nucleotides of one gene (called FMR-1) on the X chromosome. The way in which this comes about is explained in Section 21.4. Since it is a sex-linked disease, males are more likely than females to show the disease. During stages of cell division this section of the chromosome appears as though it is hanging from a thread, and thus the name *fragile*.

The number of times this trinucleotide duplicates determines the extent to which the syndrome is exhibited in the individual. Up to forty repeats does not appear to have any effect but if a person has more than 200 duplications of this segment, the gene completely switches off and does not attempt to make the coded protein. This results in severe mental retardation. The exact function of the protein coded by the FMR-1 gene is not known at present but it is thought that it is associated with communication between nerve cells in the brain.

Symptoms of this disease are varying degrees of mental retardation, learning difficulties, behavioural and emotional problems and physical features. In children they may include:

- delayed development (e.g. sitting, walking, speaking)
- frequent temper tantrums
- difficulties in paying attention
- hand flapping and biting associated with high levels of anxiety
- physical signs such as a long narrow face, large ears, a high arched palate, flat feet and extremely flexible joints
- seizure.

20.5.2 Genetic screening and counselling

Knowledge of the pattern of inheritance of certain diseases has increased dramatically in recent years. Some of these conditions, however, cannot be predicted from family histories with any certainty. Although the risk of having a Down syndrome child increases with the age of the mother, this is not the only determinant. Thus an accurate estimate of a woman's chances of producing such a child is not possible.

Other diseases can, however, be more precisely predicted. Genetic counselling has been developed to assist people with a known family history of a particular genetic disease. Research is carried out on the family history of the disease, and the couple can be advised on the likelihood of their children inheriting it. The advice, however, can only be based on probability. There may be a one-in-fifty chance of inheritance of the trait. If the couple decide to have children, all, some or none may actually have the disease.

Gene tracking is a method of determining the position of particular genes on the chromosome. Since it is not possible to make selected crosses with humans to determine chromosome maps for defective alleles, researchers attempt to find another gene which is linked with it on the same chromosome. The linked gene is called a **genetic marker**. An easily distinguished feature, such as blood group, is correlated with the incidence of the disease allele to establish linkage. Gene tracking can be used to predict the likelihood of a couple producing a child with the particular disease. This is particularly important for predicting diseases, such as Huntington chorea, which do not show up in the individual until they are in their 40s or 50s.

As described in Chapter 19, modern techniques such as amniocentesis, fetoscopy and chorionic villus sampling allow the early detection of genetic diseases. Usually, however, it is not possible to cure them. Some conditions can be corrected by fetal blood transfusions using endoscopy before birth. Normally, however, early detection gives the parents the option to terminate the pregnancy, or alerts medical practitioners to the problem so that appropriate treatment can be given after the child is born.

SUMMARY

Many diseases are inherited. They may result from chromosomal abnormalities (e.g. Down syndrome) or from particular alleles. Lethal alleles are mutations which cause the death of the individual at some time after fertilisation and are usually recessive. Other alleles that are expressed cause malfunction, often by exclusion of an enzyme in a metabolic pathway.

Knowledge of patterns of inheritance in certain diseases has enabled genetic counselling of the probability of a couple having a defective child. Techniques have been developed which can detect genetic anomalies in the fetus.

Review questions

20.28 There are a number of inherited human abnormalities which are recessive. During this century, marriages between closely related people have become progressively less common.

(a) What factors could have contributed to this?

(b) What effect might this change have on the incidence of recessive abnormalities?

20.29 Why is diabetes mellitus considered a geneticist's nightmare?

20.30 (a) Differentiate between autosomal and sex-linked diseases.

(b) Explain how the sex of a baby can influence whether or not it will exhibit each type of disease.

(c) Name one sex-linked and one autosomal human genetic disease.

20.31 Describe how gene tracking is achieved in humans. Suggest an easier method in fruit flies. Explain why this method is not possible in humans.

EXTENDING YOUR IDEAS

1. UB Suppose recombinations between alleles *A* and *B* in a pair of homologous chromosomes occurs in 20 per cent of the gametes in an individual heterozygous for *Aa*, *Bb* and *Cc*, and that it occurs between *A* and *C* in 8 per cent of the gametes. How often would you expect recombination between *B* and *C*?

2. UB In peas, tall plants (*T*) are dominant to dwarf (*t*), yellow colour (*Y*) is dominant to green (*y*) and smooth seed (*S*) is dominant to wrinkled seed (*s*). What would be the phenotypes of the offspring of the following matings?

   (a) *Tt Yy Ss* x *tt yy ss*

   (b) *Tt yy Ss* x *tt Yy Ss*

3. UB In tomatoes, red fruit colour is dominant to yellow; round-shaped fruit is dominant to pear-shaped; and tall plant is dominant to dwarf plant.

   (a) What is the appearance in the F_1 of a cross between true-breeding tall plants bearing red, round fruit and a dwarf plant bearing yellow, pear-shaped fruit?

   (b) Assuming that the genes controlling the three characteristics are inherited independently, what are the possible phenotypes in the F_2 generation? What are their expected ratios?

4. UB Work has been done on the waxy and non-waxy characters of maize seeds. The blue-black staining reaction with iodine is given by the starch amylose. Seeds of different kinds have been analysed for their amylose content, with the following results. (Note that the endosperm of the seed develops from a triploid nucleus and so has three genes for each characteristic, not two.)

Genotype of endosperm	Amylose content (%)
Wx Wx Wx	22.0
Wx Wx wx	20.4
Wx wx wx	18.4
wx wx wx	0.0

   (a) Attempt to account for these results. If one simply looks at the seeds, non-waxy is clearly dominant to waxy. Does it appear to be dominant on chemical analysis?

   (b) In the light of your present understanding of gene action, how would you account for this inheritance?

5. The frequencies per thousand births of some genetic UB diseases, in populations of northern European origin, are shown in the table below.

(a) What is the probable frequency of an individual of northern European origin simultaneously having:

(i) Huntington chorea and albinism

(ii) achrondroplasia, sickle-cell anaemia and cystic fibrosis?

(b) Although the alleles for some disease conditions are autosomal dominant, the frequency of the disease in the population is less than that for some recessively inherited diseases. Suggest possible reasons for this. Use examples from the table below to explain your answer.

(c) An individual has inherited both myotonic and muscular dystrophy. From your knowledge of human physiology, explain the effects of these diseases. How could this impact on the person's quality of life? What is the likelihood of the individual surviving?

(d) Explain why frequencies of sex-linked diseases were recorded for males only.

6. In some breeds of dogs, a dominant allele controls the char- UB acteristic of barking while trailing. In these dogs, another independent allele produces erect ears; it is dominant over the allele for drooping ears. Suppose a dog breeder wants to produce a pure-breeding strain of droop-eared barkers, but he knows that the genes for silent trailing and erect ears are present in his kennels. How would he proceed?

7. The long hair of Persian cats is recessive to the short hair of UB Siamese cats, but the black coat colour of Persians is dominant to the black-and-tan coat of Siamese. If a pure black, long-haired Persian is mated to a pure black and tan, short-haired Siamese, what will be the appearance of the F_1? What is the probability of getting a long-haired black-and-tan cat if two of the F_1 mate?

8. In domestic fowls the gene for rose comb (*R*) and pea- UB shaped cone (*P*) together produce the so-called 'walnut' comb shape (genotypes *RR PP, Rr PP, RR Pp or Rr Pp*). These are shown in Figure 20.17.

The recessive alleles *r* and *p* produce normal single comb shape (genotype *rr pp*). What phenotypes would you expect from the following crosses, and in what proportions?

Inheritance pattern	Frequency (per 1000 births)	Pathology
Autosomal dominant		
Huntington chorea	0.1	Progressive dementia from mid-life
Achrondroplasia	0.04	Dwarfism
Myotonic dystrophy	0. 05	Progressive muscular weakness
Neurofibromatosis	0.25	Tumours of peripheral and other nerves
Autosomal recessive		
Phenylketonuria	0.1	Mental retardation
Cystic fibrosis	0.4	Mucoid build-up; lung congestion
Beta-thalassaemia	0–10	Severe anaemia
Sickle-cell anaemia	0–10	Haemolytic anaemia
Albinism	0.1	Lack pigment; abnormal vision
Sex-linked	**Frequency (per 1000 males)**	
Red–green colour blindness	80	Inability to distinguish red and green colours
Haemophilia	0.2	Defect in blood clotting
Muscular dystrophy	0.3	Progressive muscular weakness
Fragile X syndrome	0.9	Mental retardation
Testicular feminisation	0.02	Sterile XY females; unresponsive to male sex hormones

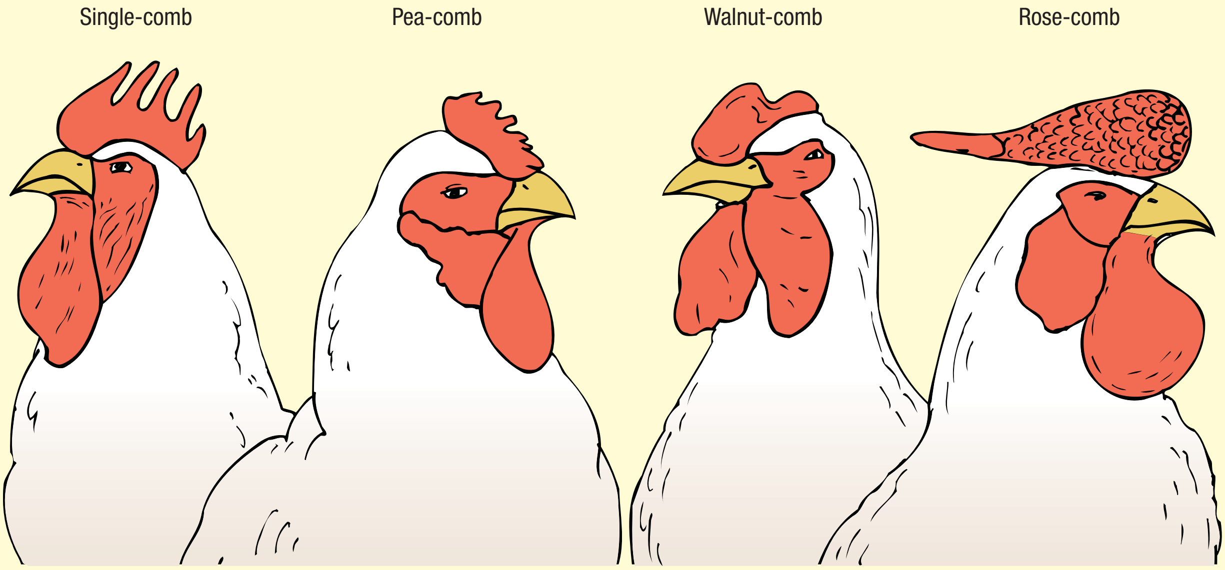


Figure 20.17 Comb shape in domestic fowl

(a) *RR Pp* x *rr Pp*

(b) *rr PP* x *Rr Pp*

(c) *Rr Pp* x *Rr pp*

9. A wild-type (i.e. showing dominant trait) female *Drosophila* heterozygous for the three sex-linked recessive alleles scute (*sc*), crossveinless (*cv*) and vermilion (*v*) which affect bristles, wing and eye colour respectively, is mated to a scute crossveinless male. What will be the phenotypes and genotypes of the progeny?

UB

10. What types and frequencies of male progeny are expected from the following crosses in *Drosophila?*

UB

y = yellow; *sn* = singed; ℓz = lozenge (recessives);
$^+$ indicates wild (normal) type

$$\frac{y\ sn\ \ell z}{-} \times \frac{y^+\ sn^+\ \ell z}{y\ sn\ \ell z}$$

11. Bar eye gene in *Drosophila* causes a drastic reduction in eye size. A male with narrow bar eyes crossed with a female with normal eyes produced progeny in which all females had wide bar eyes and all males had normal eyes. Does this cross demonstrate that the bar gene is located on the X chromosome? Explain your answer.

UB

12. Genes A and B are 10 crossover units apart. What genotypes, and in what proportions, are expected from the cross?

UB

$$\frac{A\ B}{a\ b}\ \text{female} \times \frac{A\ B}{a\ b}\ \text{male}$$

13. Haemophilia and colour blindness are both sex-linked recessive genes in humans. The linkage of these two genes is 12 per cent. The *Xg* blood group is also sex linked. It has a linkage of 46 per cent with the haemophiliac gene and a linkage of 34 per cent with the colour blindness gene.

UB

Draw the chromosome map of these three genes.

21 GENE ACTION

Research in genetics has revealed that:

- genes are carried on chromosomes
- genes come in alternative forms (alleles)
- alleles occupy corresponding positions (loci) on homologous chromosomes
- chromosomes and their alleles are reassorted at meiosis.

It has also been discovered that:

- segments of chromosomes are exchanged during meiosis
- analysis of recombinant gametes allows construction of chromosome maps
- mutations, or changes in genes, are inherited in the normal fashion.

The outward manifestations gave no significant clue as to the real nature of the gene and how it influenced the phenotype of the individual. However, chemical analysis of the chromosomes of higher organisms showed that they consist of protein and DNA, either of which could carry the genetic code.

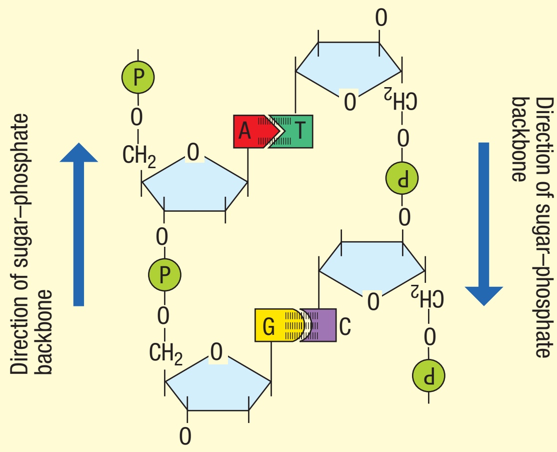


Figure 21.1 Base-pairing in nucleic acids

21.1 CHEMICAL STRUCTURE OF THE GENE

It was originally thought that genes were composed of protein, with the twenty amino acids forming a 'genetic alphabet' spelling out the language of life. Further studies were carried out using bacteria and viruses, which do not have protein in their chromosomes, and it became evident that DNA was the chemical which transmitted information from parent to offspring.

In 1953 two British researchers, Watson and Crick, were eventually able to formulate a working model of the DNA molecule after studying a vast array of known data on the chemical constituents.

They discovered that DNA is a complex molecule consisting of three units:

- a five-sugar (deoxyribose)
- phosphate groups
- bases containing nitrogen.

The three parts combine to form subunits called nucleotides, each nucleotide being named according to the base it contains. Many nucleotides are joined together to form the DNA molecule. They contain four different bases: adenine, guanine, thymine and cytosine. Each base has a specific shape as a result of its chemical structure, and this determines the bonds it forms. One side of a base bonds with a sugar molecule and the other side joins, via hydrogen bonding, to another base with a complementary shape. Thus two complementary base pairs can be formed: adenine–thymine and guanine–cytosine.

The DNA model proposed by Watson and Crick is built like a ladder, consisting of two chains of nucleotides joined together. The uprights are composed of the sugar and phosphate parts of the nucleotides and the rungs are the nitrogen bases. The entire structure is twisted around a common central axis, forming a double helix.

In a non-dividing cell, DNA is spread out in the form of chromatin, which is a DNA–histone complex with the appearance of strung 'beads'. (Histone is a protein.) Each 'bead' is composed of eight histone molecules around which the DNA helix is wrapped one-and-three-quarter times. Lengths of DNA separate the 'beads'. The DNA–histone 'bead' is called a **nucleosome**.

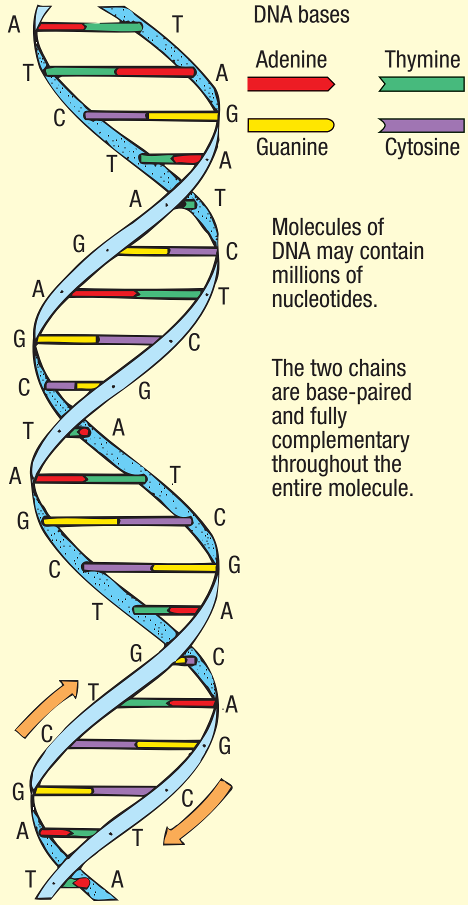


Figure 21.2 The DNA molecule

The nucleosomes coil up to shorten the chromatin complex. Just before cell division, the coiling becomes tighter to form chromosomes.

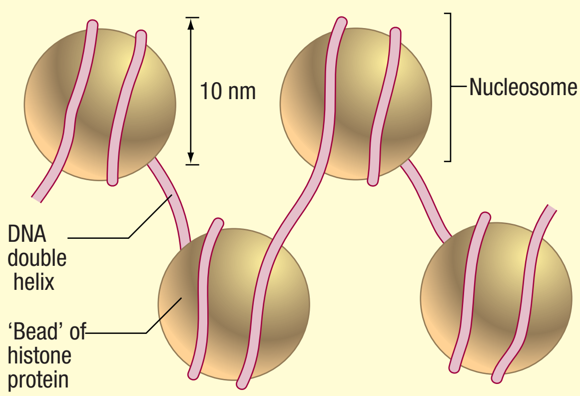


Figure 21.3 Model of the DNA–histone complex

SUMMARY

Chromosomes are composed of DNA and protein in eukaryotic organisms. Protein is not present in the chromosomes of bacteria and viruses. Genes are segments of DNA. According to the Watson and Crick model, the DNA molecule is a double helix composed of two chains of nucleotides, cross-linked by hydrogen bonds between complementary bases. Two pairs of bases occur: adenine–thymine and cytosine–guanine. The sequence of nucleotides along the length of each strand of DNA differs from chromosome to chromosome and species to species.

In non-dividing cells the DNA is spread out in the form of chromatin. Eight histone protein molecules are surrounded by coiled DNA at intervals along the DNA molecule. Each protein–DNA 'bead' is termed a nucleosome. Chromatin condenses to form chromosomes prior to division by the coiling action of the nucleosomes.

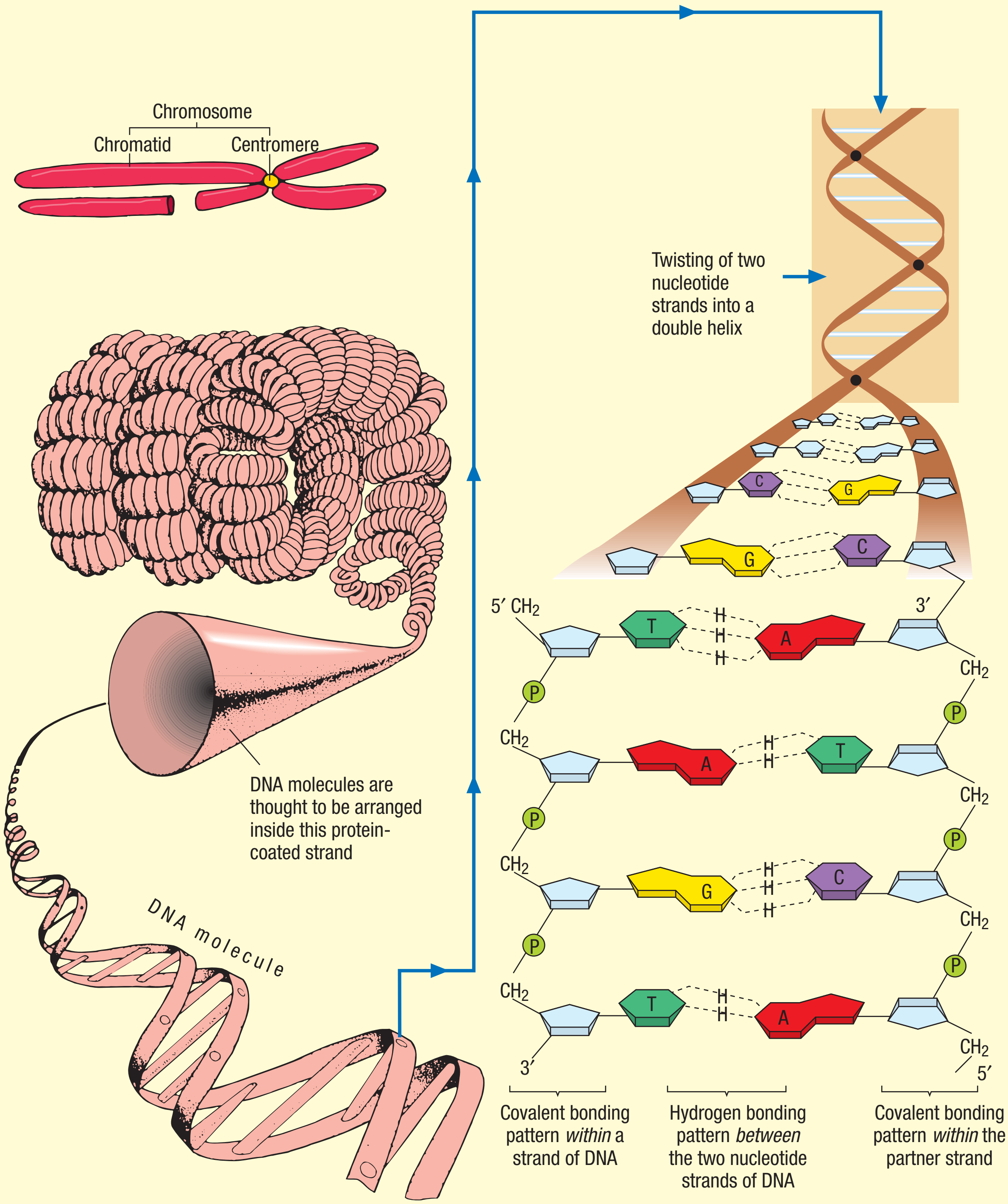


Figure 21.4 Coiling of the DNA helix

> **Review questions**
>
> **21.1** What is a model?
>
> **21.2** What facts did Watson and Crick hope to explain by constructing a model of DNA? Did they succeed?

21.2 Replication of DNA

During DNA replication, it is proposed that the helix unwinds from its twisted position and the weak hydrogen bonds between the base pairs break under enzyme influence. The molecule 'unzips'. As the separation occurs, the bases of the nucleotides become exposed to the contents of the nucleus which contains many already formed nucleotides. The free nucleotides align with the complementary bases on the exposed chains of the DNA molecule and hydrogen bonds are formed between the bases. With the input of energy (ATP), an enzyme, DNA polymerase, forms phosphate bonds between the sugars of each nucleotide to complete the new chains. The result is two DNA molecules exactly like the original.

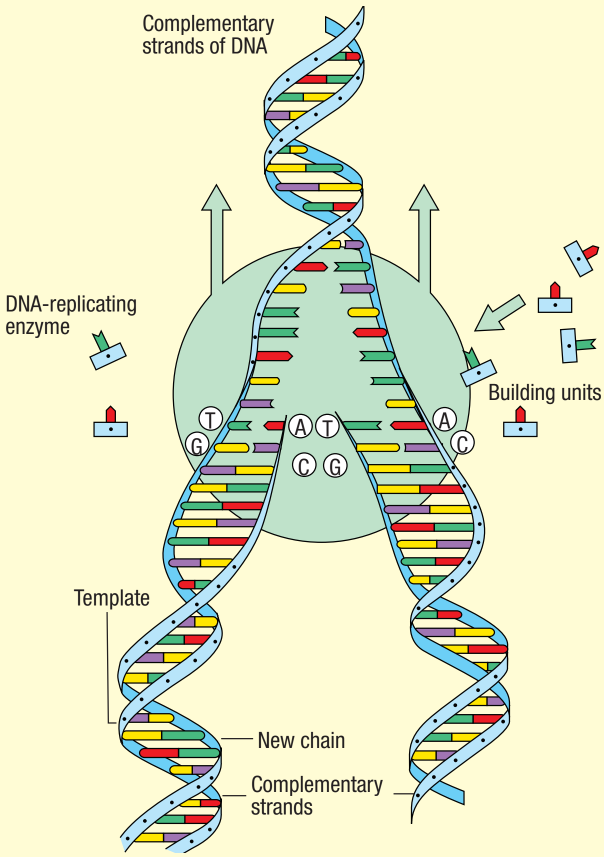


Figure 21.5 Replication of DNA

During cell division the chromosomes replicate, resulting in cells and new organisms which have the proper genetic instructions. This is essentially a replication of DNA. The number of DNA molecules per chromosome is variable, but regardless of the number, each DNA molecule must be replicated.

It would take a considerable time for each DNA chain to be replicated linearly and it is believed that replication occurs simultaneously at many points along the chain. This action is coordinated by special control proteins, many of which are enzymes.

The hydrogen bonds between the nitrogen bases are of necessity weak to allow 'unzipping' and thus DNA replication. They are, however, very susceptible to heat. This makes living cells vulnerable to temperature changes, since an increase could cause automatic separation of the DNA strands. It has been found that special proteins (**heat shock proteins**) move into the nucleus if the cell becomes overheated. Researchers believe that they bind with the DNA and prevent separation of the strands of the helix.

SUMMARY

During replication of chromosomes, the DNA helix unwinds and the weak hydrogen bonds between complementary bases break. Free nucleotides in the nucleoplasm align with exposed complementary bases of the two existing chains. Bonds form between the nucleotides and the bases to form two new strands, each attached to an original. It appears that replication, coordinated by special proteins, occurs simultaneously along the DNA chain.

The hydrogen bonds between the bases are susceptible to heat. Unzipping of the DNA helix at inappropriate times is prevented by heat shock proteins.

> **Review questions**
>
> **21.3** (a) Sketch a segment of a molecule of DNA which is six base pairs long.
> (b) Show how this segment of a DNA molecule probably replicates.
> (c) What happens to DNA during interphase?
> (d) Why is this process necessary?
> (e) What would happen during mitosis if this process did not occur?

21.3 The role of DNA: protein synthesis

DNA contains information for protein synthesis. Proteins include structural components of the cell, hormones, antibodies and enzymes. All of these are significant in maintaining homeostasis. Different proteins differ in the combinations of the twenty types of amino acids and the ways in which these long chains are coiled or folded to form three-dimensional shapes. Everything a cell does—what it breaks down, what it synthesises, what it develops into—is controlled by enzymes. Enzymes, like other proteins, consist of hundreds of amino acid groups. The phenotypes of an individual are the result of which proteins are produced by certain combinations of alleles or segments of DNA. All phenotypes have a chemical basis. An organism is a set of thousands of phenotypes, each of which is based on the synthesis of proteins.

In plants, amino acids are formed in the mitochondria and chloroplasts. Nitrates are absorbed from the soil and transported in the transpiration stream. These are converted to amino groups (NH_2), and combined with a carbohydrate skeleton. Amino groups can be transferred from one carbohydrate skeleton to another in a process called **transamination**. In this way all twenty amino acids can be formed. Animals are able to synthesise eleven amino acids through transamination. These are termed non-essential amino acids. The other nine essential amino acids must be provided in the diet.

21.3.1 The genetic code

Since there are twenty amino acids and only four kinds of base in DNA, a single base cannot determine which amino acid will be synthesised. Experiments have shown that a sequence of three bases codes for a single amino acid. Triplets of bases specifying particular amino acids form the basis of the **genetic code**. Each allele codes for a protein, consisting of a specific number of amino acids. The allele must therefore contain at least three times as many nucleotides as there are amino acids in the protein.

Triplet combinations

There are sixty-four possible triplet combinations. Of these, all but three combinations have been found to correspond with an amino acid. Those that do not are believed to be the 'punctuation marks' (e.g. stop or start signals) of the code. Since sixty-one triplets code twenty amino acids, there are 'synonyms' for many of the amino acids. The code bases for all twenty amino acids have been worked out but the order of nucleotides in each triplet is not yet fully determined: all 'synonyms' have been found to contain two out of the three possible nucleotides, but in varying sequences. It is possible, therefore, that the triplet codes contain more information than that relating to the actual amino acid.

Transfer of the code

The DNA does not leave the cell's nucleus during protein synthesis, but the actual synthesis occurs on ribosomes which are located in the cytoplasm. The code must, therefore, be conveyed by some means from the DNA in the nucleus to the ribosomes. Evidence suggests that chromosomal DNA causes the production of another nucleic acid molecule, RNA. This molecule passes out of the nucleus and conveys the instructions to the cytoplasm. For this reason it is called **messenger RNA** (**mRNA**). The triplets carried on the mRNA are termed **codons**.

Ribonucleic acid, or RNA, is chemically similar to DNA. Differences are:

- The sugar is ribose (deoxyribose in DNA).
- It is a single chain of nucleotides (double in DNA).
- The base uracil replaces thymine.

21.3.2 Transcription

Protein synthesis begins as the appropriate part of the DNA molecule 'unzips' to expose the bases which will form the template for the formation of messenger RNA. Each exposed base of the DNA molecule attracts its complementary RNA nucleotide. The enzyme RNA polymerase moves along the unwound section of DNA, adding a nucleotide at a time until the message is completed. Formation of phosphate bonds between the sugars of the RNA nucleotides brings about the completion of the RNA strand, which then breaks away from the DNA template. The two DNA chains then rejoin. The messenger RNA thus formed has a specific sequence of bases determined by the sequence of DNA bases, but with uracil replacing thymine.

DNA base sequence: GTG ACC TAT CGA

mRNA base sequence: CAC UGG AUA GCU

The process of transferring the code from DNA to mRNA is called **transcription**. After the mRNA is made, enzymes 'snip' out certain regions which are not involved in the protein code. These are broken down and the remaining pieces are rejoined. The mRNA then leaves the nucleus and becomes associated with the ribosomes.

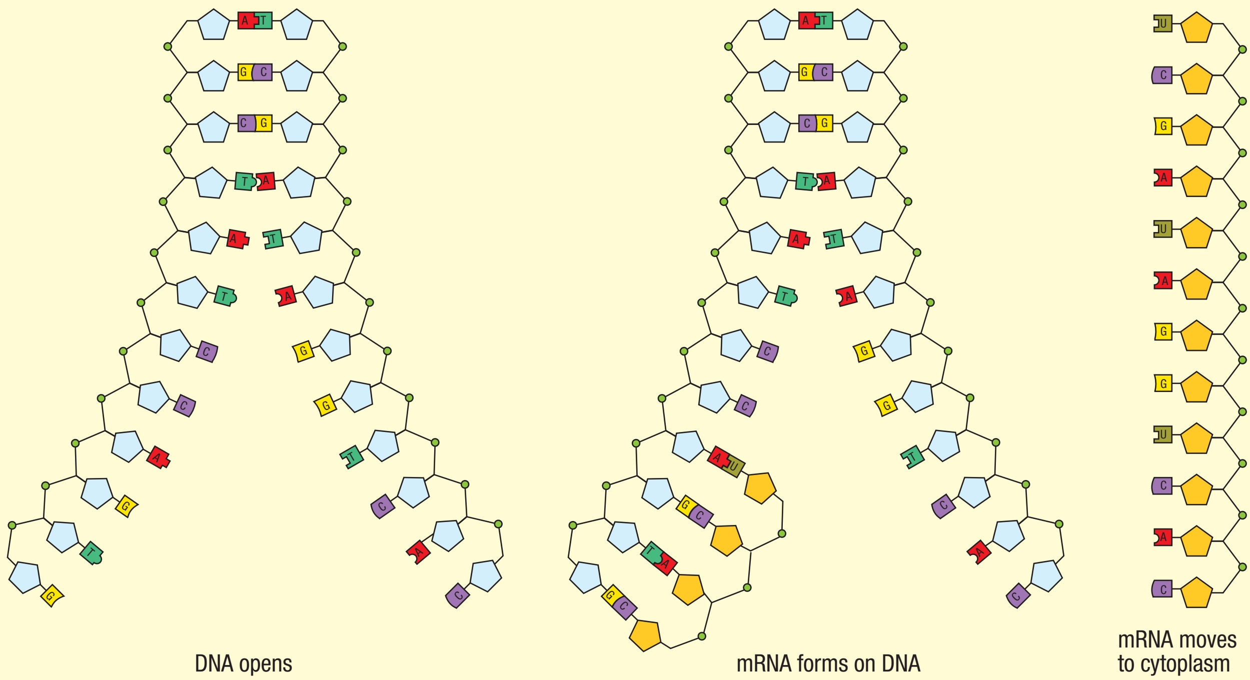


Figure 21.6 Transcription: the formation of messenger RNA

21.3.3 Translation

Certain genes produce another type of RNA called **transfer RNA (tRNA)**. The chain of nucleotides in tRNA is folded into a clover-leaf arrangement. The open end of the chain is the site for attachment of a specific amino acid (determined by the base sequence). Many of the bases in the configuration are bonded together by hydrogen bonds but one area consists of a triplet of unpaired bases. These bases serve as an **anticodon** to 'plug in' the molecule to a specific mRNA codon. There are as many different kinds of tRNA molecules as there are mRNA codons.

Each tRNA combines with only one type of amino acid, in a process which requires an enzyme and ATP.

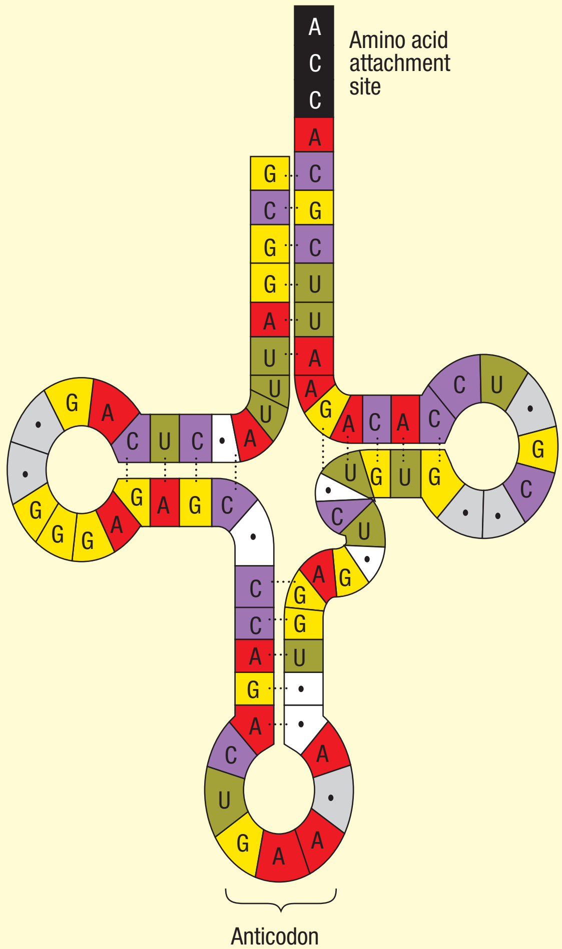


Figure 21.7 Structure of a tRNA molecule

The ribosomes

When protein synthesis begins, mRNA has become associated with the ribosomes (composed of ribosomal RNA) of the endoplasmic reticulum. Translation is initiated by a signal code followed by the 'start' codon, AUG. Any AUG codon not preceded by the signal is read as the codon to the amino acid methionine. A ribosome moves along the mRNA strand, one codon at a time. It acts as a pointer to the appropriate tRNA. As the ribosome moves into a codon position, a tRNA carrying its amino acid approaches. If the anticodon is appropriate (i.e. has a complementary base sequence to

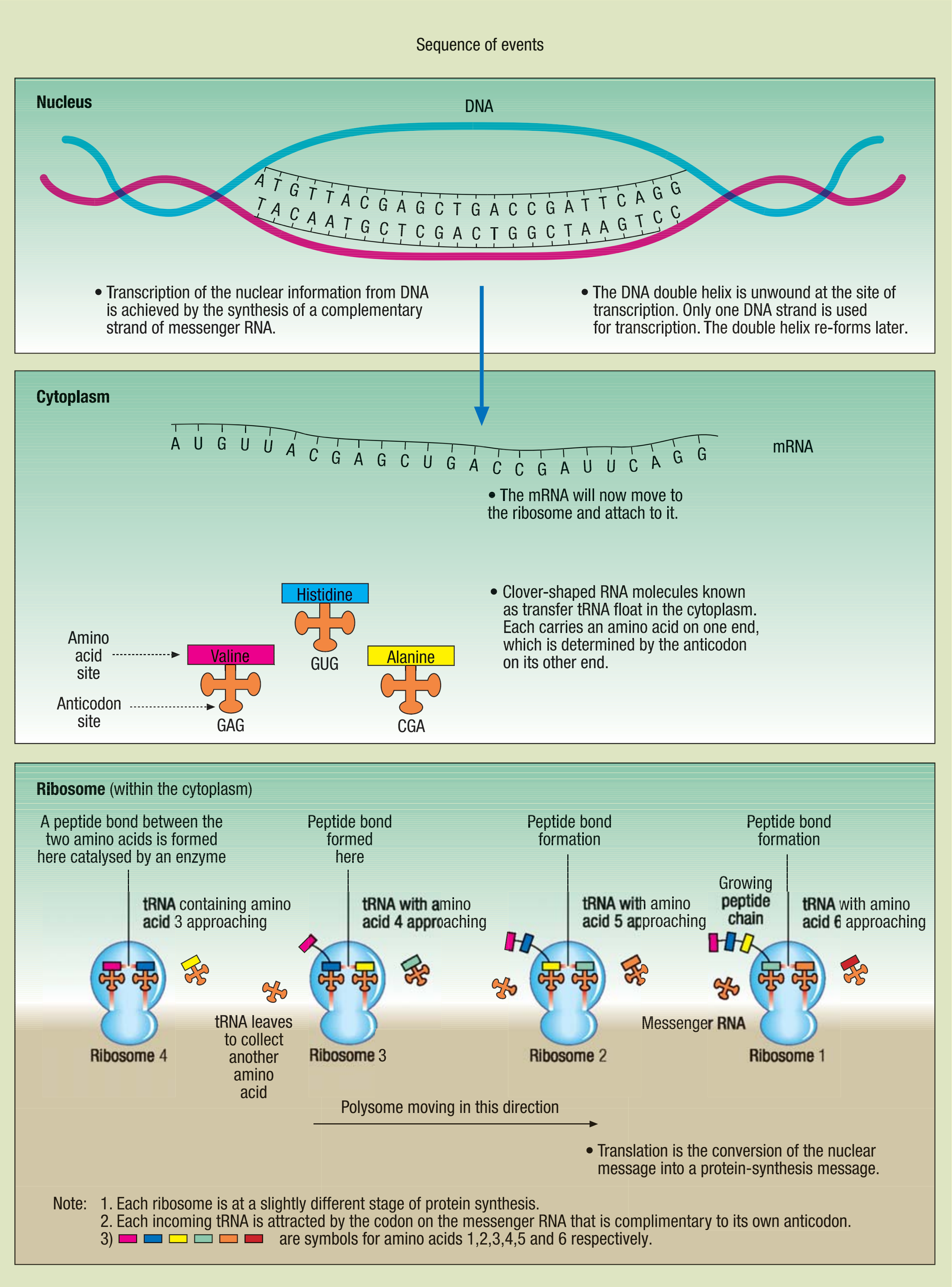


Figure 21.8 Protein synthesis

Table 21.1 The relationships between DNA, mRNA, tRNA and amino acids in protein synthesis

Transcription		*Translation*	
DNA triplet (code)	**mRNA triplet (codon)**	**tRNA (anticodon)**	**Amino acid**
AAA	UUU	AAA	phenylalanine (phe)
AAG	UUC	AAG	phenylalanine
AAT	UUA	AAU	leucine (leu)
AAC	UUG	AAC	leucine
AGA	UCU	AGA	serine (ser)
AGG	UCC	AGG	serine
AGT	UCA	AGU	serine
AGC	UCG	AGC	serine
ATA	UAU	AUA	tyrosine (tyr)
ATG	UAC	AUG	tyrosine
ATT	UAA	AUU	**stop**
ATC	UAG	AUC	**stop**
ACA	UGU	ACA	cysteine (cys)
ACG	UGC	ACG	cysteine
ACT	UGA	ACU	**stop**
ACC	UGG	ACC	tryptophan (trp)
GAA	CUU	GAA	leucine
GAG	CUC	GAG	leucine
GAT	CUA	GAU	leucine
GAC	CUG	GAC	leucine
GGA	CCU	GGA	proline (pro)
GGG	CCC	GGG	proline
GGT	CCA	GGU	proline
GGC	CCG	GGC	proline
GTA	CAU	GUA	histidine (his)
GTG	CAC	GUG	histidine
GTT	CAA	GUU	glutamine (gln)
GTC	CAG	GUC	glutamine
GCA	CGU	GCA	arginine (arg)
GCG	CGC	GCG	arginine
GCT	CGA	GCU	arginine
GCC	CGG	GCC	arginine
TAA	AUU	UAA	isoleucine (ile)
TAG	AUC	UAG	isoleucine
TAT	AUA	UAU	isoleucine
TAC	AUG	UAC	methionine (met)—**start**
TGA	ACU	UGA	threonine (thr)
TGG	ACC	UGG	threonine
TGT	ACA	UGU	threonine
TGC	ACG	UGC	threonine
TTA	AAU	UUA	asparagine (asn)
TTG	AAC	UUG	asparagine
TTT	AAA	UUU	lysine (lys)
TTC	AAG	UUC	lysine
TCA	AGU	UGA	serine
TCG	AGC	UCG	serine
TCT	AGA	UCU	arginine
TCC	AGG	UCC	arginine
CAA	GUU	CAA	valine (val)
CAG	GUC	CAG	valine
CAT	GUA	CAU	valine
CAC	GUG	CAC	valine
CGA	GCU	CGA	alanine (ala)
CGG	GCC	CGG	alanine
CGT	GCA	CGU	alanine
CGC	GCG	CGC	alanine
CTA	GAU	CUA	aspartic acid (asp)
CTG	GAC	CUG	aspartic acid
CTT	GAA	CUU	glutamic acid (glu)
CTC	GAG	CUC	glutamic acid
CCA	GGU	CCA	glycine (gly)
CCG	GGC	CCG	glycine
CCT	GGA	CCU	glycine
CCC	GGG	CCC	glycine

that of the codon), it links to the mRNA. The ribosome then moves to the next codon position. The appropriate tRNA brings its amino acid into position and a peptide bond is formed between the two amino acids. The formation of the bond releases the first tRNA to seek another amino acid in the cytoplasm.

As the ribosome moves along the mRNA, more and more amino acids are added to the growing polypeptide chain. This process is repeated until the ribosome reaches the end of the mRNA, where it drops off and liberates its polypeptide chain. The end of the mRNA strand contains one of three codons—UAG, UAA or UGA—which is thought to stop the 'message', thus causing the ribosome to release the chain. The polypeptide chain either forms a protein in the cytoplasm by cross-bonding, or is released into the endoplasmic reticulum canals for further processing.

Since many ribosomes (**polysomes**) move along the mRNA simultaneously, each synthesising a polypeptide chain, a large number of polypeptides can be assembled on a single mRNA strand in a comparatively short time. After a period of time the mRNA is broken down and production of that specific polypeptide ceases. The interaction of mRNA, tRNA and ribosomes to form a polypeptide is called **translation**. The newly made polypeptide chain is then assembled into a protein by spiralling to form a secondary structure, folding to produce a tertiary structure or combining with other groups of chemicals to produce a quaternary structure.

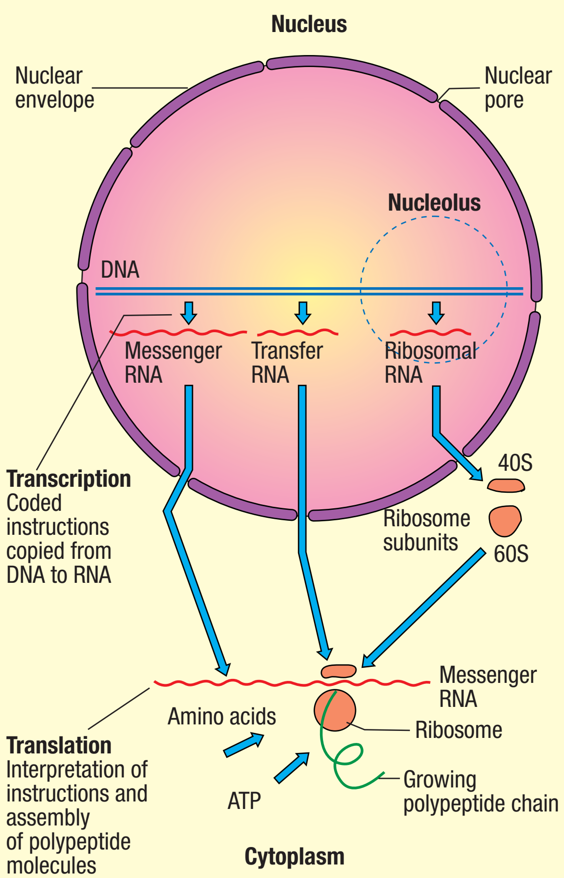


Figure 21.9 Summary of protein synthesis

21.3.4 Control of gene expression

Any particular cell requires different polypeptides at different times and in different amounts. There obviously must be some mechanism which determines when a particular gene is activated.

Gene control in bacteria

In bacteria (prokaryotes) the main genetic code is contained in a single circular chromosome which consists of DNA only. In addition to the chromosome there are other small pieces of DNA, called **plasmids**, in the cytoplasm. These are variable in composition. Some confer resistance to antibiotics for bacteria carrying them. There is no nucleus, and so movement of mRNA to a ribosome is a rapid process.

Each bacterium is a single cell which interacts with the environment. Moment-to-moment metabolic activities within this cell appear to be a major determinant of which gene is activated at any one time.

An enzyme is produced only when a particular substrate (**inducer**) is present. Three types of gene, which act as a single functional unit called an **operon**, determine whether or not the production of a specific enzyme is activated.

- **Regulator genes** synthesise mRNA which brings about production of **repressor** proteins.
- **Operator genes** are responsible for production of enzymes which 'unzip' the DNA of the structural gene.
- **Structural genes** code for the proteins needed by the bacterium.

If the inducer is absent, repressor proteins link with the operator gene. This blocks the activation of the structural gene since the 'unzipping' enzyme cannot be produced (Figure 21.10(a)).

When the inducer is present, however, it combines with the repressor molecule and so changes its shape. The operator is no longer blocked and the structural gene can then perform its function. All regulation of gene expression in bacteria occurs at the level of transcription in bacteria (Figure 21.10(b)).

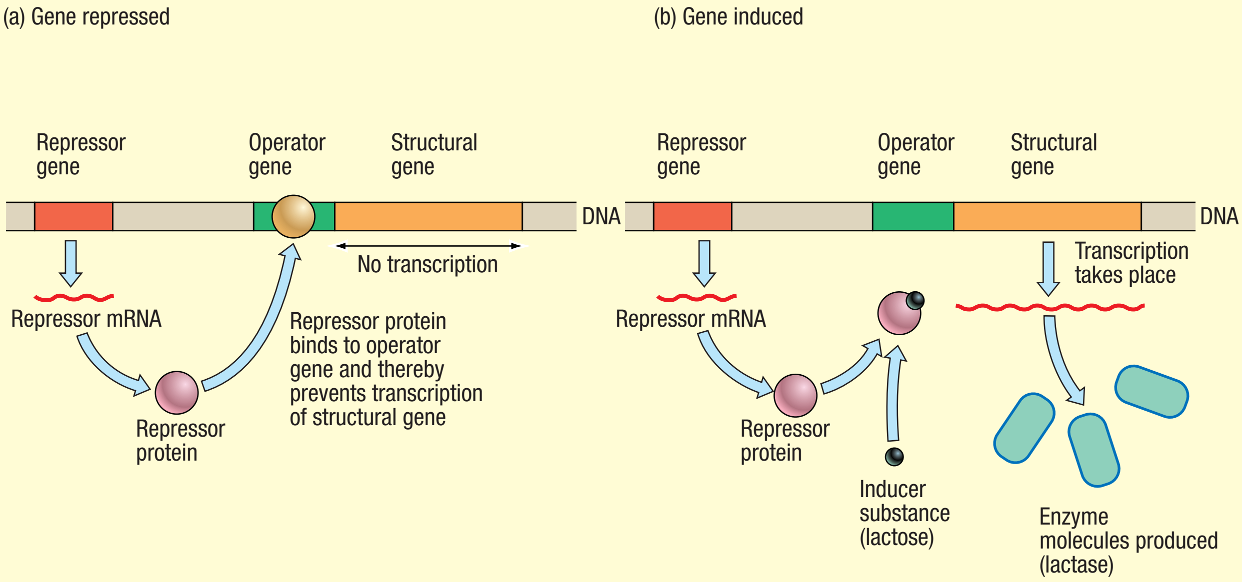


Figure 21.10 Operon control of protein synthesis

Inducers are cell chemicals. Intake of lactose, for example, increases its concentration within the cell. Lactose must be broken down to glucose for use by the cell. Thus lactose acts as an inducer for the gene which produces the enzyme lactase. When all of the lactose is converted to glucose, the regulator gene blocks further formation of lactase, and that which is present in the cell is broken down.

Through induction and repression of specific genes, a steady state (homeostasis) is maintained within the bacterium's cell regardless of the fluctuations in the supply of materials.

Gene expression in eukaryotes

Gene control in eukaryotes is more complex. DNA is intimately connected with histone proteins and contained within the nucleus. This means that mRNA must be transferred through the nuclear membrane to the ribosomes. Since the cells of multicellular organisms are differentiated into a variety of tissues, different cells must simultaneously transcribe different information. One kind of cell may also transcribe different information at different times during its life. All this is possible despite the fact that the total amount of DNA per cell is the same for every diploid cell of a given species.

Types of sequence

There are five major types of sequence within the DNA of multicellular organisms:

- a gene which produces the code for a single mRNA and thus polypeptide
- **origin** and **terminus sequences** which are involved in replication
- **centromeres** (points of attachment of chromatids during cell division) and **telomeres** (caps at the end of each chromosome which provide chromosome stability)
- **repetitive sequences** which are either spaces between genes or **satellite DNA**. These may provide structure and organisation to the chromosome.
- transposable elements (**transposons**) which can be replicated and the copy inserted into another location. These are also known as 'jumping genes'.

Control of transcription

Transcription occurs only during interphase when the chromosomes exist as chromatin threads. There are two different forms of chromatin: **heterochromatin**, in which the nucleosomes remain fairly tightly coiled; and **euchromatin**, which is not so condensed. The euchromatin contains the genes. The degree of condensation of any particular portion of euchromatin, which can vary from cell to cell, determines whether or not a particular gene is activated. The more open the portion is, the more likely it is that transcription will occur.

The degree of euchromatin condensation appears to be controlled by one of several factors.

Most of the protein molecules bound to the DNA are histones and are structural in function. Other proteins, non-histones, are present in smaller amounts. Some of these are thought to inactivate a gene by binding to it. Others may activate the gene by removing a bound protein. Some hormones bind to specific sites on DNA and thus 'switch on' genes. Methyl groups which bind to genes (**methylation**) also activate them. Thus inducers act through non-histone proteins and methyl groups in the nucleus.

Transcription is only the first phase of protein formation. Genes are not fully expressed until their polypeptide products are converted to fully functional proteins. Many 'post-transcriptional' events are also significant in gene action of eukaryotic cells.

Post-transcriptional events

When mRNA is produced there are extra parts at the beginning and end which are removed while it is still in the nucleus. This is termed **trimming**. After the RNA is made and trimmed, a guanine 'cap' is added at one end of the mRNA, and a long 'tail' of adenines at the other end. They are thought to aid the binding of the RNA to the ribosome and make it more stable.

Many genes in complex organisms are called **split genes**. They contain sections of DNA called **exons** which code for the protein, separated by sequences called **introns**. The mRNA produced from the transcription of these genes also contains the non-protein code. Removal of the intron and splicing of the cut ends of the mRNA ensures a continuous set of exons. The completed mRNA must then move out of the nucleus into the cytoplasm. It is thought that this is done in association with special proteins, the presence or absence of which further controls gene action.

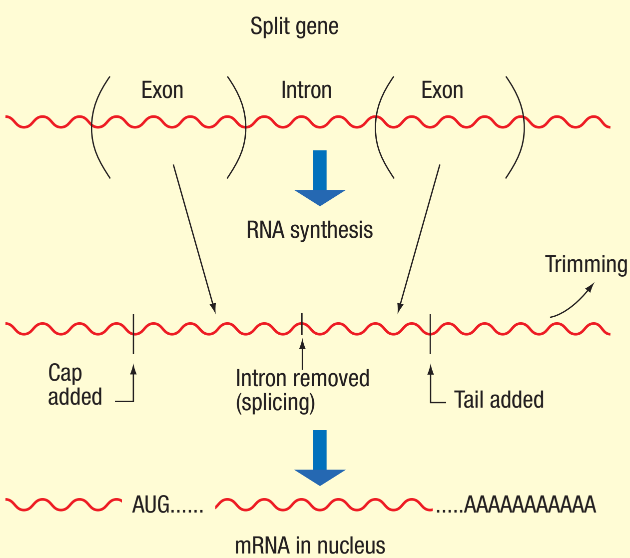
In some cells mRNA is not used immediately it enters the cytoplasm. It is covered, or masked, by protein and stored in the cytoplasm. Unmasking is accomplished by specific inducers in the cytoplasm.

Polypeptides produced from translation are converted to proteins. There are then several factors that may influence the action of these proteins.

If proteins are to be moved within the cell or to another cell, they will require the addition of specific amino acids which facilitate their movement through membranes. Some require the addition of sugars in the Golgi bodies, and others (e.g. hydrolytic enzymes) may need to be activated by the presence of other chemicals before they can operate.

In summary, gene expression in eukaryotes is controlled at several points:

- transcription—removal of inactivation blockage by inducers or chemical signals such as hormones
- maintaining the stability of mRNA by trimming, capping, tailing and splicing of segments with introns removed
- movement of mRNA across the nuclear membrane in association with specific proteins
- translation
- protein production.



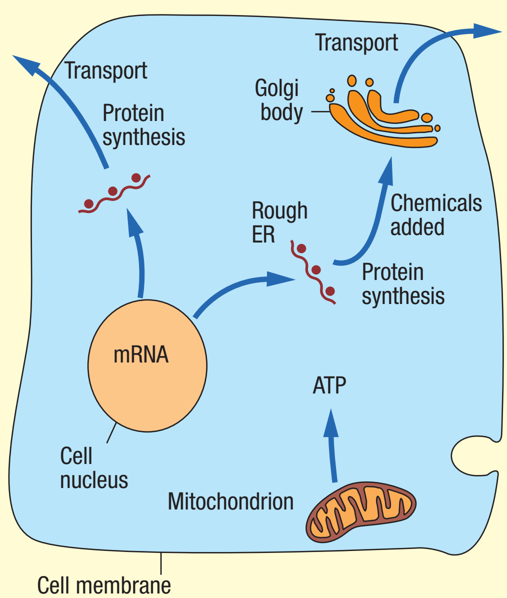


Figure 21.11 Splicing, capping and tailing of mRNA in eukaryotic cells

SUMMARY

DNA exerts its influence by controlling protein synthesis. A gene is a segment of DNA with one gene generally controlling the synthesis of one protein. The DNA, which is confined to the nucleus in eukaryotes, controls the sequence of amino acids in the polypeptide chains formed on the ribosomes. Each amino acid is coded by a triplet of DNA bases.

Under the action of specific controls, a segment of DNA unzips to expose a particular gene. A length of RNA is formed along the exposed nucleotides and detaches. The messenger RNA formed by this process of transcription leaves the nucleus and attaches to ribosomes on the endoplasmic reticulum. Within the cytoplasm transfer RNA molecules, only three bases long and containing an anticodon (complementary bases to the mRNA), collect up amino acids specific to the particular tRNA. Ribosomes move along the mRNA one codon at time. As the ribosome moves into a codon position, the appropriate tRNA links with the mRNA. Condensation between the two adjacent amino acids occurs and this frees the tRNA to return to the cytoplasm to pick up another of its amino acids. The process continues until the end of the mRNA is reached. Large numbers of the polypeptide chains can be produced from the one mRNA. The interaction between the mRNA, ribosomes and tRNAs is termed translation. At some point the mRNA is destroyed and no more of that protein is produced.

Differences in control of gene expression occur between prokaryotic and eukaryotic cells.

Review questions

21.4 The following sequence of bases occurs in one of the two chains of a DNA molecule:

C A G G T A C T G

What will be the sequence of bases in the other chain?

21.5 How does DNA differ from RNA in the following characteristics?

(a) kind of sugar in the molecule

(b) usual location in the cell

(c) nitrogen bases present in the molecule

(d) usual number of strands

(e) functions in the cell

21.6 Briefly explain how the DNA in the nucleus of a cell is believed to control the synthesis of proteins in the cytoplasm.

21.7 How does protein synthesis result in control of a cell?

21.8 Suggest why a codon is composed of three nucleotides rather than any other number.

21.9 What does a codon represent?

21.10 The following sequence of bases in DNA codes for the formation of a section of polypeptide containing ten amino acids:

G T T A A C C G A A C G G T T A G A T G T A C A T T T A A G

(a) Give the base sequence of the mRNA responsible for transcribing this code.

(b) Using Table 21.1 on page 583, give the sequence of amino acids in the resulting polypeptide.

21.11 A certain protein is composed of 1500 amino acids. How long is the gene responsible for its synthesis?

21.12 In bacteria, gene control operates at the transcription phase only. What does this mean? Explain how this control operates in bacteria.

21.13 In multicellular organisms there are several post-transcriptional controls on gene activity. List these.

21.14 Suggest reasons for a more complex system of gene control in multicellular organisms.

21.4 Mutations

The mechanisms that control DNA replication and cell division usually result in cells which contain the same kind of genetic information as the parent cell. Sometimes, however, changes or **mutations** occur in either chromosomes or genes (DNA).

21.4.1 Chromosome mutations

Chromosome mutations may occur in many ways. For example, homologous chromosomes may fail to separate during meiosis I (nondisjunction) and form gametes with extra or missing chromosomes (see Section 19.3.2). Abnormal gametes will also form if a chromosome fails to attach to a spindle during cell division. During crossing-over, parts of chromatids can be lost (deletion), rejoined to wrong chromosomes (translocation), the segment of chromosome repeated (duplication), or attached upside down

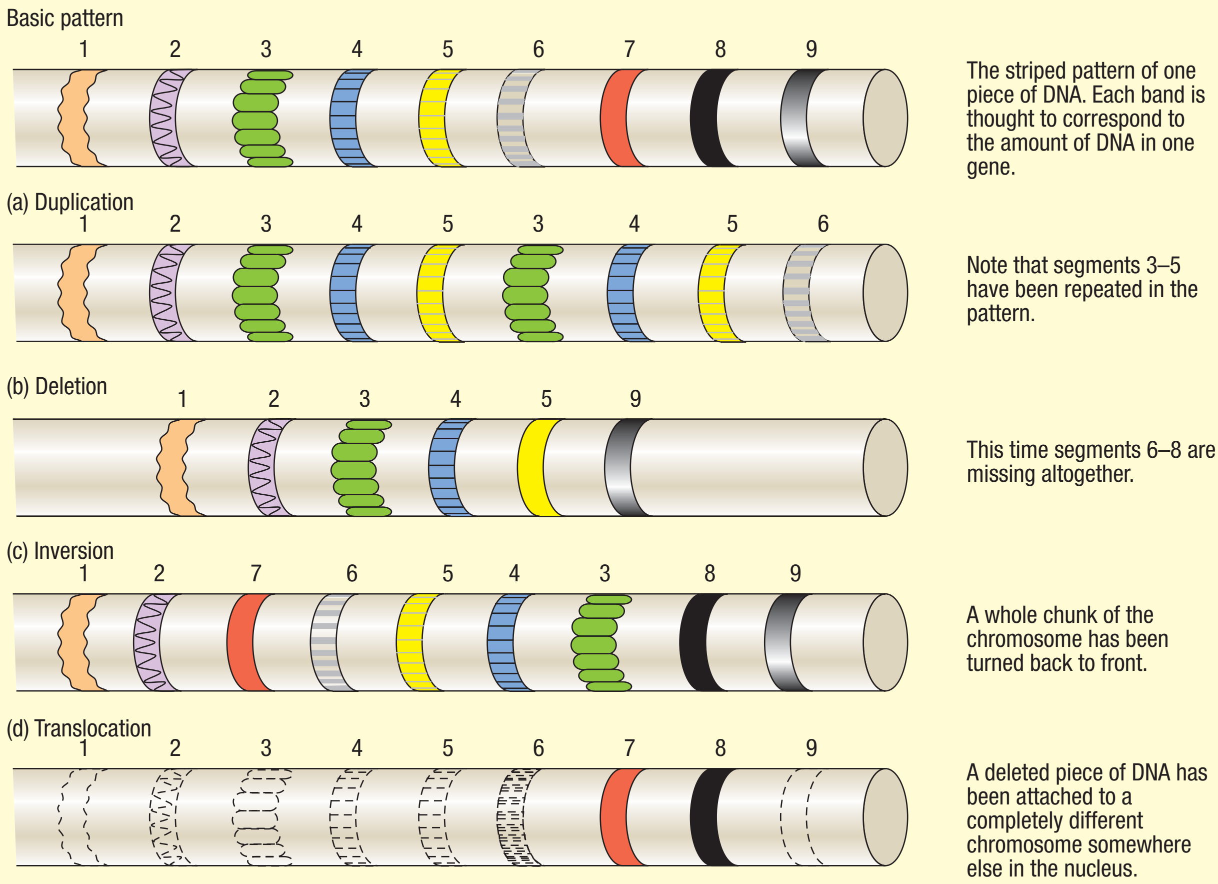


Figure 21.12 Chromosomal mutations

(inversion). All of these changes can result in abnormal information in the genetic code.

21.4.2 Polyploidy

Sometimes whole sets of homologous chromosomes may fail to separate. This may lead to a triploid individual (with three sets of chromosomes), a tetraploid individual (with four sets of chromosomes) or more multiples of the haploid condition. The existence of more than two sets of chromosomes is known as **polyploidy**. It is rare in animals but relatively common in plants. Approximately half of the angiosperms, including many important food plants, are polyploids.

If a diploid gamete fertilises a haploid gamete, a triploid individual arises. Since the chromosomes cannot form homologous pairs during division, these individuals are usually sterile. Fertilisation between two diploid gametes results in a tetraploid individual. The chromosomes can form homologous pairs during division and thus further diploid gametes are formed.

Horticulturists have been able to induce polyploidy using the chemical colchicine, which inhibits spindle formation and thus separation of chromosomes during anaphase. New varieties of plants have been formed by hybridisation between different species. Most of these hybrids are infertile because they do not contain chromosomes which can form homologous pairs; but some are fertile.

The major variety of bread wheat grown today is a result of polyploidy. The haploid number of wild grasses is seven. A tetraploid (emma wheat) with twenty-eight chromosomes was accidentally crossed with a wild grass. The resultant hexaploid offspring (with forty-two chromosomes) produced larger grains which yielded a greater quantity of flour.

21.4.3 Gene mutations (= point mutation)

Gene mutations can also occur in many ways. During DNA replication a nucleotide may be missed out, an extra one included or an incorrect one substituted. In each case the triplet code will be read incorrectly. For example:

DNA code:	CGA*	ACA	AAC	CCA
Amino acids:	ala	cys	leu	gly

Deletion of the nucleotide marked with an asterisk (*) results in:

DNA code:	CGA	CAA	ACC	CA–
Amino acids:	ala	val	trp	

that is, an entirely different amino acid sequence.

Addition of an extra A after A* results in:

DNA code:	CGA	AAC	AAA	CCC	A – –
Amino acids:	ala	leu	phe	gly	

Substitution of G with A in the first triplet results in:

DNA code:	CAA	ACA	AAC	CCA
Amino acids:	val	cys	leu	gly

Duplication of the first triplet results in:

DNA code:	CGA	CGA	ACA	AAC	CCA
Amino acids:	ala	ala	cys	leu	gly

Inversion of the first triplet results in:

DNA code:	AGC	ACA	AAC	CCA
Amino acids:	ser	cys	leu	gly

Similar anomalies can occur during transcription of the DNA code to mRNA. Nucleotides can be added to, or deleted from, the mRNA or in translation between mRNA and tRNA. As a consequence the correct protein will not be produced. These types of errors seem to occur more regularly in older individuals and are believed to be a function of the natural aging process or senescence. Since this type of mutation generally affects body cells as opposed to the gonadial cells, it is referred to as **somatic mutation**.

The rate of mutation varies. It has been estimated that in the fruit fly, *Drosophila melanogaster*, gene mutation occurs about once in 200 000 gametes. Some mutations occur at a higher frequency. Several factors have been shown to increase the rate of mutation by causing bonds to break in DNA. These are known as **mutagens**. Radiation, high temperature and chemicals such as formaldehyde are among the known mutagens.

21.4.4 The effects of mutations

Some mutations have little effect on the individual, others may be helpful, some may be harmful and some may be lethal. Lethal mutations may have an immediate effect upon the cell (or the individual), killing it directly. This type of lethal mutation will therefore not be transmitted to offspring. Others may not exert their effect until some specific stage of development. Examples of such mutations are sickle-cell anaemia and PKU. A great many non-lethal mutations, however, may be important for the future by providing a store of variations in a population which may benefit it in changing environmental conditions. All alleles for any particular gene have arisen from mutation.

Once a mutation has occurred, it becomes part of the genetic framework of the cell and with subsequent cell divisions will be perpetuated through DNA replication. If the mutation occurs in a body cell, it will not be important to the species as a whole, although it could bring about significant changes to a particular organ or tissue of the individual (e.g. tumour formation). Mutation in the sex cells may, however, affect the entire population because the mutation may be passed on to subsequent generations through the gametes.

SUMMARY

Mutations result from changes in chromosomes or genes. Although some mutations may be lethal or result in genetic diseases, many do not have an adverse effect on the individual as a whole, and some may be advantageous. All alleles have arisen from gene mutations.

Chromosomal mutations include:

- nondisjunction of a single chromosome
- failure of whole sets of chromosomes to separate
- failure of one or more chromosomes to attach to a spindle
- deletion, duplication, translocation or inversions during crossing-over.

These changes mostly occur during meiosis.

Gene mutation generally occurs during DNA replication. It may result from nucleotide deletion, substitution, duplication, inversion or addition. Errors are more prevalent in older individuals and this leads to senescence. Such changes are usually somatic and thus affect the individual only. If mutation occurs in the gametes, then the genetic structure of the population may be affected.

Mutation rates are increased by mutagens such as radiation, heat and certain chemicals.

? Review questions

21.15 How are gene mutations caused?

21.16 How can a mutation be passed on to future generations?

21.17 How can chromosome mutations occur?

21.18 Why is it that mutations occurring in the body cells of an organism are not important to the entire species, whereas those in the sex cells are?

21.5 Extrachromosomal DNA

In eukaryotic cells DNA is also found outside the nucleus. Such **organelle DNA** is found in cellular structures such as mitochondria and chloroplasts. Evidence suggests that both mitochondria and chloroplasts were originally free-living organisms which evolved a symbiotic relationship with other primitive organisms. The extrachromosomal DNA found in these organelles is known to be significant in the replication of mitochondria and chloroplasts as well as coding for tRNA and the RNA of the ribosomes.

Nuclear DNA is thought to control the synthesis of the outer protein parts of these organelles, proteins of the ribosomes and enzymes needed for organelle protein synthesis. Mitochondrial DNA produces substances which complement those made from nuclear genes.

In animals mitochondrial DNA is always inherited from the mother: sperm heads which penetrate the ova do not contain mitochondria. Evolutionary patterns can therefore be traced by examining this DNA.

Research indicates that the mRNA of frequently used nuclear genes may sometimes be converted into mitochondrial genes (i.e. DNA). This process is similar to the way tumour viruses function. These viruses have RNA instead of DNA as their coding molecule. When they infect a host cell, an enzyme called reverse transcriptase forms a DNA molecule from the viral RNA template. This DNA then instructs the host cell to form more viral matter.

SUMMARY

DNA is found outside the nucleus in some organelles such as chloroplasts and mitochondria. Organelle DNA is important in replication of mitochondria and chloroplasts, coding for tRNA and ribosomal RNA.

Since any mitochondria in a zygote are of maternal origin, studies of mitochondrial DNA have been significant in tracing some evolutionary pathways.

? Review questions

21.19 What is the meaning of the term ‘extrachromosomal DNA’?

21.20 Where would you find extrachromosomal DNA?

21.21 How does the existence of extrachromosomal DNA support the symbiosis hypothesis of eukaryotic evolution?

21.22 How does organelle DNA aid researchers in tracing evolutionary pathways?

EXTENDING YOUR IDEAS

1. UB Match each phrase in column A with the proper term from column B.

Column A	Column B
1. organelle where protein synthesis occurs	(a) codon
2. has an anticodon	(b) DNA
3. genetic mistake	(c) mitochondrion
4. where transcription occurs	(d) mutation
5. represents an amino acid	(e) mRNA
6. contains non-nuclear DNA	(f) nucleotide
7. carries DNA code to ribosomes	(g) nucleus
8. material of which genes are made	(h) ribosome
9. four kinds in DNA	(i) tRNA

2. UB Let the amount of DNA present in the nucleus of a cell at the beginning of interphase be *x*.
   What will be the amount present at:
   (a) the end of interphase
   (b) the end of mitosis
   (c) the end of a first meiotic division
   (d) the end of a second meiotic division?
   Give reasons for your answers.

3. UB Analysis of a sample of DNA extracted from a tissue showed that 38 per cent of the bases were adenine. What percentage of the bases in the DNA would be guanine? Show how you arrived at your answer.

4. Bacterial cells were fed with labelled nitrogen-containing food. After division, the DNA strands of the daughter cells were found to contain labelled nitrogen. These daughter cells were then fed on normal food and, when they in turn divided, it was found that the cells they produced contained DNA in which only half the strand contained labelled nitrogen atoms. How can this be explained?

5. The following poem was written by Payson Stevens. The lines of the poem are shown divided into six groups. Interpret each group of lines in relation to your knowledge of DNA replication and protein synthesis.

Imagine being
a strand of DNA
unwinding in the
fluid maze } 1

uncoiling like a breeze
while the cloud enzymes
envelop your backbone } 2

and the cell wisdom
replicates its patterns
drawn by the needs of bonds } 3

your mosaic
a vision of the past
is locked in chemical messages
which
etch the face of life } 4

and energy,
energy, energy
is lowered and raised } 5

while
the economy of balance
telescopes
the cytoplasmic ballet
into
the forms of the future. } 6

6. What problem would arise with a DNA model that had nitrogen bases as the sides of the ladder and sugars and phosphates as the rungs?

7. In the bread mould *Neurispora crassa*, a biosynthetic pathway can be interrupted by three mutations. Mutant X will grow if provided with cystathionine, homocystine or cysteine; mutant R will grow only on homocystine but accumulates cystathionine; mutant W will grow if provided with homocystine or cystathionine, but will not grow on cysteine.
   (a) Sketch the sequence of biosynthesis of these three chemicals and indicate the positions of the metabolic blocks imposed by mutants X, R and W.
   (b) What do you predict would be the result of crossing the mutants in the following pairs?
      (i) X with R
      (ii) X with W
      (iii) W with R
   . . . and what conclusion would you draw if your predictions turned out to be correct?

8. Suppose a gene contains the code for the synthesis of an enzyme. During replication of the gene a mutation occurs so that one of the nucleotides is left out. Is it more likely that the enzyme produced will be close to ‘normal’ if the deleted base occurs near the beginning or near the end of the gene? Explain.

UNIT 8

Evolution

A scientific theory of biological evolution has been developed to explain the origins of the diverse forms of life that share our planet, and the interrelationships between them. Evidence for such a theory has been assembled from a wide variety of scientific disciplines: palaeontology, geology, molecular biology, comparative anatomy, embryology, serology and genetics.

The theory of natural selection, first proposed by Charles Darwin and Alfred Russel Wallace, outlines a mechanism accounting for the observed phenomenon of biological evolution. The Darwinian theory of natural selection has subsequently been enhanced by the discoveries of modern biology. These discoveries have contributed a deeper understanding of the origins of genetic variation, the alteration of gene frequencies and the processes of speciation. The result is a Neo-Darwinian theory of natural selection, the most widely accepted contemporary scientific theory accounting for biological evolution. This theory is the unifying principle of biological science, providing explanations for mechanisms by which organisms become adapted to specific environmental conditions, change and diversify. The exact nature of these mechanisms is still the subject of scientific debate. Natural selection is the major force of evolution as it acts through interactions between the phenotype of individual organisms and their environment. This results in adaptations of populations to their environment, which in turn provides the basis for convergent and divergent evolution, and coevolution.

Key concepts

- Organisms live an interdependent existence in environments to which they are adapted.
- A variety of mechanisms result in continual change at all levels of the natural world.

Key ideas

- The external features and internal functioning of organisms together enable an organism to obtain its needs.
- An organism has adaptations specific to its environment.
- Evidence shows that organisms and ecosystems change through time.
- During reproduction DNA is passed from parent(s) to offspring.
- Theories of evolution by natural selection can be used to explain speciation and changes in organisms through time.
- The genetic variations within a population determine its long-term survival.
- Evolutionary processes acting on the gene pools of populations have given rise to diversity of organisms.

22 Theories of evolution

22.1 The origin of life

Over the years many attempts have been made to explain the origins of living organisms and their great diversity. Most of these explanations have been linked to a religious or philosophical doctrine, and feature some form of creator. The Aboriginal Dreaming stories belong to such a creation tradition. In the Western world there is a **special creation** doctrine that originates from the Old Testament book of Genesis. It is based on the precept that species were created separately and the numerous descendants survived through time in their created form.

Another theory was that of spontaneous generation: the formation of the different species of organisms spontaneously from non-living material. This theory originated with Aristotle (384–322 BC). Although waning in popularity with the growth of Christianity, it was still accepted by many until Redi (1688) was able to show that life can arise only from pre-existing life (biogenesis). It was not until 1860, however, when Pasteur validated biogenesis in controlled experiments, that the theory of spontaneous generation was finally dispelled. Then, in 1923, a combination of theories began to gain currency. Oparin showed experimentally that organic molecules can be synthesised from inorganic molecules under certain conditions which, from geological evidence, are thought to simulate primeval earth. Thus the very first living organisms on earth could have been spontaneously generated. From these original molecules, cells and then organisms could have been formed, with further changes resulting from biological evolution.

The **steady state theory** asserts that the earth and all its living organisms had no origin. What is now always was. Thus, in the history of a species, only the numbers vary or it becomes extinct. In contrast, the **cosmozoan theory** states that life could have arisen at various times in various parts of the universe. It favours the idea that life on earth has an extra-terrestrial origin.

Case study 22.1: The cosmic phenomenon of life

Some eminent scientists, including cosmologist Fred Hoyle, speculate that planets are 'seeded' from space by particles carrying primitive organisms such as bacteria and viruses. Should they land in a hospitable environment, such as the 'primordial soup' of the ancient earth, they are then able to undergo evolutionary processes dictated by natural selection pressures.

Possible simple life forms on Mars were reported in August 1996 by a NASA/Stanford University research team, and in November of the same year by a British team. These discoveries have reopened the cosmozoan debate. In both cases, the data came from meteorites which landed on Antarctica. Mass spectrograph analysis of both rock samples, and of Martian soil samples obtained from the Viking missions, show that they all have similar isotope 'signatures' and therefore origins. The NASA/Stanford University research is based on a 15-million-year-old meteorite, 1.9 kg in mass, which is believed to have landed on earth 13 000 years ago. This rock may have formed on Mars 3–6 million years ago. The British observations are based on a younger meteorite, 180 million years old, which is thought to have broken off Mars only 600 000 years ago.

Various observations, some of them controversial, led the NASA/Stanford University team to their contention that simple life forms existed on Mars.

First, they found carbonate globules in fissures in the meteorite. These form when surface water reacts with atmospheric carbon dioxide. Embedded on these globules were a variety of markings, some round, others long and thin, and measuring between 20 and 200 nanometres; these have been interpreted as microfossils. It is suggested that bacteria enhanced the natural process of carbonate formation.

Some scientists have proposed that the carbonates could have formed as the asteroid or comet collided with Mars. The impact could have created a hot surface fluid rich in carbon dioxide which deposited on the sub-surface rock as carbonate as it was flung into space as a meteorite. In this case the structures on the carbonate globules could not be fossilised micro-organisms. Further calculations of strontium and rubidium in the meteorite suggest that the carbonates are not as old as proposed by the NASA team. Thus the 'fossil' markings must also be younger.

Two main carbon isotopes, ^{12}C and ^{13}C, are used in determining the likelihood of organic formation of carbonate. Enzymes have a tendency to incorporate the lighter ^{12}C, and the remains of living matter are therefore ^{12}C enriched. Analysis by the NASA team of the carbon isotope ratios in the carbonate suggested that the carbonate in the meteorite showed this tendency. Independent analysis suggested that the carbonate merely reflected the isotope ratio of the Martian atmosphere, and thus did not prove the existence of life on the planet. However, tests by the British team on the younger rock showed the ^{12}C component to be much richer, and consistent with the levels produced by methane-producing microbes on earth.

Other scientists argue that the 'microfossils' are too small to contain the necessary genetic material for living systems, and that there is no sign of cellular composition in their electromicroscans. These fossils are thousands of times smaller than the oldest known microfossils on earth, the cyanobacteria of stromatolites in Western Australia. A geologist from the University of Texas, however, believes that he has discovered 'nanofossils', 2 billion years old, on the surface of carbonate rocks at an Italian hot spring. Since no-one has been able to reveal DNA, metabolites or cellular structure in these structures, most scientists are reserving judgement on their placement within the living system.

Magnetite and iron sulfide crystals, similar to those produced by certain known chemosynthetic bacteria, were found in the carbonate globules. The researchers claim that inorganically grown crystals of these iron-containing substances are symmetrical, whereas those produced by biological action have a teardrop shape as found in the Martian rock.

Other meteorite specialists contend that the ratio of two of the sulfur isotopes in these samples is consistent with non-biological processes. Further, terrestrial bacteria which produce teardrop crystals of magnetite are both rare and large, using the crystals as magnetic 'compasses' to find their way around sediments. Even if the Martian teardrop crystals are of biological origin, this raises the question of what their purpose might be on Mars where there is a very weak magnetic field.

Molecules of polycyclic aromatic hydrocarbons (PAHs) were found in the carbonate globules. PAHs are known decay products of living matter. They were found in concentric rings around the 'fossil' marks, further suggesting that they were exuded by the bacteria. The NASA team concluded that, since the concentrations of PAHs were greater on the inside than on the outside of the meteorite, PAHs were unlikely to be the result of contamination of the rock from terrestrial sources. They were, therefore, most likely a product of life on Mars.

This evidence has not been accepted by all scientists. PAHs have been found to be widespread in asteroids and meteorites not thought to be from any planet, and thus are not considered to be diagnostic of life. It has been further revealed that spectrum analysis of the Mars PAHs is much less diverse than that of fossils and remains of biological material. It is also proposed that the black meteorite would have absorbed heat once it settled in Antarctica, and the surrounding melting snow could have seeped into the fissures and concentrated the PAHs. Meanwhile ultraviolet light would destroy surface PAHs.

Cynics suggest that NASA's report was timely, in that there was a serious threat to continued US funding for meteorite research. Nevertheless, there is no doubt that the controversy surrounding the findings will generate further research and possibly a greater understanding of the evolution of life.

The theory of **biological evolution** (= unfolding) is a unifying theory which attempts to provide an explanation of the changes that have occurred in species over time, based on scientific evidence. In Chapter 21, it was shown that mutations of genes within an individual's reproductive cells could lead to changes within a population. This concept will be developed further in Chapter 23. On a large scale this can be extended to the concept of evolution as the development of complex organisms from pre-existing simpler organisms over the course of time.

Although Charles Darwin is credited with the theory of biological evolution, his contribution was mainly in providing empirical evidence for an idea which had been developing among scientists for some time, and for suggesting mechanisms whereby such change could occur. Early Greek philosophers had proposed that life began in the sea (Thales, in 6 BC), that everything is 'transposed into new shapes' (Heraclitus) and that there was a natural progression from plants to plant–animals to animals, finally leading to man (Aristotle); but no scientifically sound process for such change had been proposed.

SUMMARY

Many theories, most rooted in philosophical or religious grounds, have been proposed for the origins and diversity of life on earth. The theory of evolution is an attempt to explain the changes to living things over time, using scientific evidence.

> **?** **Review question**
>
> **22.1** What is meant by biological evolution?

22.2 Lamarck, Darwin and Neo-Darwinism

22.2.1 Lamarck's theory of evolution by acquired characteristics

In 1809 Lamarck proposed a hypothesis to account for evolution, based on:

- use and disuse of parts of an organism; and
- inheritance of acquired characteristics.

Change in the environment may lead to increased use or disuse of an organ or structure. Extensive use of such a structure would lead to its increased size or efficiency. Disuse would lead to its atrophy. He believed that such acquired traits in the individual would be passed on to the next generation, becoming part of the inheritable material.

Although Lamarck's belief that the environment has a role in producing phenotypic changes has been shown to be correct, there is no evidence to support the contention that the environment actively changes the genotype. For example, exercise can cause a change in phenotype by building up particular muscles, but the offspring of a person who has developed such a physique will not automatically have a similar musculature.

A biologist named Weismann tested this theory by cutting off the tails of mice for hundreds of generations. Each new generation was born with tails, thus showing that these acquired body changes are not transmitted from one generation to the next. Weismann then showed that only material from the egg or sperm passes between generations.

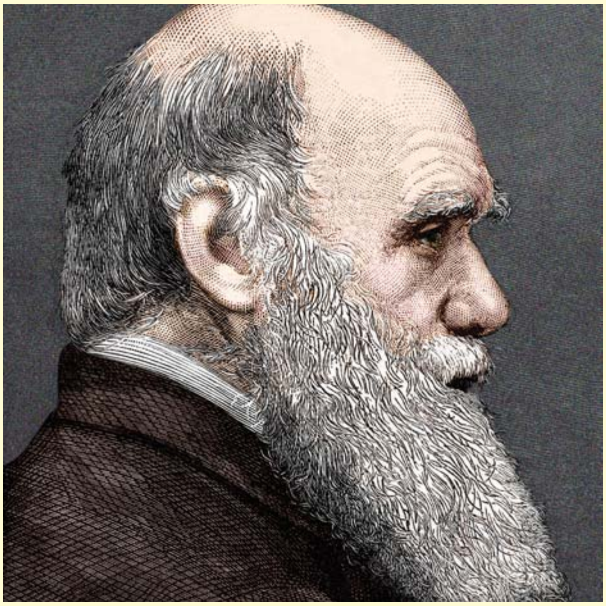


Figure 22.1 Charles Darwin

Case study 22.2: Charles Darwin

Charles Robert Darwin was born in 1809. Both his father, Robert Darwin, and his grandfather, Erasmus Darwin, were well-known physicians who attempted to explain life in evolutionary terms.

Left motherless at the age of eight, Darwin grew up on his father's estate where his father held long discourses on a variety of subjects, including his grandfather's Lamarckian views. Charles was not a particularly academic young man, preferring natural history pursuits and shooting. He was sent to the University of Edinburgh to study medicine but found that he could not handle the surgery. At his father's insistence, he completed a degree in Divinity at the University of Cambridge, with the intention of becoming a country clergyman in the Church of England.

During this time he was influenced by Reverend John Henslow, Professor of Botany, and his reading of natural history. Although he read Lamarck and the Greek philosophers, he was not at that time influenced by them. He was a conservative young man brought up in a society where biblical interpretations went beyond belief to a basic tenet of society.

On graduation Darwin had the opportunity to join the *Beagle* on an extensive exploratory-scientific expedition. During an initial bout of seasickness, he read a new book by Charles Lyell (*Principles of Geology*) which argued that the earth's continents were shaped, not by Noah's flood, but by the action of the rains, winds, earthquakes, volcanoes and other natural forces—forces which were still altering the earth.

At the first anchorage in the Cape Verde Islands, Darwin recognised what Lyell was describing as he discovered a white shell bed on a sea cliff face high above the beach. As the *Beagle* sailed towards Brazil, further fossil discoveries suggested to him that, although existing animals in North and South America were now quite distinct, in the past both had harboured very similar species. The fossils also suggested that these animals were far more like the animals of Asia and Europe than were living American species.

Although he remarked on the incredible variations within the beetles and other fauna along the South American coast, it was the visit to the Galapagos Islands, a dry volcanic archipelago west of Ecuador, that stirred his insights into variation and possible evolutionary significance. He discovered the giant Galapagos tortoise, found nowhere else in the world; two species of iguanas (both herbivorous, with one algal-eating marine form); and new species of plants, insects, fish and birds. Of the birds, thirteen species were finch-like. They were structurally very similar and yet very distinctive. All of these organisms bore a marked resemblance to related groups on the American mainland, approximately 700 km away and separated by sea. Further, it was revealed that the fauna from island to island differed. The shells of the tortoises from Charles Island, for example, were turned up at the front, whereas those from James Island were rounder and blacker.

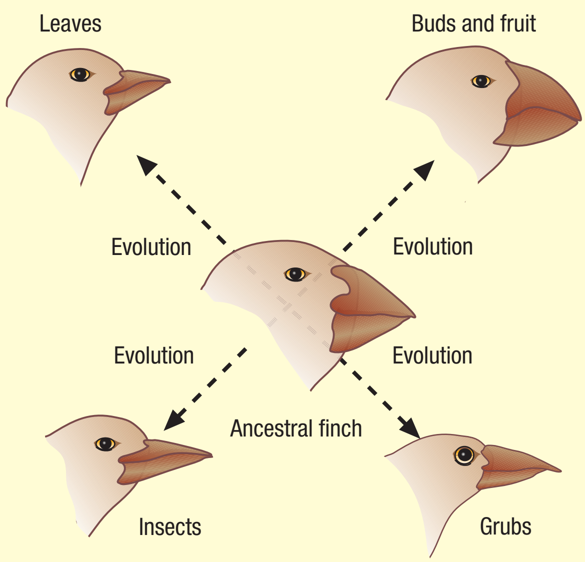


Figure 22.2 Darwin explained the variety of finches from a common ancestor on the Galapagos Islands as a response to competition for food.

On his return to England in 1836, Darwin catalogued the vast number of specimens and fossils he had collected and edited his journals for publication (*The Voyage of the Beagle*). He was again impressed by both the variation and the similarities of many of the species collected.

This led him to contemplate the varieties of domestic animals and the breeding programs that many people undertook to produce features they desired in a particular animal. He carried out painstaking research and experimentation to substantiate his ideas during the next 20 years. He gleaned ideas from the published works of Malthus (1798) and gained confirmation from the observations of Alfred Russel Wallace, whose work in South America, Malaya and the East Indian Archipelago was published in 1858. He finally published *On the Origin of Species* in 1859 and, in 1871, *The Descent of Man*. The controversy raised by those books among fundamentalist religious groups still rages today.

Darwin was well recognised and respected by the scientific community for his rigorous observation and experimentation. His theory was, therefore, at least given a positive reception by his peers.

22.2.2 Origin of species by natural selection

Influenced by Malthus's study of the reproductive potential of the human species, and observations of living organisms in various parts of the world, both Darwin and Wallace came to a similar conclusion: that natural selection was the basis for evolution. Fifty years after Lamarck's proposal was published, Darwin formalised his theory in his book *On the Origin of Species*. His theory was based on the following observations and considerable follow-up experimentation:

- Individuals within a population have a great reproductive potential.
- The numbers of individuals in a population remain approximately constant.

  Many individuals fail to reproduce. There is a 'struggle for existence' within a population.

- Variation exists within all populations.

  In the 'struggle for existence', those individuals showing variations best adapted for their environment at that particular time have a 'reproductive advantage' and produce more offspring than less well adapted individuals.

- Over many generations new variations gradually accumulate which may result in new species.

In this natural selection of the fittest, the variation already exists within the population: it is already part of the gene pool. Changes in the environment 'select for' those individuals in the population that have variations making them better adapted to survive in the changed conditions, and 'select against' individuals that do not have these traits. In this way natural selection leads to increased vigour within the species and ensures its survival.

22.2.3 Neo-Darwinism

The theory of natural selection has been extended and elaborated as a result of contemporary evidence from genetics, molecular biology, palaeontology, ecology and ethology. **Neo-Darwinian** evolutionary theory is now defined as the theory of organic evolution by the natural selection of genetically determined characteristics. It can refer to both the results and the process of evolution. Thus:

- Organisms produce far more offspring than can possibly survive.

- Organisms differ in ways that affect their survival.
- Many variations within an organism are controlled by genes.
- Natural selection keeps species adapted to their environment.
- New species may arise by isolation of populations.

Most of these studies still suggest a gradual change in populations over time, but there is some evidence that occasionally these changes may be dramatic. Mutation of several genes may occur within a short period of geological time in rapidly changing environmental conditions. This theory, known as **stepped** or **punctuated evolution**, proposes a relatively rapid change in population traits and could explain why sometimes there are no intermediate stages in the fossil records between two closely related species.

It should be noted that evolutionary *theory* is a theory, a working hypothesis through which certain observable phenomena can be explained. Although

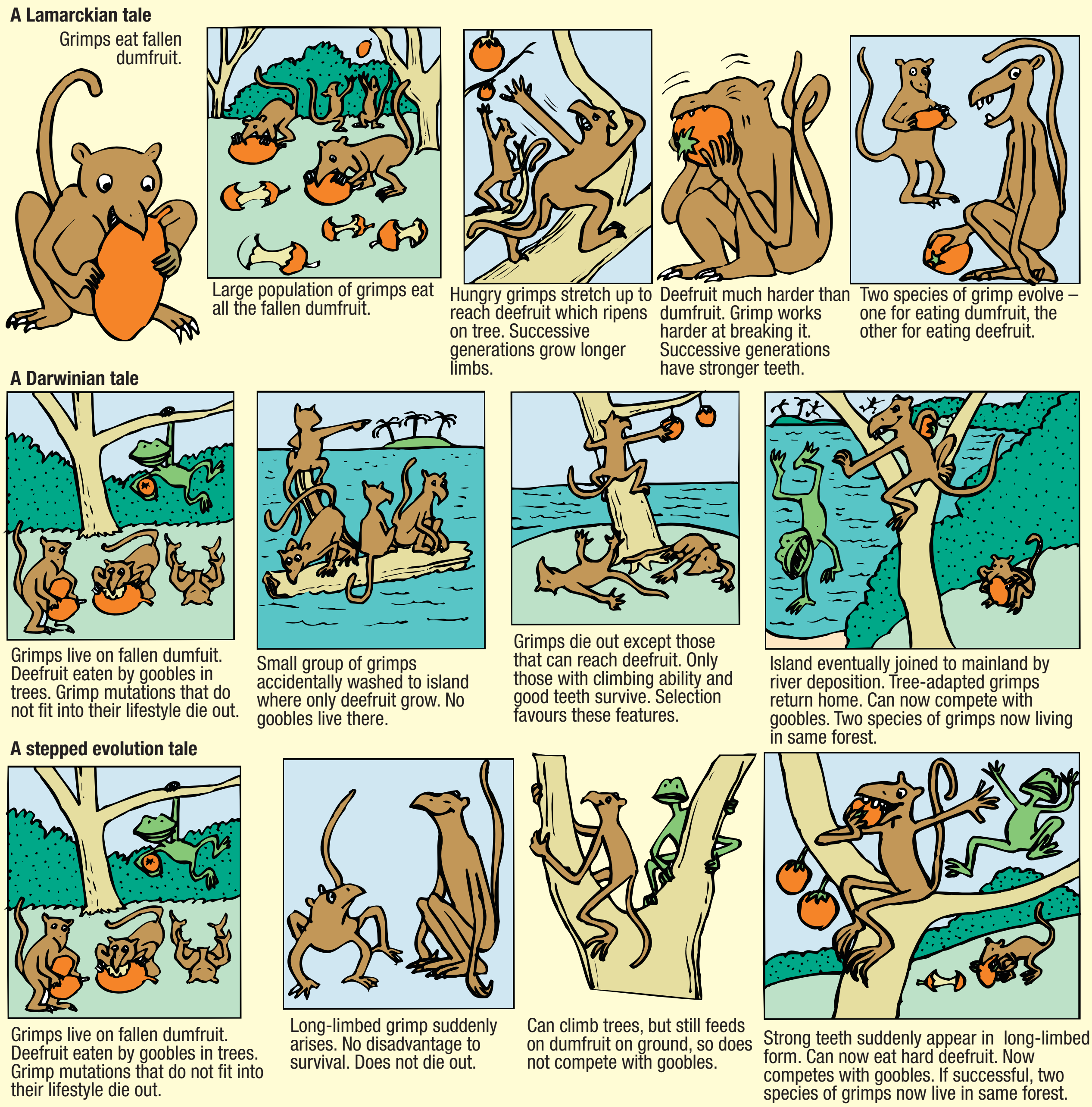


Figure 22.3 Three evolutionary tales

there is much evidence to suggest that this is a supportable hypothesis, there is no absolute proof and thus no laws or dogmatic truths. Among the scientific community, however, the evidence is sufficient for widespread acceptance of its reality, even though there is continued debate on the exact mechanisms by which it is achieved.

SUMMARY

Lamarck suggested that evolution occurs by the transmission of acquired characteristics brought about by use or disuse. This has been shown to be an inaccurate premise.

According to Darwin, evolution occurs by natural selection of chance variations in a population. He described the conflict which occurs between organisms and their environment as the struggle for existence. Those members of a population which have the characteristics that better enable them to survive in any particular habitat will be more successful at reproducing offspring than those less well adapted. There is natural selection for the better adapted members of the population.

Darwin's theory, updated by the findings of modern genetics, molecular biology and other scientific disciplines, is referred to as Neo-Darwinism.

It has been suggested that at particular stages of the earth's history there may have been simultaneous mutations of genes within a short period of time, resulting in dramatic changes in the gene pool: stepped or punctuated evolution.

? Review questions

22.2 Lamarck's statement of use and disuse was based on observation, but his idea on inheritance of acquired characteristics was not.

(a) What was Lamarck's observation about use and disuse?

(b) Give an example of use and disuse which is observable.

(c) What was Lamarck's theory about the inheritance of acquired characteristics?

(d) How did Weismann's experiment help disprove the inheritance of acquired characteristics?

22.3 What does the theory of natural selection attempt to explain?

22.4 What are the three main ideas in the theory of natural selection?

22.5 The largest antler span of any living animal belongs to a species of moose. The male's antlers have a span of about 300 cm.

(a) How might Lamarck have explained the enormous antlers present in this species?

(b) How might Darwin have explained them?

22.6 What is artificial selection? How has selective breeding been used?

22.7 According to Neo-Darwinism, what are the sources of variation described by the theory of natural selection?

22.8 Darwin recognised the existence of variation and the fact that variations are inherited. However, he knew nothing about genetics. How do the following support his theory?

(a) Mendel's work

(b) events of mitosis, meiosis and fertilisation

(c) mutation and crossing-over

(d) the role of DNA

22.3 Evidence for evolution

22.3.1 Palaeontology

Palaeontology is the study of fossils—any form of preserved remains thought to be derived from a living organism. Fossils are an important source of evidence for evolution.

The types of fossils, and the ways they are formed, are summarised in Table 22.1 on page 600.

The fossil record supports a theory of progressive increase in the complexity of organisms, and denies the fixity of species. Geophysical evidence suggests that geographical regions and climatic conditions have varied throughout the earth's history, and these changes would have favoured a mechanism for evolutionary change. Ecological considerations also support this. Thus plants appeared on land before animals, and insects before insect-pollinated plants. There are, however, many gaps in the fossil record. This is because:

- dead organisms decompose rapidly
- dead organisms are eaten by scavengers
- soft-bodied organisms do not fossilise easily
- only a small fraction of organisms die in conditions favourable to fossilisation
- only a fraction of the fossils have been unearthed.

Table 22.1 Types of fossils, their formation and examples

Fossil	Fossilisation process	Examples
Entire organism	Frozen into ice during glaciation	Woolly mammoths found in frozen Siberian soils
	Encased in hardened resin of coniferous forests (amber)	Insect exoskeletons found in Oligocene rocks of Baltic coast
	Encased in tar	'Mummies' found in asphalt lakes of California
	Trapped in acid bogs; lack of bacterial and fungal activity preventing total decomposition	'Mummies' found in bogs and peat in northern Europe
Hard skeletal materials	Trapped by sedimentary sand and clay which forms sedimentary rock (e.g. limestone, sandstone and silt)	Bones, shells and teeth found at Riversleigh (Qld) and other sites
Moulds and casts	Hard materials trapped as above. Sediments harden to rock. The skeleton dissolves, leaving its impression as a mould of the organism. This can be infilled with fine materials which harden to form a cast. Great detail is thus preserved.	Gastropods from Portland Stone, Jurassic; casts of horsetails (*Calamites*) of carboniferous forests; internal casts of mollusc shells showing muscle attachment points
Petrification	Gradual replacement by water-carried mineral deposits such as silica, pyrites, calcium carbonate or carbon. Slow infilling as organism decomposes, producing fine detail.	Silica replacements of the echinodern *Micraster*
Impressions	Impressions of remains of organisms in fine-grained sediments on which they died	Feathers of *Archeopteryx* in upper Jurassic; jellyfish in Cambrian rock found in Ediacara, SA; carboniferous leaf impressions in Qld coalfields
Imprints	Footprints, trails, tracks and tunnels of various organisms made in mud are rapidly baked and filled in with sand, and covered by further sediments.	Dinosaur footprints and tail scrapings indicating size and posture of organisms
Coprolites	Faecal pellets preserved from decomposition, later compressed in sedimentary rock. Often contain evidence of food eaten, such as teeth, scales, seeds	Cenozoic mammalian remains

Formation of rocks

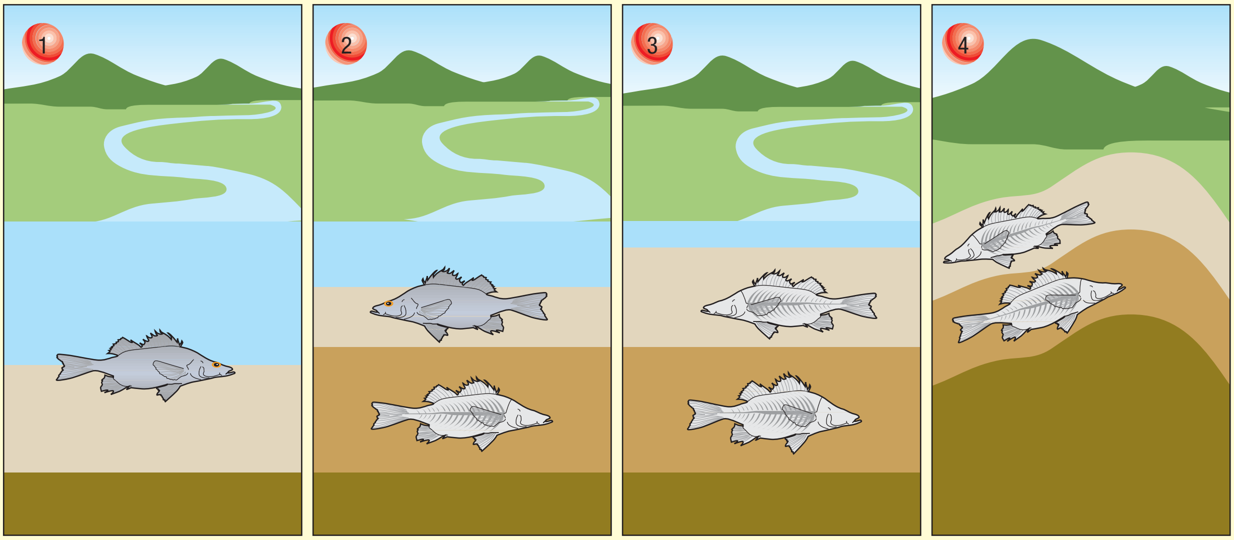
There are three main types of rocks: **igneous, sedimentary** and **metamorphic rocks**.

- The rocks of the original crust of the earth, formed from its molten state some 4600 billion years ago, are classified by geologists as igneous rocks. They also include rocks produced subsequently by volcanic eruptions from the earth's still-molten core.
- Forces of erosion wore these rocks away and reduced them to sediments. These accumulated in hollows in the earth's crust into which rivers drained, known as sedimentary basins. The sediments compacted to form sedimentary rock. With ever-continuing uplifting and erosion, existing sedimentary rocks have been reduced to sediments once again, and new sedimentary rocks have been formed.
- When rocks and sediments are subjected to heat and/or pressure, further changes can occur. The product of such forces is called metamorphic (= changed) rock.

The earth of today is the product of a continuous cycle of rock formation, erosion and crystal movements through the ages. It is possible, with modern technology, to determine the age of some of the minerals in the rocks, so that the successive sedimentary layers can be 'read' and the history of their formation can be interpreted.

Fossils

Fossils may be formed in sediments which later compact to form sedimentary rocks. The soft stages of igneous rocks are so hot that any living organism trapped in them would immediately disintegrate. Some footprints have been found in volcanic ash



1. A fish dies and is covered by sediment.
2. When the sediment compacts into rock, the remains of the fish become fossilised; other fish die and are covered with sediment in upper layers.
3. Different layers of sedimentary rock become established; they contain fossils of different ages.
4. The rocks may undergo folding, be upthrust and surface erosion may expose fossils.

Figure 22.4 One way that a fossil may form

which has later hardened into rock, but the forces of heat or pressure involved in the formation of metamorphic rock tend to destroy any existing fossils.

The most likely places for fossilisation to occur are in seas and lakes where there is a slow accumulation of sediments. On land, rocks are not usually built up by deposition but broken down by erosion. Deposits such as sand dunes are only rarely created and preserved. The only land-dwelling creatures likely to be fossilised in sedimentary rock probably fell into a body of water. As the strata of the sedimentary rock sequences were laid down, bits and pieces of plants and animals were washed down in the sediments, protected from decay by rapid burial, anaerobic conditions, or acid or mineral-rich water, and thus were preserved. Other terrestrial fossils can be formed in areas of constant snow and ice, where the organisms have been caught in snow and frozen or freeze-dried in caves.

Evidence from fossils

Studies have shown that:

- the lowest rock layers are usually the oldest
- the oldest rock layers contain the oldest fossils—very simple organisms which may now be extinct
- the rock layers that formed later contain more complex kinds of organisms
- the variety of fossils increases in the upper, more recent layers of rock
- no fossil records exist of modern, living plants and animals.

This suggests that, over very long periods of geological time, life has been constantly changing from one form to another and there has been a progression from simple to more complex forms.

The Grand Canyon in the western United States is the deepest cleft in the earth's surface. This has been eroded out by the Colorado River over vast periods of time. The walls of the canyon, mostly sandstone and limestone, display a series of strata which originated when the area was covered by a shallow sea. Breaks in the succession of strata represent times when the land rose, the seas drained away and there was erosion of the dry seabed.

The top strata are believed to be about 200 million years old and, although there are no remains of birds or mammals, there are reptilian remnants present as well as fossils of insects and leaves. About midway down the canyon the limestones have been dated at 400 million years old. These rocks contain no reptilian fossils but those of armoured fish. Still lower down, rock strata 500 million years old have no signs of vertebrates, but there are a few shells and worm traces. Three-quarters of the way down, the limestone shows no visible fossilisation at all. At the bottom is a twisted, granite-impregnated rock formation which has been dated at 2000 million years old.

Limestone from Lake Superior, of similar antiquity to the bottom strata limestone of the Grand Canyon, has revealed the presence of structures called stromatolites. These contain fossils about one-hundreth of a millimetre across, similar in shape to living cyanobacteria. The oldest stromatolites have been found in Western Australia. These were described in Chapter 4.

Aging rocks and fossils

Palaeontologists can now compile a reasonably accurate picture of the age, climate and local topography of an area under study; they can also obtain general indications of global climate. All this has been made possible by technical developments in radioactive dating, detection of rock magnetisation and determination of specific chemicals in sedimentary rocks.

Rock magnetisation

Latitude is the fundamental factor determining climate. This can be determined in ancient rocks by measuring the inclination of the remnant magnetism. It has been found that '**magnetic stripes**' exist in rocks. These arise because the earth's magnetic field periodically reverses through geological time. Iron-bearing minerals in molten lava become magnetised in the direction of the earth's magnetic field as the lava cools and solidifies to form igneous rock. As this rock is pushed out of alignment with the formation of new rock, it maintains its original magnetised alignment in spite of the new orientation.

Minerals

The presence of evaporites (salt, gypsum and related minerals) implies an arid climate at the time of their formation; coal or peats imply moist conditions at the site of their accumulation.

Radioactive dating

Certain isotopes undergo **radioactive decay** through emission of alpha and beta particles or gamma radiation to form a more stable element. This change occurs at a set rate for each type of radioactive isotope. The half-life of a substance is the time taken for half of the original matter to change its form.

Carbon was first used to date fossils, since this is an element common to all living matter. The half-life of carbon is 5760 years. There is always a certain amount of radioactive carbon (^{14}C) present in the atmosphere. The assumption is made that at the time of fossil formation a similar amount was present, and that the rate of emission of particles in degrading to ^{12}C is constant. This carbon is taken up by autotrophs during photosynthesis and enters all organisms through the food chain. A given mass of living tissue contains a certain amount of radioactive carbon, and this is compared with the amount of radioactive carbon remaining in fossil material of the same mass.

For example, suppose a modern skull of a particular vertebrate contains 2 g of ^{14}C, whereas a fossilised skull of the same mass contains 0.1 g.

The half life of ^{14}C is 5760 years. Thus:

After 5760 years 1.0 g of ^{14}C remains

After 11 520 years 0.5 g of ^{14}C remains

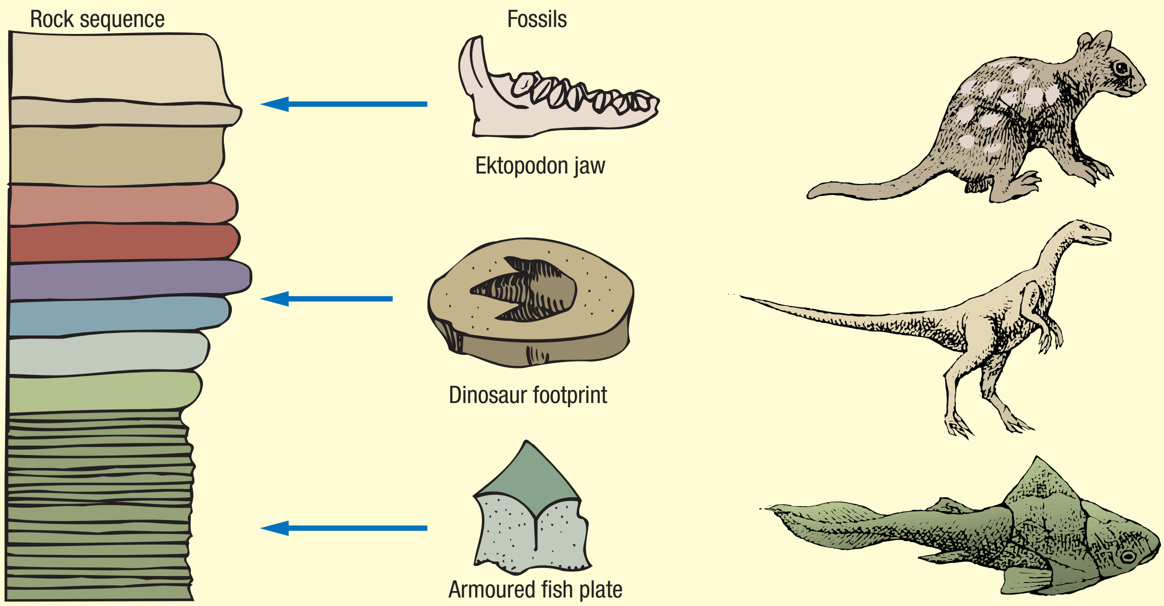


Figure 22.5 A vertical section through sedimentary rocks showing strata containing different fossil forms

After 17 280 years	0.25 g of ^{14}C remains
After 23 040 years	0.125g of ^{14}C remains
After 28 800 years	0.063g of ^{14}C remains.

Using this method, the fossil would be aged at between 23 040 and 28 800 years old. Due to the small quantities of radioactive carbon present in older fossils, this method can give valid results only up to about 20 000 years old.

Ages of older fossils can be estimated by studying surrounding rock samples for other radioactive elements such as uranium and potassium, which have a much longer half-life than ^{14}C. Uranium has a half-life of 4.5×10^9 years and potassium has a half-life of 1.3×10^9 years. Since there are usually several radioisotopes in any particular rock, decaying at different speeds, it is possible to make cross-checks.

Fission track dating is a comparatively new method based on the fact that a small proportion of the uranium-238 nuclei undergoes spontaneous fission. In certain crystalline materials the heavy fission fragments leave tracks in the crystal lattice. The tracks may be made visible by etching, and then counted.

Although there are inherent problems in the radioactive dating method due to the assumptions which must be made, it is believed that the earth is about 4600 billion years old. The time taken to transform the dead planet into the living world of today is called 'geological time'. It was once thought that life originated on earth during an age termed the Cambrian. Recently discovered fossils in South Australia, however, indicate that simple life forms did exist before this time. Nevertheless, for the first 4000 billion years—the Precambrian times—there is little record of air-breathing life forms which now characterise this planet.

Geological time has been broken up into three eras—Palaeozoic (= ancient), Mesozoic (= medium age) and Cenozoic (= recent). These eras are further subdivided into periods. As plants and animals evolved, new forms arose, flourished and then became extinct, to be replaced by other new forms. The different plants and animals characterise different geological periods. Consequently, the fossils found in rocks can be used to determine the age of the strata in which they occur and to correlate rocks found in geographically separated areas. The geological timetable and major life forms associated with them are illustrated in Figure 4.15 on page 61.

22.3.2 Geographical distribution

In spite of similarities in habitat, there is a discontinuous distribution of plant and animal species on the different continents. At the same time, many related forms are found in widely separated regions. Remnants of an ancient Antarctic beech forest (*Nothofagus moorei*) exist in the temperate and subtropical rainforests of eastern Australia and the mountains of New Guinea, New Zealand and South America. Fossil records indicate that in past times these forests also existed in New Caledonia and Antarctica. There are three existing genera of lungfish found separately in tropical regions of

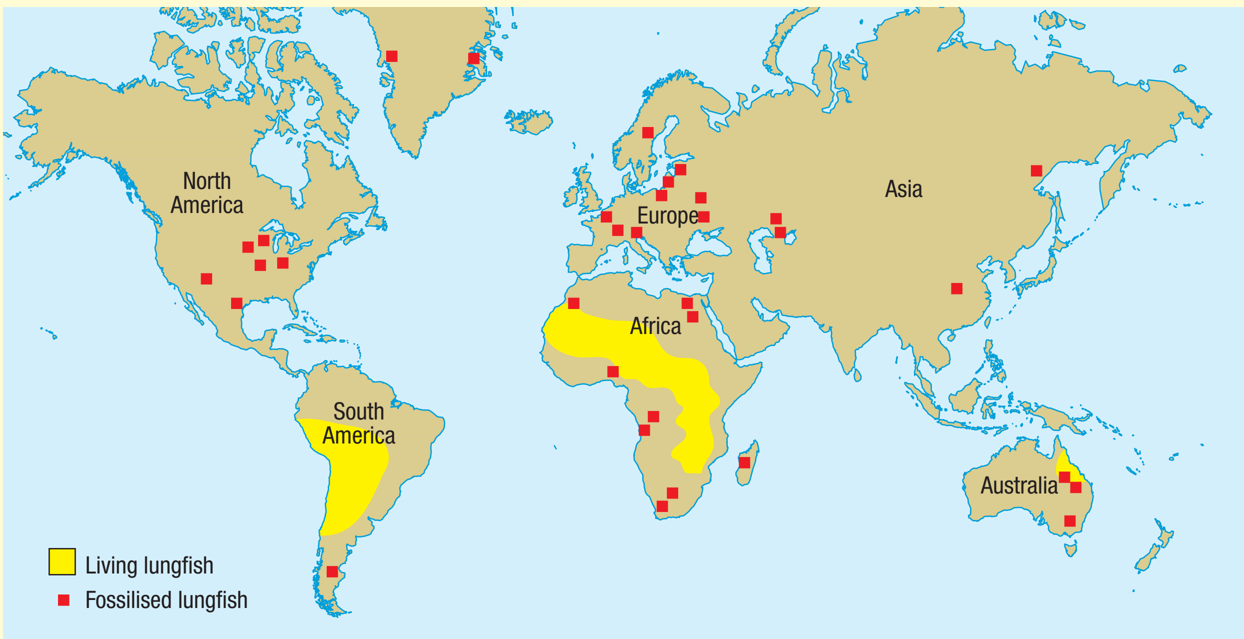


Figure 22.6 Distribution of living and fossil lungfish

South America (*Lepidosiren*), Africa (*Protopterus*) and Australia (*Neoceratodus*). Fossils also have this discontinuous distribution.

Fossils of *Mesosaurus*, a reptile that existed 200 million years ago, are found only in western South America and south-eastern Africa. A sheep-sized reptile of the same vintage, *Lystrosaurus*, flourished in South America, India and Antarctica. Species of *Glossopteris*, early gymnosperms which existed as trees and woody shrubs, are characteristic plants of the Permian period. Fossils are commonly found in coal beds in India, Australia, South Africa, South America and Antarctica, but not in any country in the present Northern Hemisphere.

Continental drift

After studying the outlines of the present-day continents, a German geologist named Wegener suggested in 1912 that in past times these all formed one landmass which has subsequently drifted apart (**continental drift theory**). The discontinuous distribution of living and extinct organisms supports Wegener's theory.

At the time when Wegener put forward his theory, the mechanisms for such a movement of the continents through the sea floor could not be envisaged, and the theory was not received favourably. However, developments in technology after World War II have increased our knowledge of the deep ocean floor. This has been found to be relatively young geologically (150 million years old). Furthermore, the age of the rocks is found to decrease towards oceanic ridges such as the Mid-Atlantic Ridge. Wegener's theory has been revised and expanded into the theory of sea floor spreading and **plate tectonics**.

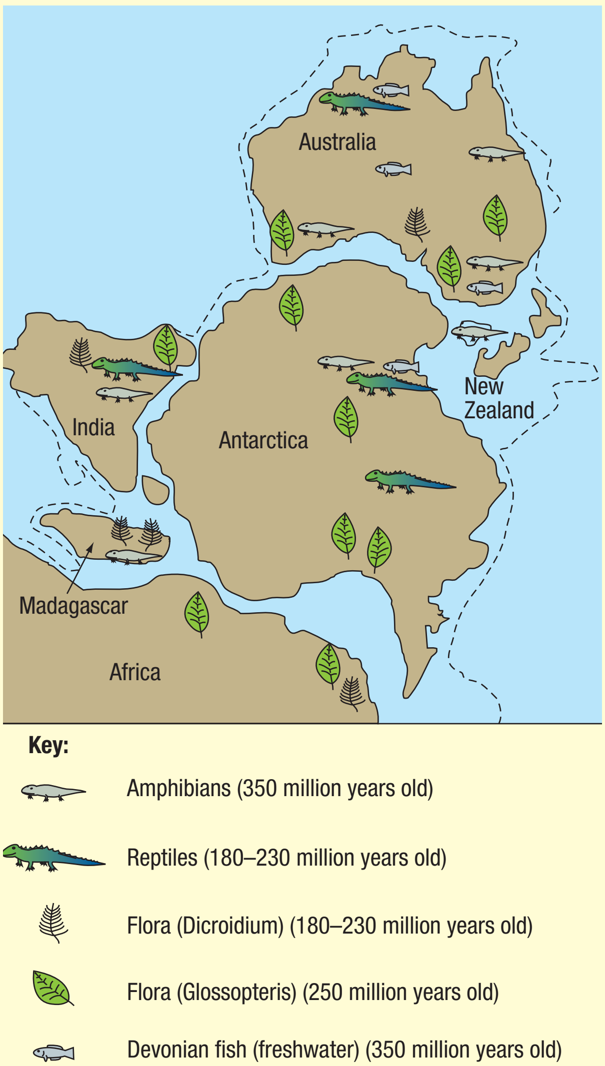


Figure 22.7 Fossil evidence of continental drift

Plate tectonics

The theory of plate tectonics suggests that the surface of the earth is divided, by a series of fractures, into large crustal plates which float on the earth's molten mantle (Figure 22.8). It is proposed that these plates are in constant, very slow motion. The continents sit on these plates. Very sensitive monitoring equipment, some of it located on the moon, measures the current rate of movement at a few centimetres each year.

The earth's core is believed to be undergoing radioactive decay which produces heat, and thus convection currents, in the mantle. These currents push the molten magma of the mantle against the crustal plates. Active zones in the earth's crust, where earthquakes, mountain building and volcanic activity occur, lie on the edges of plates. The boundaries between the plates are of four types:

- spreading or divergent zones
- subduction zones
- collision zones
- transformation faults.

Spreading or divergent zones

On the seafloors are great rifts and ridges that circle the world like giant zips. The convection currents in the mantle continually push new material to the surface along the lengths of these rifts, forcing the seafloor to spread apart (Figure 22.9). This spreading zone provides the power that drives the plates. An example of this is the movement apart of the American and African plates. As a result of the formation of new crust, the island of Surtsey, south of Iceland, appeared out of the sea in 1963.

Figure 22.8 The main continental plates

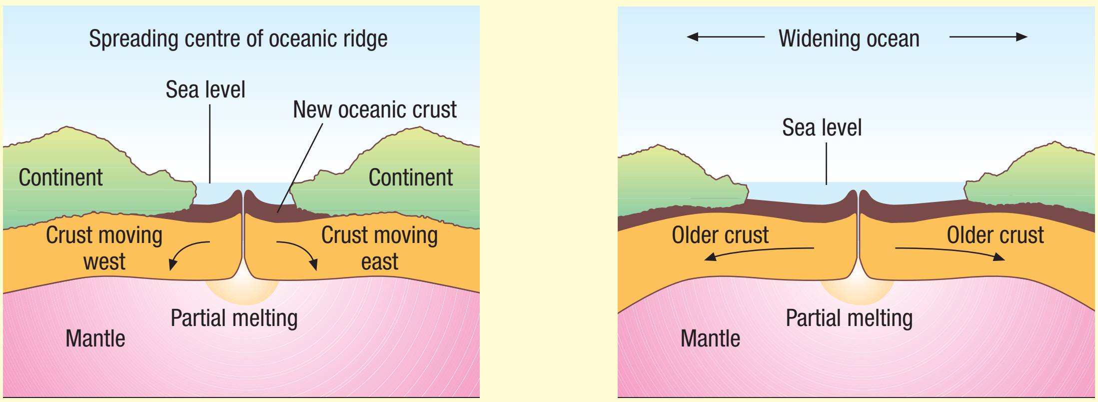


Figure 22.9 Seafloor spreading

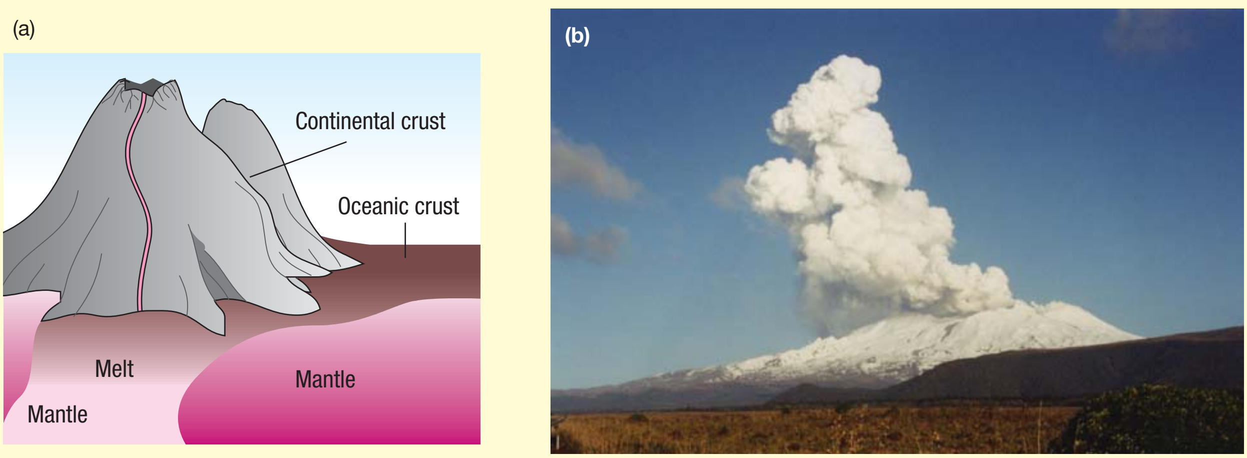


Figure 22.10 (a) Subduction (b) Eruption of an active volcano in New Zealand

Subduction zones

At this type of boundary, plates converge and the edge of one is forced down and consumed by the heat of the mantle. When the boundaries of these plates are covered with ocean, deep-sea trenches result. At a surface distance of up to 60 km from the trench, a line of volcanoes often develops parallel to the trench. This is because the subsiding plate causes rocks to melt; the liquid rock then rises through the overriding plate and emerges in volcanic eruptions. The Pacific plate is currently sliding under the Eurasian plate, resulting in the Pacific 'Ring of Fire' volcanic activity. Earthquakes also develop from the deep-seated friction.

Collision zones

If plates collide, a folded mountain range may be formed as the crustal material is compressed and thrust upwards. This process is thought to have caused the formation of the Himalayas, by the collision of the Indian and Eurasian plates.

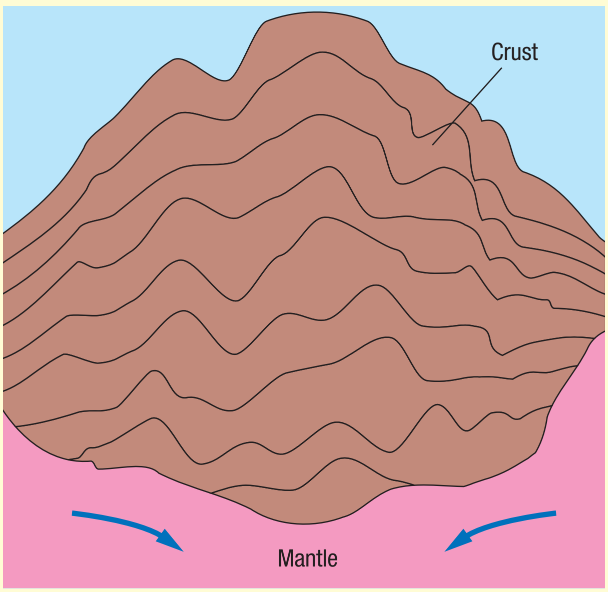


Figure 22.11 Collision zone

Transformation faults

In some localities one plate slides past another without production or destruction of actual crustal material. The movement along these boundaries is seldom smooth. There is usually a period of little surface movement while pressure builds up underneath, followed by sudden release of pressure which results in violent earthquakes.

The San Andreas Fault in California is an example of a transformation fault. In areas inland of Los Angeles the Pacific Plate is moving slowly north at a rate of 25 mm a year. Movements of this fault between the Pacific and North American plates in 1906 (a movement of 6 m) and in 1989 caused severe earthquakes in San Francisco. The 1989 earthquake measured 6.9 on the Richter scale. The largest recorded earthquake, in Alaska in 1964, measured 8.6.

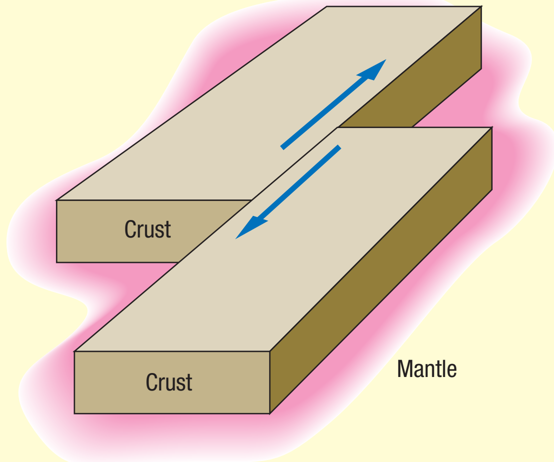


Figure 22.12 Transformation fault

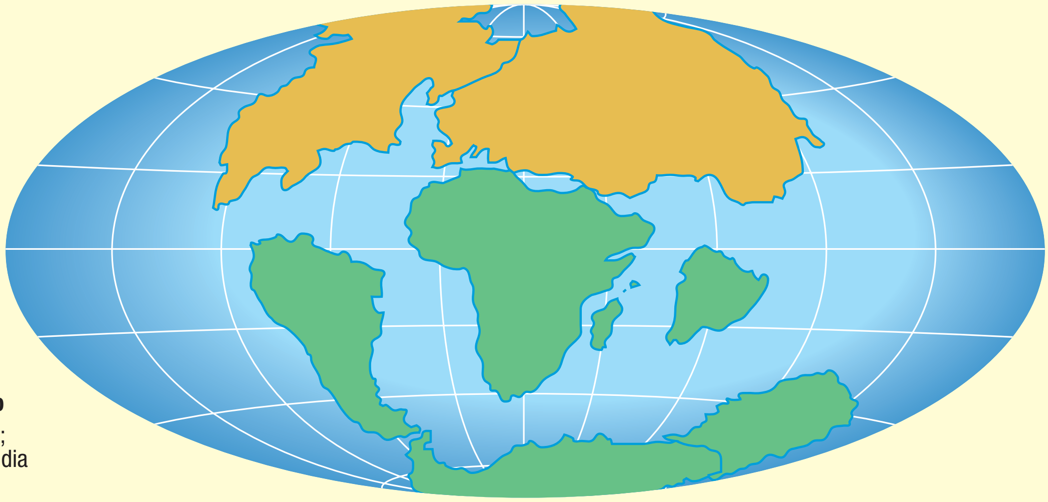
According to the plate tectonics theory, the continents in the Cambrian period (570 million years ago) were one large landmass called Pangaea. Movement of the crustal plates about 200 million years ago resulted in two landmasses, Laurasia in the Northern Hemisphere and Gondwana in the Southern Hemisphere. Further seafloor spreading has resulted in the current distribution of continents.

Many of the distribution patterns of plants and animals, such as the presence of marsupials only in South America and the Australian region, can be neatly explained by this theory. The marsupial record shows fossils of these animals in both of these continents as well as in Antarctica. It is believed that Australia separated from South America prior to the expansion of the eutherian mammals, which were very successful competitors. Thus in Australia the marsupials were able to expand and adapt to the wide variety of habitats available to them.

A more recent influence on the distribution of plants and animals, particularly animals of the Northern Hemisphere, has been the series of ice ages. These have occurred over geological time, possibly due to cosmic influences. The overall lowering of global temperatures resulted in a lowering of sea levels due to formation of ice (see Figure 22.14 on page 608).

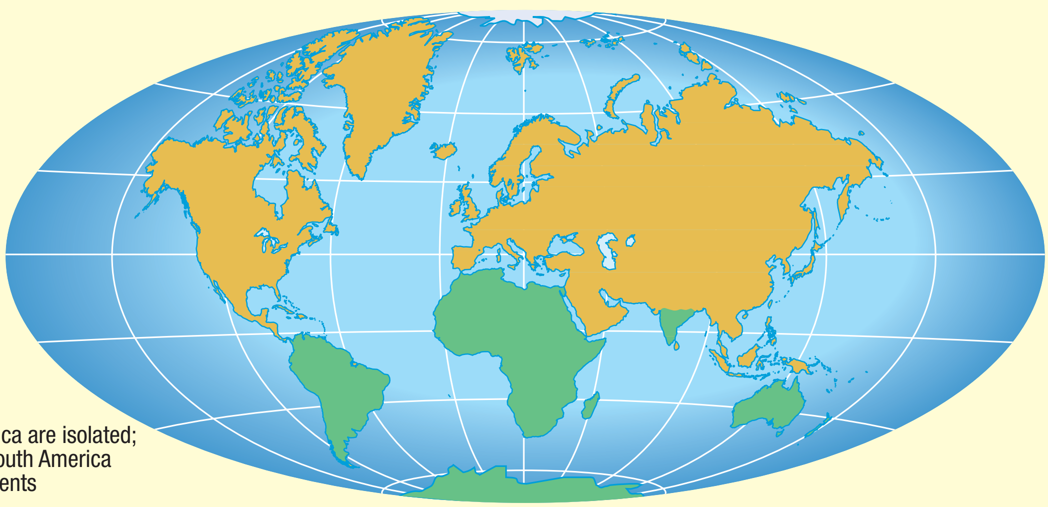
240 million years ago

Major landmasses grouped to form the super continent known as Pangaea, which split into Laurasia and Gondwana.



60 million years ago

Continents separated; South America and India are islands.



Present-day

Australia and Antarctica are isolated; North America and South America are linked; the continents are still moving.

Figure 22.13 Continental drift

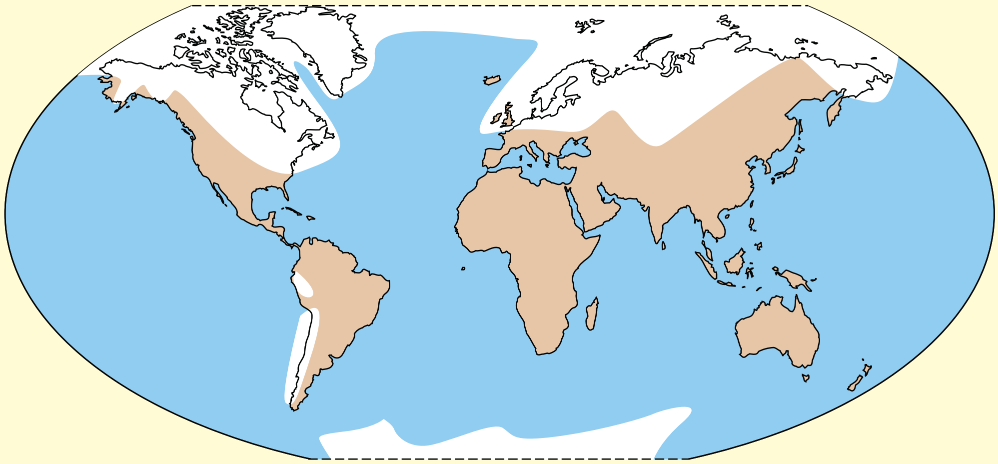


Figure 22.14 Extent of Pleistocene glaciations (1 million years ago)

22.3.3 Comparative anatomy

Comparative anatomy deals with similarities and differences in structures. Similarities are used as a gauge of evolutionary relationships between different species: the more similar the structure, the more closely related they are. Structures may be analogous, homologous or vestigial.

Analogous structures

Analogous structures have a similar function but no structural relationship. Thus the wing of an insect and the wing of a bird serve the same function — flight—but are structurally dissimilar. This suggests that these two groups have different ancestral origins. These structures are regarded as examples of **convergent evolution**, whereby structures with different origins have become adapted to a common function.

Homologous structures

Homologous structures are those that are similar in structure and development but which may have different functions. Thus the wing of a bird, the flipper of a whale and the leg of a dog all possess the structural plan of the **pentadactyl** (5-digit) **limb** (see Figure 4.36, page 78) although their functions differ. Similarly, although they may differ in detail, all flowering plants share the following features:

- roots
- stems with branches
- leaves with chlorophyll
- flowers usually composed of sepals, petals, pistil and stamens.

Homology, therefore, implies common ancestral origins and suggests that differences in structure have evolved in response to different environmental conditions. This is called **adaptive radiation** (Figure 22.15). Diversity of form arising from different selection pressures has resulted in divergent evolution of differently adapted structures. (See Figure 2.3, page 25).

Vestigial structures

The possession of vestigial structures is also taken as evidence of a common ancestral origin. Examples include:

- the reduced bones in the limb of a horse
- stomata on the petals of flowering plants
- the appendix and coccyx of humans
- the hind limb bones of snakes and whales.

22.3.4 Comparative embryology

Embryology has shown that embryos of certain animals closely resemble each other, even though the adults show wide divergence. All vertebrate embryos (including humans) go through a stage with gill slits (visceral clefts) and a tail. It was once thought that the embryology of an individual (ontogeny) recapitulates its phylogeny (i.e. goes through the complete stages of its ancestors). This theory has been modified somewhat, and the current view is that at some stage in its development, an individual resembles the embryos of its ancestors.

Embryological evidence has also been used to show the relationships between different groups of plants. The life cycles of the thallophytes through to the spermatophytes demonstrate a common origin.

Similarities in different embryological structures, therefore, indicate inheritance from a common ancestor. Although adult starfish show pentameric

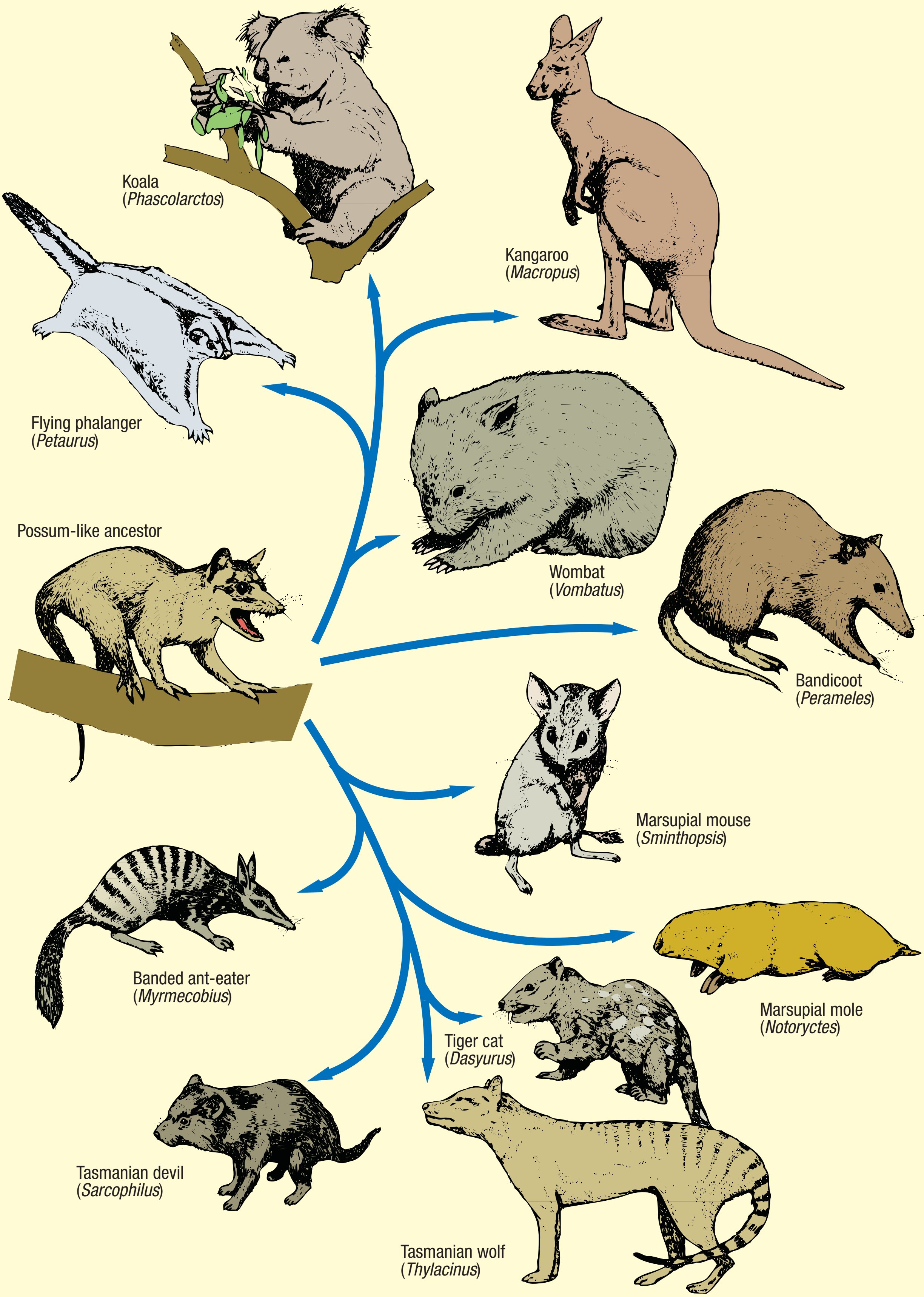


Figure 22.15 Adaptive radiation of marsupial mammals

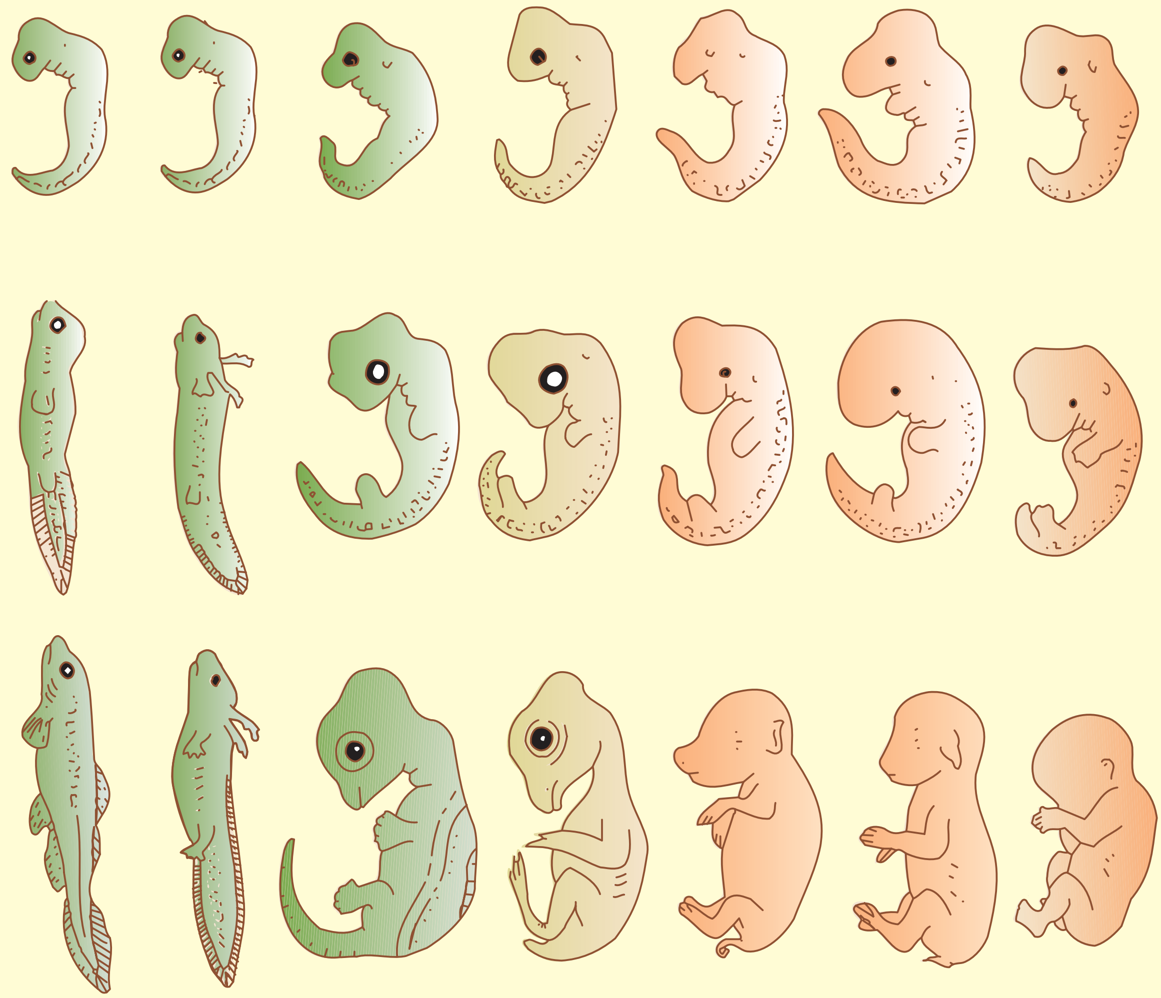


Figure 22.16 Early embryonic stages of some vertebrates

symmetry, the embryo is bilaterally symmetrical. This is the only invertebrate showing such embryological development. Scientists therefore suggest that the chordates and echinoderms are related.

22.3.5 Biochemical evidence

Early schema of evolutionary patterns were derived from structures only—the size, shape and age of fossils, comparative anatomy and comparative embryology. Any genetic variations between groups could only be inferred from the phenotypic expression. These visible aspects of an organism, however, are several steps away from the actual genes that determine their possible expressions. Furthermore, development is also influenced by the environment. The interpretation of the phenotype is also subjective in that certain differences can be deemed as more significant than others. The relevance of a particular set of data over another can vary from one interpreter to another.

The unravelling of the DNA molecule and its role in controlling the development and phenotype of the organism through protein synthesis paved the way to a greater understanding of relationships between organisms and thus evolutionary pathways. Each protein present in the body is coded by a gene—a specific piece of DNA. Protein comparisons between different organisms is, in effect, a comparison of the DNA. The greater the number of similar proteins, the closer the relationship between organisms.

Serological tests

There is, however, a remarkable uniformity of cell structure and function in all living organisms. The biochemical pathways are similar in most living cells. The ability of an organism's defence system to recognise non-self antigens does differ between different groups. Serological tests can therefore indicate protein similarity between organisms. For example, rabbit serum may be used as a testing standard. When serum from other mammals is added to rabbit serum, antibody/antigen reactions will take place and cause precipitation. The amount of precipitation formed with serum from a variety of mammals indicates the degree of serum similarity, and thus similarity of the DNA which codes for the serum proteins. The more similar the DNA composition, the closer the evolutionary relationship is between the organisms.

Table 22.2 Amounts of precipitate produced by adding various serums to rabbit serum containing anti-human antibodies

Source of serum	Precipitation (%)
Man	100
Chimpanzee	97
Gorilla	92
Gibbon	79
Baboon	75
Spider monkey	58
Lemur	37
Hedgehog	17
Pig	8

The figures in Table 22.2 indicate a close relationship between humans and chimpanzees and only a remote relationship between both of these and the pig. The chimpanzee is closer to humans than it is to the gorilla, suggesting that the evolutionary pathway shown in Figure 22.17 (a) is more likely than that shown in part (b).

Although this technique has been used for a long time, it was initially a fairly crude technique involving the entire serum. It is now possible to use purified extracts of particular proteins. The degree of difference between two proteins is termed the **immunological difference**. Comparisons of specific proteins of particular organisms can therefore be examined and the total immunological differences between them gives a much more accurate picture of possible evolutionary pathways. One of the significant features of these studies has shown that particular serum proteins (e.g. albumin) evolve at a constant rate, and that the rate differs from protein to protein. The serum proteins are acting like a clock and thus immunological differences between two species is proportional to how long ago their common ancestor lived. By calibrating the protein clock with fossil dating, an estimate of 'real' time differences can be determined.

Amino acid sequences

Although serological data give information about differences in proteins, it does not show what the exact difference is. Each protein is distinguished by the sequence of amino acids along its polypeptide chain. A change in one amino acid along this chain results in changes to the protein. New technologies have resulted in relatively rapid analyses of the primary structure of proteins. An objective measure of the number of amino acid differences between two related proteins (e.g. the alpha chain of haemoglobin) can then be determined and used to show relatedness between the species from which they came. Thus the alpha chain of haemoglobin is identical between chimpanzees and humans and differs from that of gorillas by one amino acid, supporting the serological data.

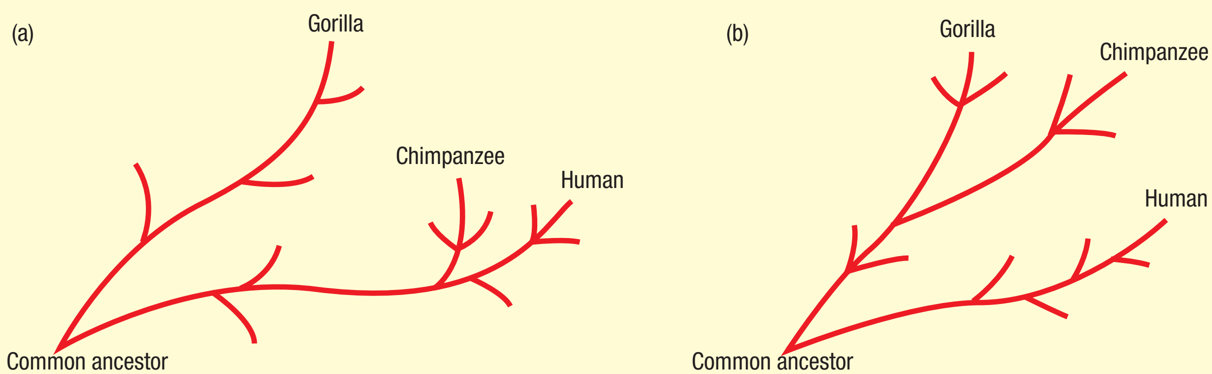


Figure 22.17 In the evolution of humans, pathway (a) is more likely than pathway (b).

DNA sequencing

It was assumed that the presence of the same proteins in two different organisms meant that the DNA triplet codes for the amino acids making up the primary structure of the protein would be identical. This, however, is not the case. It has been found that most amino acids are specified by more than one DNA triplet. Thus two species may have exactly the same amino acid sequence for a protein but have different DNA base sequences. Comparison of these sequences in determining relatedness between species is therefore more powerful than comparison of proteins.

The technique used to compare DNA of different species is called **DNA hybridisation**. Because the two chains of the DNA molecules are bound by weak bonds between complementary bases, they are easily broken by heating to about 85°C. If the sample of separated chains is allowed to cool slowly, the bonds reform the normal strand of DNA. When a mixture of DNA from two species is heated and then allowed to cool, hybrid duplex DNA can form between the two species. The strength of the bonding between the two chains is determined by how many complementary base pairs are formed between them. Thus the more bonds that are formed between the two chains, the greater the similarity between the two types of DNA. The strength of bonding is tested by the temperature needed to separate the hybrid strand. If the chains separate at a low temperature, there are fewer complementary bases and thus bonds than if a higher temperature is required.

Karyotype

Each species has a set number of chromosomes. In the majority of species, at a particular stage of the life cycle, these chromosomes are found to form pairs. Each chromosome of a pair carries genes that code for specific proteins. Thus the genes on one pair of chromosomes will differ from the genes carried on the other chromosomes. Differences between the types of chromosome in any species can be determined by:

- the position of the centromere. The centromere occupies a characteristic position on each of the chromosomes that form a pair that is usually different to the position in other pairs.
- banding on the chromosomes. When specific stains are used on the chromosomes, transverse banding, similar to bar codes, show up. The patterns made by these bands are unique to the particular chromosome. Thus chromosome pairs can be identified. Additionally regions of each type of chromosome can be compared.

Similarities and differences between species can therefore be determined by comparing their karyotypes—the sum total of chromosomal characteristics. Differences in karyotype between species can sometimes be explained by chromosomal mutations (see Section 21.4, Figure 21.12 on page 588).

Regulatory genes

Complex multicellular organisms are composed of different types of cells, each type having a specific function. Every cell, however, has exactly the same genotype. Growth and development would seem to involve the switching on and off of genes in an orderly sequence. The riddle to how these cells could look and behave so differently was explained by the discovery that functionally there are two types of genes. The amino acid sequence of proteins is determined by **structural genes**. Which protein is formed in any particular cell at any particular time is, however, controlled by **regulator genes**. These genes code for proteins that can bind to, and thus switch off, structural genes. During early development of an individual, the regulatory genes determine the metabolic pathways of groups of cells and thus their final form and action. Because each metabolic pathway is controlled by a number of enzymes, and thus genes, a single regulatory gene controlling the start of that pathway can determine the outcome of a large number of structural genes. Any mutation in a regulatory gene can result in dramatic changes to the organism. If, for example, disruption in a regulatory gene that switches on a process in adult development occurs, then that organism may retain its juvenile features—a process called **developmental neotany**. This could explain the axolotl, a group of amphibians that retain the juvenile gills and thus are restricted to an aquatic environment.

Mitochondrial DNA

Each strand of nuclear DNA of any sexually reproducing individual is composed of a chain inherited from the individual's mother and a chain inherited from its father. The recombination of genotypes that results from sexual reproduction render tracing the origins of any mutations almost impossible. However species differences can be traced through either the paternal or maternal line.

In mammals the Y chromosome must be inherited from the paternal line. Thus any mutations in the Y chromosome should be able to be traced, or at least comparisons between the Y chromosomes of different species can be made for relatedness. This is a relatively new field and few conclusive results have been forthcoming.

In all sexually reproducing species, mitochondria are inherited from the mother only. The female produces large eggs that contain at least some food material. Thus the cytoplasm in the egg is important to the future development of the zygote. Cytoplasmic organelles must therefore be replicated in some way in order for the egg to function correctly. Two organelles, the chloroplasts of plants and algae and the mitochondria, are able to replicate themselves. Like the bacteria from which they are thought to have originated, these organelles contain a circular molecule of DNA that codes for the enzymes essential for their chemical activities. There are no equivalent genes on the nuclear DNA. In the human, the mitochondrial genome consists of about 16 500 base pairs which are known to code for thirteen proteins, twenty-two tRNAs and two rRNAs. During fertilisation only the sperm nucleus is injected into the ovum, thus even if present in the sperm cytoplasm, no paternal mitochondrial DNA will be found in the zygote.

The advantages of using mitochondrial DNA (mtDNA) over nuclear DNA in tracing evolutionary lineages include:

- Direct genetic lines can be traced, since only maternal mtDNA is passed on to offspring.
- mtDNA does not exhibit recombination creating a garbled genetic history.
- Mitochondria are present in large numbers in each cell, so fewer cell samples are required to obtain large amounts of mtDNA.
- mtDNA has a higher rate of substitution (mutations where one nucleotide is replaced by another) than nuclear DNA, making it easier to resolve differences between closely related individuals. By determining the rate at which this mutation occurs, a molecular clock can be calculated that can give the point in time at which different groups diverge.

Although the human mitochondrial genome was one of the first human chromosomes to be analysed and sequenced in its entirety, it has only been very recently that the technology to allow comparisons of the whole sequence has been fully developed. Therefore most studies have been restricted to a small section called the D-loop that contains about 7 per cent of the genome. One of the reasons for selecting this particular section of the mtDNA was its particularly high mutation rate, so that only a short sequence needed to be studied in order to resolve differences between closely related sequences. It appears, however, that this very high rate of mutation in the D-loop could be confusing the information since it has recently been found that:

- sites that have already undergone a substitution can rapidly undergo another substitution back to their original state
- parallel substitutions can occur at the same site in independent lineages
- different sites undergo mutations at different rates within the same region of the mtDNA.

By comparing whole mitochondrial genomes it was found that the rest of the genome outside the D-loop was evolving at an even rate between different sites, different genes and between different gene clusters. Thus analysis of mtDNA is a powerful tool in determining both the age of fossils (the pulp cavity in teeth and remnants of bone marrow are preserved in fossils) and the probable evolutionary pathways through which a series of fossils may have passed.

SUMMARY

Evolution reveals itself in the geographical distribution of animals and plants, comparative anatomy, embryology, cell biology, DNA studies and palaeontology.

Fossils have been formed in the past under limited conditions and can be dated using a variety of radioactive techniques of both the fossil and surrounding rocks.

Isolation of specific organisms on different continents can be explained by the theories of seafloor spreading and plate tectonics.

Comparative anatomy seeks to ascertain analogous and homologous structures. This aids in the understanding of:

- species similarities resulting from convergence due to similar environmental selection pressures
- divergent evolution resulting in dissimilar features of closely related species due to differing environmental pressures.

Comparative biochemistry ascertains similarities and differences between proteins and DNA between different species. The more alike these chemicals are in two species, the more likely it is that a close relationship exists between them, or that they share a recent common ancestor.

? Review questions

22.9 Briefly describe the means by which fossils can be formed, and give examples of each type of fossil.

22.10 Describe the use of the following dating techniques for fossils:

(a) evidence from sedimentary rocks

(b) radioactive decay.

?

22.11 In studying a fossil, a scientist determines that only one-quarter of the original carbon-14 remains. How old is the fossil?

22.12 How can each of the following provide evidence for evolution?
(a) homologous organs
(b) development of vertebrate embryos
(c) serum protein analysis

22.13 Indicate which of the following are examples of homologous structures:
(a) leg of frog and leg of grasshopper
(b) mango leaf and pine needle
(c) ribs of dog and ribs of cat
(d) human eye and horse eye.

22.14 Explain the term 'adaptive radiation'. Illustrate your answer by reference to either the fauna of Australia or that of the Galapagos Islands.

22.15 What evidence exists for the theory of plate tectonics and seafloor spreading?

22.16 How can serum analyses show the relationship between organisms?

22.17 Describe how DNA hybridisation can help our understanding of evolutionary pathways.

22.18 Explain why an understanding of DNA sequencing gives a more accurate picture of relationships between organisms than the presence or absence of particular proteins.

22.19 What features of chromosomes determine a species karyotype?

22.20 A few regulatory genes can have a major effect on the phenotypic expression of an organism. Explain how this can occur.

EXTENDING YOUR IDEAS

1. IB Van Helmont, a seventeenth-century scientist, believed that human sweat was the active ingredient in a dirty shirt. He said that if you placed kernels of wheat and a dirty shirt in an open box, mice would be formed in 21 days by abiogenesis (spontaneous generation). Design an experiment to test Van Helmont's idea in a way that would provide convincing evidence for people of his day.

2. UB Dinosaurs belonging to the same genus have been found in North America and East Africa, and others in South America and India. However, the mammals found in these areas belong to different genera. How would you explain these facts?

3. UB The similarities between the fauna of different continents are cited as evidence for evolution, but so are the differences. How would you reconcile this apparent contradiction?

4. UB The fossil record of Australian mammals includes both marsupials and placental mammals. The marsupials are represented by many species that are now extinct, and by some species that survive to the present day. The placental mammals resemble living species and appear only in the most recent fossil deposits.
   (a) Suggest two possible reasons for the absence of placental mammals from earlier fossil deposits.
   (b) Some of the extinct marsupials are very large and anatomically adapted for feeding on the foliage of trees, but their fossils are found in regions which are currently treeless. Explain the previous survival of these species in such areas.
   (c) Within some surviving marsupial species, present individuals are smaller than their fossil counterparts.
      (i) What is the name of the process that would have brought about this change?
      (ii) Name two factors on which this process depends.
   (d) There is evidence of the arrival in Australia of a human population with a hunter–gatherer way of life at about the same time as the large marsupials became extinct. At the same time the vegetation changed, with fire-resistant species of trees becoming more common.

   Suggest two ways in which the human population might have contributed to the extinction of the large marsupials.

5. UB Different molecules evolve at different rates due to mutation. Many recent studies have been made on nuclear DNA that encodes for ribosomal RNA (rRNA). There are three genes that form a unit that is repeated many times along a chromosome. The three rRNA genes have evolved at a very slow rate and contain some of the most highly conserved sequences of DNA that occur in living organisms. Between the rRNA genes in each unit are regions of genes which have evolved at a rapid rate. This information has provided two 'molecular clocks' by which to trace the evolutionary history of life on earth. The diagram below is a possible evolutionary tree based on the homologous parts of rRNA genes.

   The cells of multicellular organisms are held together by protein filaments. In animals, collagen fibres bind the cells together. This protein was considered to be unique to animals. Recently it has been found in a yeast-like fungus that grows on the anthers of flowering plants.

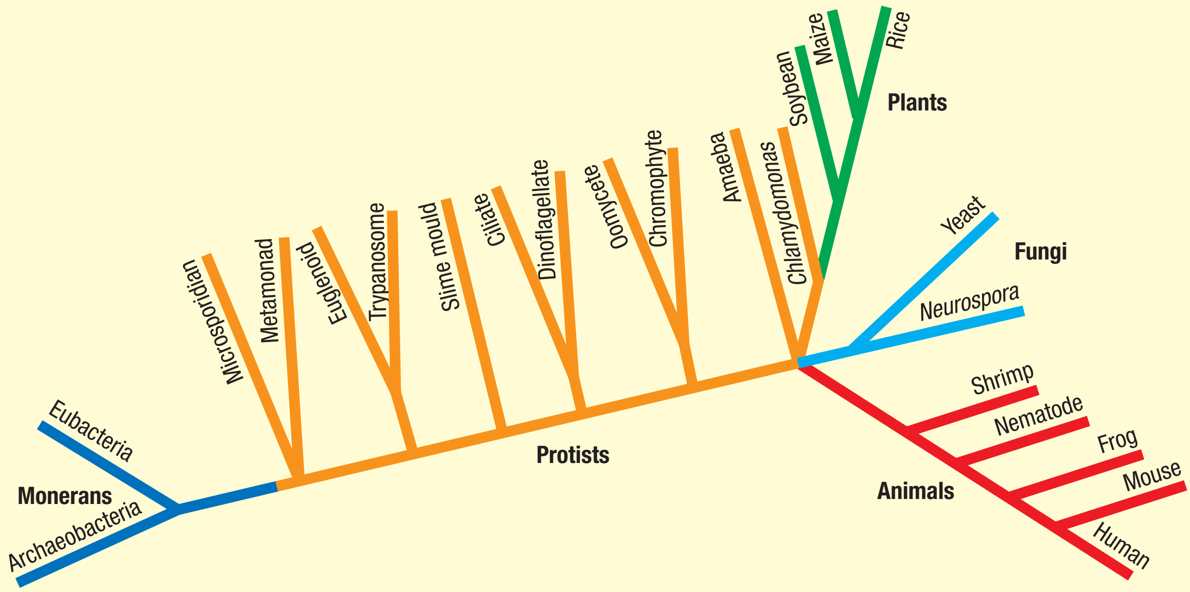


Figure 22.18

Fungi, although heterotrophic, have always been considered to be closely related to plants since they, unlike animals, have cells surrounded by a cell wall. The cell wall in plants is composed of a polysaccharide, starch. The cell wall of fungi (and the exoskeletons of insects and crustaceans) is a modified form of cellulose, chitin.

Based on the information above, explain to which group (plants or animals) the fungi are most closely related.

6. Konrad Lorenz states that:

UB *Beneath the varying behaviours which animals learn lie the unvarying motor patterns which they inherit. These behaviour traits are as much a characteristic of a species as bodily structure and form. Just as the skeletal structure of the whale's flipper, bat's wing and human arm are essentially similar (despite diverging functions), indicating a common ancestor, so too certain behaviour patterns also point out common ancestries.*

As an example he describes scratching in dogs, birds and reptiles, a behaviour he maintains is inherited.

Is this similarity of behaviour conclusive evidence of the common ancestry of these animals? Justify your response.

7. In his book *After Man*, Douglas Dixon predicts that the **EBI** human species is doomed to extinction. This will be as a result of an increased reliance on agriculture, industry and medicine and demands upon non-renewable resources; that is, the demise of the human species will be a consequence of cultural evolution supplanting biological evolution.

Discuss this statement from either an affirmative or negative view, making sure you draw upon your biological knowledge and illustrate your answer with concrete examples.

23 THE MECHANISMS OF EVOLUTION

Two concepts are basic to the modern theory of evolution:

- The characteristics of living things change with time.
- The changes may be acted upon by natural selection.

Both the genetic make-up and the expression of the developmental potential of a population can change. Natural selection—the differential reproduction of genotypes resulting from interactions between individual organisms and their environment—is the driving force of evolution. Through natural selection, populations become better adapted to the prevailing environmental conditions. This can result in coevolution of interdependent species, convergence of the phenotype of different types of organisms, and formation of new species through divergence of characteristics of different populations.

Evolution is the result of accumulated changes in the composition of the gene pool. The gene pool is the sum of all of the alleles of all the genes of every individual in a population.

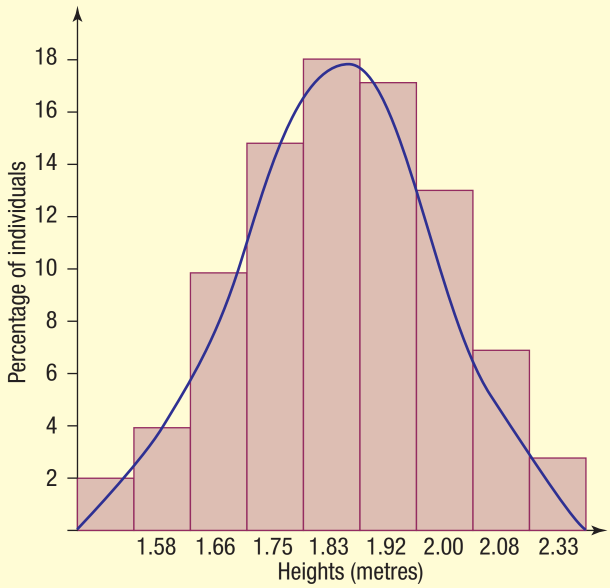


Figure 23.1 Histogram of the heights in an adult human population. The curve derived from this approximates a curve of normal distribution.

23.1 VARIATION WITHIN A POPULATION

23.1.1 STABLE ENVIRONMENTAL CONDITIONS

A population consists of many individuals of the same species, each of which displays distinctive anatomical and physiological characteristics as well as distinctive abilities and behavioural traits. These characteristics are determined by the genotype. Some of these differences are obvious but most are subtle. The phenotypic expression of many traits shows variations which can be plotted, as shown in Figure 23.1.

Typically a normal distribution curve is symmetrical about a mode (the most frequent measurement), although some curves may be distinctly asymmetrical. If either environmental or hereditary characteristics are plotted separately, they tend to give a normal distribution curve. In nature, however, both operate together and it is not possible to distinguish genetic from environmental influences. If a frequency distribution based on all the individuals born into a population is compared with a diagram based only on those which reproduce, a basic similarity can be seen. As long as the environment remains constant, the curve for the breeding individuals is narrower but has the same mean as that for the total population.

The mean represents the type that is best adapted to the environment. It can be viewed as the set point in a homeostatic control mechanism. Differential mortality (i.e. death of individuals at either extreme) favours this ideal type and is biased against the extremes. This kind of selection is called **stabilising selection** because it maintains constancy of species over the generations.

At any particular time, features in the environment will favour some phenotypes over others. If there is selection *against* certain variants and *for* others within a population, then the overall make-up of that population will change with time. Natural selection acts only on the characteristics expressed in the phenotype of the individual. Those individuals with characteristics which give them greater reproductive success produce more offspring. Consequently the frequency of those alleles in the population changes. This leads to adaptation of the population to its environment. Stabilising selection does not mean, however, that all species in a habitat remain unchanged. If a niche becomes vacant, it is very likely that some members of a population will have adaptations which enable them to successfully fill it.

23.1.2 Changing environmental conditions

If the environment suddenly changes, selection will be biased in its favour. For example, an environmental change could make it an advantage to be slightly taller than before, so the new height becomes the 'ideal'. The result is that the mean in the frequency curve of the breeding individuals shifts to the right, and an appreciable overall increase in the mean height of the population results. This kind of selection favours the emergence of new forms and is called **progressive** or **directional selection**. Once the new mean has been established, it is maintained over successive generations by stabilising selection.

This type of selection could account for the evolution of the long legs and neck of the giraffe. As food sources became depleted, selection pressure favoured those individuals in the population with longer legs and necks which enabled them to reach higher foliage.

The resistance of rabbits to the myxomatosis virus is another example of directional selection. A few rabbits either had, or developed, a mutant allele which rendered the virus ineffective. Others had another allele which altered their behaviour so that they spent less time in their burrows. Since the virus is spread by rabbit fleas, this behaviour reduced the chance of spread of fleas by close contact between individuals. Both rabbit variations, therefore, made them less likely to develop myxomatosis and die. Thus there was directional selection in their favour.

Since the results of natural selection at any given moment depend upon the interaction of genetic and environmental variables, a situation could arise where there is an increase in the frequencies at the extreme types in a population and the intermediate (modal) types are eliminated. This is referred to as **disruptive selection**. Plants growing on soil previously contaminated by mining operations often show disruptive selection. Examples are the grasses *Festuca ovina* and *Agrostis tenuis*. There is often a sharp boundary between contaminated and uncontaminated soil. Some of the plants have alleles which allow them, unlike the 'normal' plants, to live on the contaminated soils, although these plants are not successful in competing for resources on uncontaminated soil. With selection against intermediate forms, marked differences between the two groups have developed.

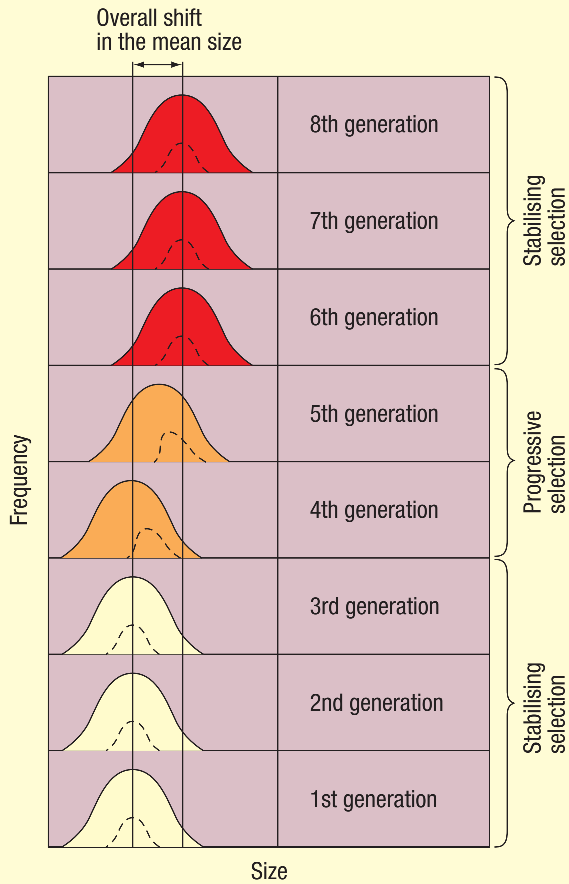


Figure 23.2 Stabilising and progressive evolution. The broken curve represents the breeding population.

Natural selection perpetuates constancy, as long as the environment remains constant; but it promotes the emergence of new forms if and when the environment changes.

Ultimately alleles of a gene arise by mutation. Once a range of alleles is in existence, recombination becomes a mechanism that provides almost endless genotypic variation in the population. Natural selection can act on genetic variation only when it is expressed as phenotypic variation. Genetic variation produced by somatic mutation in sexually reproducing organisms is not raw material for evolution. The variation must be in the gametes to be passed on to offspring.

SUMMARY

Evolution is a change in the genetic make-up of a population in successive generations, usually as a result of natural selection. The genetic make-up of a population can only be changed if parental variations are passed on to offspring in the gametes.

Within any population there are a great many characteristics. Many of these show great variation in their expression. With stable environmental conditions there is a tendency for selection against the extreme traits of a particular characteristic. Instead, selection favours the ideal type: *stabilising selection*. Natural selection perpetuates constancy in a stable environment, unless an unoccupied niche is available.

With changes in the environment, the ideal type may also change. This results in selection pressures directed towards this expression of the characteristic: that is, there will be a shift in the mean for the trait over a succession of generations—*progressive selection*.

Disruptive selection occurs when both extremes are selected for and intermediate forms are selected against.

Natural selection promotes the emergence of new types in unstable environmental conditions. It is the process which results in adaptation to a particular environment.

Review questions

23.1 (a) Differentiate between stabilising, disruptive and progressive selection.

(b) Under what conditions is each type of selection likely to be found?

23.2 Explain why natural selection acts on individuals but evolution occurs only in populations.

23.3 Although the genotype of the population is changed in the process, explain why natural selection acts only on phenotypes.

23.4 How does natural selection result in adaptations?

23.2 The gene pool

The **gene pool** is the sum total of all alleles of all of the genes possessed by all the individuals in the population. Two scientists, Hardy and Weinberg, independently determined that the frequencies of the alleles of any gene in a population can be calculated from the following formula:

$$(p + q)^2 = 1$$

where p = frequency of the dominant allele and
q = frequency of the recessive allele.
This formula can be expanded to:

$$p^2 + 2pq + q^2 = 1$$

where p^2 represents the ratio of homozygous dominants, $2pq$ the heterozygotes and q^2 the homozygous recessives in a population.

Whether or not an allele for a characteristic is recessive can be determined from a family tree. If two parents show one phenotype for the characteristic (e.g. both can roll their tongues) but an offspring shows a different phenotype (e.g. cannot roll the tongue), the parents must be heterozygotes and that offspring is homozygous recessive (i.e. q^2) for the characteristic. The proportion of homozygous recessives in the population can then be determined:

$$\frac{\textit{Number of individuals showing the recessive phenotype}}{\textit{Total number of individuals in the population}}$$

Since $(p + q)^2 = 1$
Then $(p + q) = 1$

Since the proportion of q^2 is known, the frequency of q can be determined:

$$q = \sqrt{q^2}$$

Thus the frequency of p can be calculated from $p = 1 - q$

Using the expansion

$$p^2 + 2pq + q^2 = 1$$

the proportion of homozygous dominants and heterozygotes can be determined for that characteristic.

Thus for the genotypes of any allele in the population (e.g. the tongue-rolling characteristic):

First allele	Second allele	Frequency
T	T	$p \times p = p^2$
T	t	$p \times q$ } $= 2pq$
t	T	$q \times p$ }
t	t	$q \times q = q^2$

By analysing the frequencies of alleles for any particular gene in a population over a period of time, changes in the gene pool can be determined. If there are no changes, the population is said to be in **genetic equilibrium**.

23.2.1 Genetic equilibrium

Change in gene frequency (i.e. evolution) occurs only when something upsets the genetic equilibrium. The **Hardy–Weinberg law** states:

In a large, randomly mating population there will be no change in allele frequency from generation to generation except where there is selection, mutation or migration.

According to this law, under certain conditions of stability, genotypic ratios remain constant from generation to generation in sexually reproducing populations.

To be in genetic equilibrium, a population would satisfy four conditions:

1. *The population must be large enough to make it very unlikely that chance alone could significantly alter the gene frequencies.*

In small, isolated populations there is great susceptibility to random fluctuations in the gene pool, which can easily lead to loss of an allele from the population. This can occur even when that allele is an adaptively superior one. Thus chance can cause evolutionary change by **genetic drift** in small populations. This is called **neutral evolution** since it is as likely to take one direction as another and has an equal chance of being adaptive or nonadaptive.

A research project was undertaken in South Australia, to study the frequencies of alleles of a gene controlling an enzyme in the heart and kidney in thirteen populations of bush rats (*Rattus fuscipes greyi*). This research revealed that small, isolated island populations tended to be homozygous for one or the other allele, whereas the mainland populations exhibited both allelic forms. This genetic drift in the island forms could ultimately lead to their demise. A population is at risk if the environment changes when there is a low level of genetic variation.

2. *Mutations must not occur, or there must be mutational equilibrium.*

This condition is never met in any population. Mutations are always occurring, and mutational equilibrium is very rare. Mutational equilibrium means that the number of mutations from the more common to the less common allele is equal to the number of mutations from the less common to the more common allele. There is usually a change in one direction, resulting in a mutational pressure which tends to cause a slow shift in the gene frequencies in the population. Since mutation is a slow process, and random, mutation pressure is seldom a major factor in producing changes in genotype frequency in a population.

3. *There must be no immigration or emigration.*

Immigration or emigration leads to either a gain or a loss of alleles in the population. Most natural populations probably experience at least a small amount of migration which will enhance variation and thus upset genetic equilibrium. Some populations, however, will experience either no migration or an insignificant amount, and thus genetic equilibrium is not affected.

4. *Reproduction must be totally random.*

Reproduction here refers to:

- selection of mates
- physical efficiency and frequency of the mating process
- fertility
- total number of zygotes produced at each mating
- percentage of zygotes developing to birth
- survival of the young until they are of reproductive age
- fertility of the young
- in some cases, survival of post-reproductive adults, when their survival affects the chances of their young surviving (e.g. noisy miner and kookaburra family groups).

If reproduction is random, then each of these factors must be random (i.e. independent of genotype). This condition is probably never met in any population. Non-random reproduction is synonymous with natural selection.

Given these four conditions for genetic equilibrium, it is not surprising that evolution occurs.

23.2.2 Effects of disturbing genetic equilibrium

Selection pressure will disturb genetic equilibrium. For example, soon after the discovery of the antibiotic activity of penicillin, it was found that the bacterium *Staphylococcus aureus* quickly developed resistance to the drug. Higher and higher doses of the drug were needed to kill the bacteria. The drug did not induce mutations for resistance; it selected against non-resistant bacteria. Some genes determining metabolic pathways that confer resistance to penicillin are already present at a low frequency in most populations. They arose earlier as a result of random mutations, or from incorporation of viral DNA into plasmids. Individuals possessing these genes survive the antibiotic treatment. Since the resistant forms reproduce and perpetuate the population, the next generation shows a marked resistance to penicillin. If such genes were not already present in the population exposed to penicillin, no bacteria would survive and the population would be wiped out.

In sexually reproducing populations, selection determines the direction of change largely by altering the frequencies of alleles that arose through random mutation many generations before. New allele combinations, and allele activities that produce new phenotypes, are established. The principal role of new mutations is in replenishing the store of variability in the gene pool. This provides the potential upon which future natural selection can act. These mutations may be important to the survival of the species in a changing environment and may lead to a dramatic change in the gene pool as a result of natural selection.

In a stable environment natural selection plays a conservative role. Each species, in the course of evolution, comes to have a constellation of genes that act in very precise ways, governing the processes upon which the continued existence of the species depends. Anything that disrupts the harmonious interaction of its genes is deleterious to the species. New groupings of alleles will form through mutation and recombinations in sexually reproducing organisms. Most of these new groupings will be less adaptive than the original grouping and will tend to disrupt the harmonious relationships between the genes. Selection, by acting to eliminate all but the most favourable groupings, is thus the chief factor in maintaining stability in a population. This concept is illustrated by the peppered moth, described in Case study 6.2, page 167.

Many genes have more than one effect. Whether an allele for a gene increases or decreases in frequency is determined by the positive and negative selection pressures that result from it. If the algebraic sum of all the separate selection pressures is positive, the allele will increase in frequency; if it is negative, the allele will decrease in frequency.

Cases are known where the effects of a given allele are more advantageous in the heterozygous than in the homozygous condition. Such a case is the recessive allele for sickle-cell anaemia found in African negroes. When the homozygous dominant (normal) genotype is present, the individuals do not have sickle-cell anaemia but are prone to contracting malaria. Homozygous recessive individuals suffer from sickle-cell anaemia. Heterozygotes, although suffering mild anaemia, display a partial resistance to malaria. Thus the allele for sickle-cell anaemia is retained in the population. Such heterozygote superiority may cause balanced polymorphic variation. **Polymorphism** is the occurrence in the population of two or more fairly sharply distinct forms of a genetically determined character. Human populations are polymorphic for the blood groups A, AB, B and O.

SUMMARY

The gene pool is the sum total of all alleles of all of the genes possessed by all the individuals in a population. The frequencies of alleles for a particular gene in a population can be calculated from the formula devised by Hardy and Weinberg:

$$(p + q)^2 = 1$$

where p = frequency of dominant alleles and
q = frequency of recessive alleles.

If the frequencies of alleles do not change in a population over time, there is genetic equilibrium. For this to occur:

- the population must be large
- there must be no mutation, or mutational equilibrium
- there must be no immigration or emigration
- reproduction must be totally random.

When something upsets the genetic equilibrium, there is a change in the gene frequencies; that is, evolution occurs.

Review questions

23.5 What is meant by a 'gene pool'?

23.6 The Hardy–Weinberg law states that in conditions of stability both allele frequency and genotypic ratios remain constant from generation to generation. List the conditions necessary for this genetic equilibrium.

23.7 What is genetic drift? Why is it considered to be neutral evolution?

23.8 Many zoos are attempting breeding programs to increase the numbers of endangered species. What is the inherent danger of such programs?

23.9 Comment on the following statement:
'The use of a new antibacterial drug may result in the development of new types of bacteria which are resistant to the drug.'

23.3 Speciation

Evolutionary change may result in a species changing greatly in the course of time, thus separating itself from its original ancestors. A species is defined as a group of interbreeding natural populations, which are reproductively isolated from other such groups.

All populations are involved in at least one of the following three structural elements of species:

- a series of gradually changing adjacent populations (**clinal variation**)
- populations that are geographically separated from the main body of the species range (**geographical isolates**)
- rather narrow belts, often with sharply increased variability (**hybrid belts**), bordered on either side by stable and fairly uniform groups of populations or subspecies.

23.3.1 Clinal variation

There are three chief reasons for clinal variation:

- Environmental selective factors vary along gradients. There are very few features that change abruptly. (A feature such as soil colour is an exception.)
- Gene flow among adjacent populations tends to smooth out existing differences.
- **Developmental homeostasis** tends to conceal genetic differences among populations, particularly those with active gene exchange. Developmental homeostasis is phenotypic uniformity despite concealed genetic variation. It is often controlled by a single gene, and can determine an entire metabolic pathway. This is sometimes referred to as 'canalisation'.

Clines are ultimately the product of two conflicting forces: selection and gene flow. Selection makes every population uniquely adapted to its local environment. Gene flow, on the other hand, tends to make all populations of a species identical.

A cline refers to a specific characteristic such as colour or size, not to a population. A population may exhibit as many different clines as it has variable characters. Clines are widespread and occur in the majority of continental species, if not all of them. The cline is theoretically independent of other characters. For example, nearly all Australian birds with size variations decrease in size from Tasmania northwards to Torres Strait along a regular cline. Intensity of colour follows a different cline, decreasing from the humid periphery of Australia to the arid interior.

23.3.2 Geographical isolates

Geographical isolates are populations or groups of populations prevented by a physical, or extrinsic, barrier from free gene exchange with other populations of the species. Geographic barriers are variable, and what might be a barrier to one species is not a barrier to another. For example, freshwater fish living in lakes may be isolated from other populations by land barriers between water systems, whereas birds feeding on the fish can fly from one water system to the next. Grasslands between forested areas may form barriers for mammal populations. The sea is a barrier for oceanic island populations.

Although isolates may occur throughout the range of a species, they are more common at the periphery. This is because the conditions in these areas are likely to be minimal for the survival of the species. Due to the environmental pressures placed on these populations, selection pressure for specific characteristics may be optimal. With time these populations may come to differ from the main body of the species in morphological, physiological, behavioural and other characteristics. Geographical isolates have three possible fates. They may:

- become separate species;
- die out altogether; or
- re-establish contact with the main body of the species.

23.3.3 Zones of hybridisation

Hybridisation usually results from expansion of isolates because of changed environmental conditions. This occurs at a high rate after periods of climatic change: for example, the end of the Pleistocene, which was a period of glaciation when many temperate-zone species contracted into small pockets. In subtropical and tropical regions there were long periods of alternation between arid and humid climatic conditions, and this has had a dramatic effect on the separation and rejoining of populations.

In Australia, drought conditions prevailed between 4000 and 20 000 years ago, resulting in the isolation of forest-dwelling birds in a number of coastal refuges. The present distribution and variation of the varied sittella (*Daphoenositta chrysoptera*) indicates that there were several such refuges. There are six varieties of this sittella—orange-winged, white-headed, striated, pied, black-capped and white-winged. With an increase in rainfall at the end of this dry period, there was expansion of the forest areas accompanied by an expansion of the range of the sittellas, resulting in recontact of the former isolates. There are now five or six zones of hybridisation. Where their ranges overlap, the birds may sometimes interbreed. There are no intermediate forms between the white-winged and striated sittellas because they are separated by an arid region. Hybridisation occurs between all other groups.

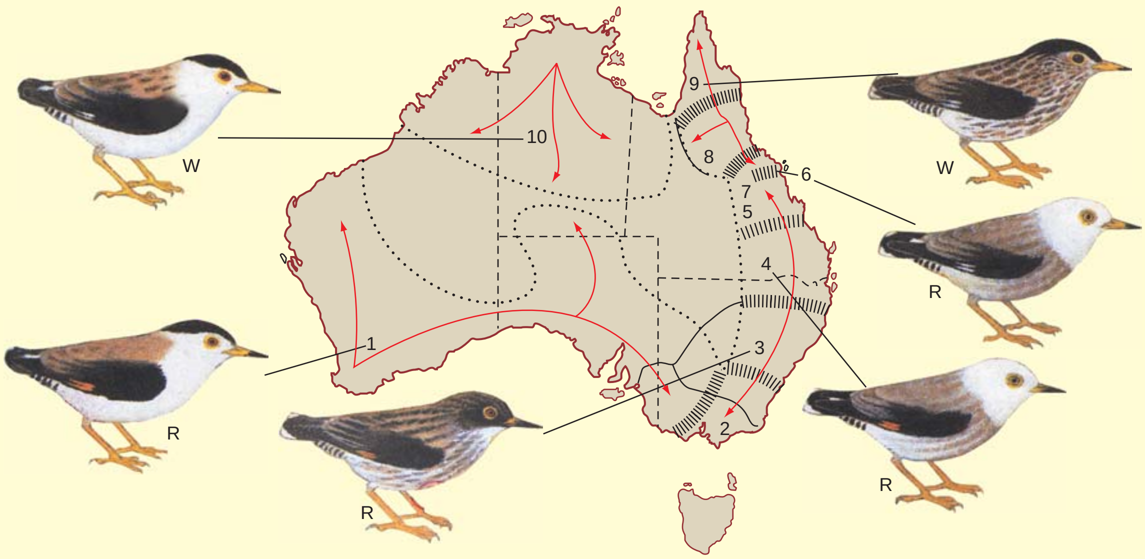


Figure 23.3 Varied sittella (*Daphoenositta chrysoptera*) in Australia. The arrows indicate expansion from post-Pleistocene aridity refuges and the subsequent belts of hybridisation (hatched areas) as former isolates met along a broad front. Birds indicated with an 'R' have a red wing bar, while those indicated with a 'W' have a white wing bar.

23.3.4 Races

When an abrupt shift in genetically determined characteristics occurs in a geographically variable species, the populations on each side of the 'step' are termed subspecies or races. Subspecies are, therefore, groups of natural populations within a species that differ genetically and are partly isolated from each other reproductively by having different ranges. The term 'race' is sometimes applied to more isolated populations when the populations are recognisably different genetically but are believed to be potentially capable of interbreeding freely.

Originally biologists classified the crimson rosella, the Adelaide rosella and yellow rosella as three different species. More recent studies, however, indicate that they are races or subspecies of the one species. Although hybridisation can occur between the crimson and Adelaide rosellas and the Adelaide and yellow rosellas, there is no interbreeding of yellow rosellas in the north-western parts of their range in NSW (Jirilderie) with the coastal crimson rosellas, because they are separated by the Eastern Highlands. It is possible, however, that the latter two birds would not be able to interbreed even if the physical barrier were removed, since their gene pools have been isolated for an extremely long period of time. These birds are now classified as races of the blue-cheeked rosella (*Platycercus elegans*).

23.3.5 Divergent speciation

Divergent speciation is the process whereby one ancestral species gives rise to two or more descendant species, which diverge (grow increasingly dissimilar) as they evolve.

Most biologists agree that in the vast majority of cases, the initiating factor in speciation is geographic separation. If an initially continuous system of populations within the system is divided by some geographic feature that constitutes a barrier to the dispersal of the species, the separated populations will no longer be able to exchange genes and their further evolution will be independent. At first the only reproductive barrier will be geographic, and they will potentially be capable of interbreeding. Eventually, however, they may become so genetically different that there would be no effective gene flow between them should they again come into contact.

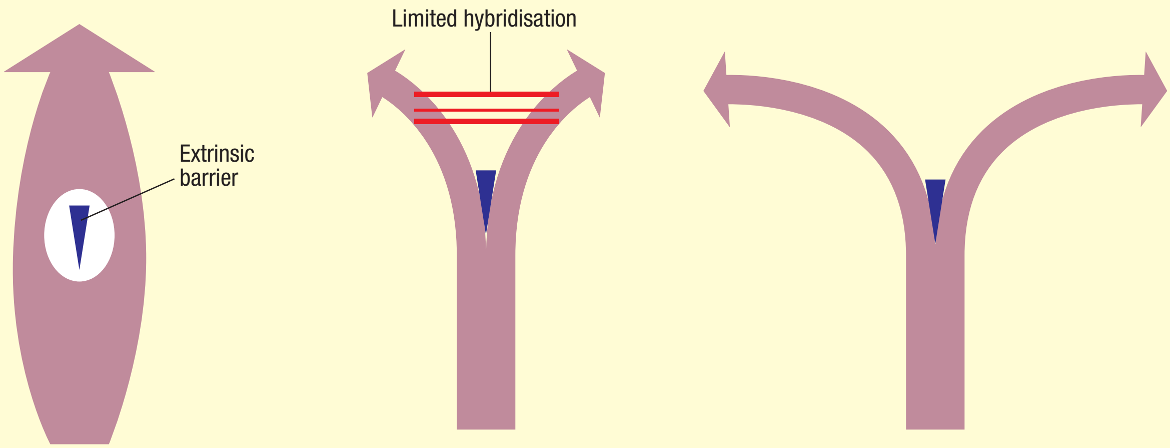
Thus speciation is initiated when external barriers make the two population systems completely **allopatric** (= *different houses*; i.e. having different ranges). This is not completed until the populations have evolved intrinsic mechanisms that will keep them allopatric, or that will keep the gene pool separate even when they are **sympatric** (= *same house*; i.e. having the same range). The eastern grey kangaroo (*Macropus giganteus*) and the western species (*M. fuliginosus*) are believed to have evolved by allopatry. Evolving in isolation in the eastern and

Figure 23.4 Distribution of the crimson, Adelaide and yellow rosella

western parts of Australia, each group subsequently expanded its range. Although their distribution overlaps in western Victoria and New South Wales, they do not interbreed.

The reasons for the initial divergence of gene pools after geographic isolation are:

- Due to geographic variation within a species (e.g. clines) it is likely that a geographic barrier would divide the common gene pool unevenly. If, from the moment of their separation, two populations have different genetic potentials, their future evolution is likely to follow different paths.
- The two populations are likely to experience different chance mutations. Since there is no gene flow between the two populations, a new mutant allele arising in one of them cannot spread to the other.
- The populations will most probably be exposed to different environmental selection pressures, since they occupy different ranges.



(a) Breakdown of extrinsic barrier leading to re-formation of a single population – e.g. white-rumped and black-eared miners

(b) Breakdown of extrinsic barrier leading to limited hybridisation of populations, with selection pressure to prevent mating, e.g. noisy and white-rumped miners

(c) Breakdown of extrinsic barriers after populations have become so different that they can no longer interbreed

Figure 23.5 Models of geographic isolation

Models of geographic isolation

A. An extrinsic barrier divides a population, but the barrier breaks down before the subpopulations have evolved intrinsic isolating mechanisms. The populations fuse together again and share a common gene pool.

B. Isolation is long enough for the development of incomplete intrinsic isolating mechanisms. The extrinsic barrier breaks down and hybridisation occurs. The hybrids are not as well adapted as the parental stock, and thus there is selection pressure to prevent mating between populations. This results in a more rapid divergence between the two populations—character displacement—due to the forces of natural selection.

C. Two populations are isolated by a geographic barrier for so long that, by the time the barrier breaks down, they are too different to interbreed. They have become sympatric species.

Case study 23.1: Demise of the black-eared miner

Miners are a group of Australian honeyeaters which derive most of their nutrients from a sweet substance produced by sap-eating insects called lerps. Before the last ice age there was probably only one type of miner inhabiting the woodlands of eastern Australia. Physical environmental changes divided these woodlands and their miner populations into several small pockets. Over time specific mutations occurred in these isolated populations. Those near the coast developed a dark rump and black face (the noisy miner). In more open, drier habitats, white-rumped miners evolved their characteristic pale rumps and yellow throats; while in the mallee, a dark form with dark ear coverts and a dark rump became the black-eared miner. For thousands of years these birds were separated so that interbreeding could not occur. Then, between 8000 and 10 000 years ago, environmental conditions became milder and members of the three different forms regained contact.

In the time that they were apart, noisy and white-rumped miners became so different that the courtship behaviours of each could not be understood by the other group. There is very limited and rare hybridisation between them. At the time of European arrival, the black-eared and white-rumped miners, although fairly similar, were in such different habitats that they never met. Black-eared miners remained exclusively in the mallee, whereas the white-rumped forms stayed in the adjacent open country. Clearing of the mallee for growing wheat reduced the black-eared miners to small pockets of mallee and resulted in further encroachment by the white-rumped birds.

The two forms have similar behaviour, and a call that is almost identical, so interbreeding between the two forms resulted in hybrids. Since the numbers of white-rumped birds outnumbered the black-eared ones, they interbred more often with the hybrids, with the result that similarities between the hybrids and the black-eared forms from which they originated disappeared within a few generations.

At present there are only a few black-eared miners in existence. Since 1984 a few colonies have been found where, for example, one black-eared bird was found in a colony of eight hybrids. It is thought that black-eared miners are now extinct in South Australia.

Figure 23.6 Distribution of the noisy miner and white-rumped miner (in dark blue)

23.3.6 Intrinsic isolating mechanisms

Intrinsic isolating mechanisms operate to prevent breeding between different populations and thus maintain species differences. They may operate at either pre-mating or post-mating stages of the reproductive cycle. There are eleven types of intrinsic isolating mechanisms:

Mechanisms that prevent mating	1. Ecogeographic isolation	*Mechanisms operative in the parents that prevent fertilisation*
	2. Habitat isolation	
	3. Seasonal isolation	
	4. Behavioural isolation	
	5. Mechanical isolation	
Mechanisms that prevent production of hybrid	6. Gametic isolation	
	7. Developmental isolation	*Mechanisms operative in hybrid, preventing its success*
	8. Hybrid inviability	
Mechanisms that prevent perpetuation of hybrids	9. Hybrid sterility	
	10. Selective hybrid elimination	
	11. Parthenogenesis	

Ecogeographical isolation

Two populations which initially are separated by some extrinsic barrier may, in time, become so specialised for different environmental conditions that neither can survive in the habitat of the other. Genetic differences under natural conditions prevent gene flow between the two species.

The sycamore (*Platanus occidentalis*) is found in the eastern USA. The oriental plane tree (*Platanus orientalis*) is found in eastern Mediterranean regions. Artificial crosses of these trees produce vigorous, fertile hybrids but, because they are adapted to different climates, these two species do not hybridise naturally.

Many eucalypts of the sand plains of southern Western Australia are adapted to winter rain and will not thrive in eastern Queensland with its summer rains.

Habitat isolation

When two sympatric species occupy different habitats within their common range, the individuals of each population will be more likely to encounter and mate with members of their own population than with members of the other population. Their genetically determined preference for different habitats helps keep the two gene pools separate.

Bufo fowleri and *Bufo americanus* are two closely related toads that can cross and produce fertile offspring. However, where the ranges of each population overlap in California, *B. fowleri* normally breeds in the quiet waters of streams and *B. americanus* breeds in shallow rain puddles.

The Australian white-naped honeyeater (*Melithreptus lunatus*) is found in forest areas along the east coast from Adelaide to Cairns. A similar species, the white-throated honeyeater (*M. albogularis*), occurs from Derby in WA across northern Australia to Grafton in NSW, associated with tropical woodland savanna. In the overlap zone in north Queensland *M. lunatus* occupies the high country and *M. albogularis* the lowlands, and in

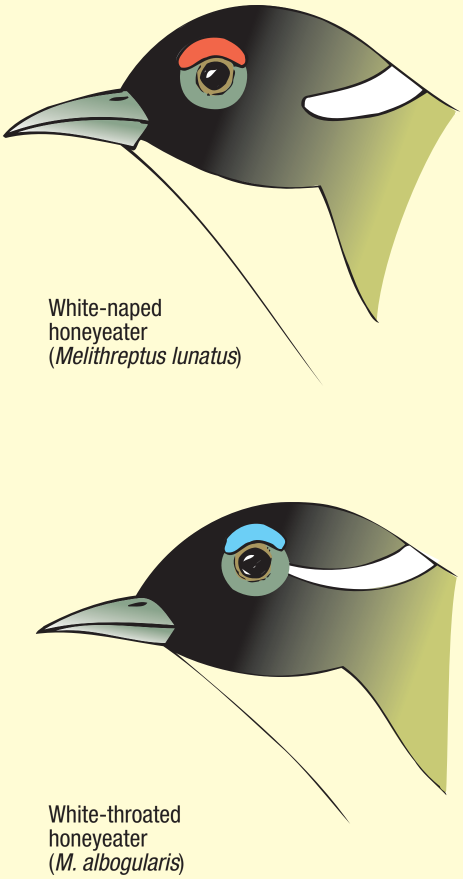


Figure 23.7 Distinguishing markings of the white-naped and white-throated honeyeater

central Queensland the former inhabit the hills and the latter the flat country.

Seasonal isolation

If two closely related species are sympatric but breed at different seasons of the year, interbreeding between them will be effectively eliminated.

Pinus radiata and *Pinus muricata* are sympatric in parts of California. They do not form hybrids in these conditions because *P. radiata* sheds its pollen in early February, whereas *P. muricata* sheds its pollen in April. Many Australian eucalypts in mixed forests, which could potentially form hybrids, also flower at different times of the year.

Behavioural isolation

Behaviour plays a fundamental role in species recognition among animals. Visual, auditory or olfactory signals, or combinations of them, are important in mating. Each species of fireflies, for example, has its own particular flashing pattern which draws the male and female together. The duration of the flash, the interval between flashes and the intensity and colour of the light varies from species to species. Bird songs, frog calls and stridulations of many insects such as cicadas (noises made by rubbing leg parts together) are all species-specific aids to correct mating.

The black-throated finch (*Poephila cincta*) inhabits savanna woodlands from south-eastern Queensland to northern Queensland. A very closely related finch, the long-tailed finch (*Poephila acuticauda*) in dry savanna in northern Australia, is somewhat similar in appearance. They both have the same courtship pattern except that the male black-throat does not dance with a piece of grass in its bill as does the long-tail. Similarly, the behaviour of the noisy miner has become too different from that of the white-rumped miner to produce more than limited interbreeding.

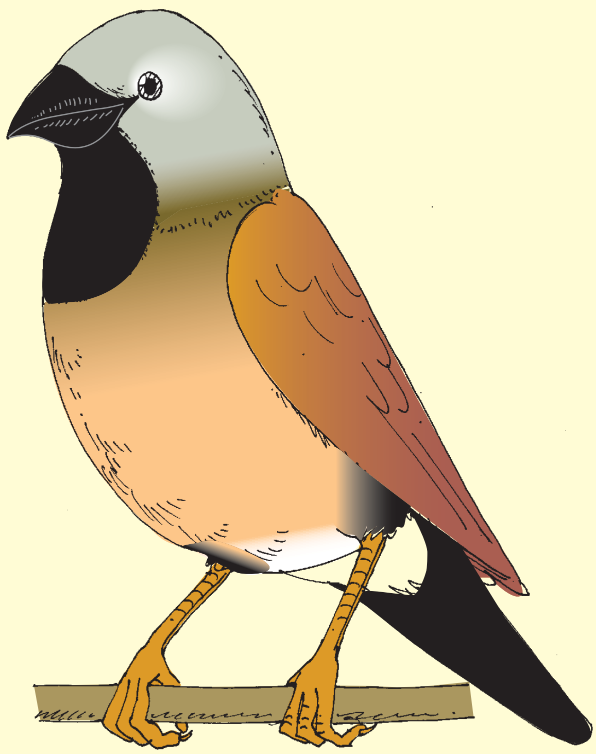


Figure 23.8 Black-throated finch

Mechanical isolation

If structural differences between two closely related species make it physically impossible for matings between males of one species and females of the other, the two populations will not exchange genes.

The pollen of cotton bushes (*Asclepias*) is contained in small sacs that stick to the legs of insects. The stigma of the flower has slits into which the pollen sac must be inserted. Each species of cotton bush has a distinctively shaped pollen sac with corresponding stigmal slit, making pollination between the species impossible even though the species are sympatric.

Gametic isolation

Even if individuals from two different species do mate, actual fertilisation may not take place. In many species of the fruit fly, *Drosophila*, interspecific matings cause an antigenic reaction in the genital tract of the female, causing the walls of the vagina to swell and kill the sperm before they reach the egg cells.

Developmental isolation

When cross-fertilisation occurs, the development of the embryo is often irregular and does not come to full term.

The frogs *Rana pipiens* and *Rana catesbiana* can produce viable embryos only up to a very young stage of development. Crosses between goats and sheep produce embryos that usually die long before birth.

Hybrid inviability

Hybrids are often weak and malformed, and frequently die before they reproduce.

Hybrid sterility

Some interspecific crosses produce viable but sterile offspring. The classic example is that of the infertile mule—a cross between a donkey and a horse. A few fertile mules, which would have occurred as a result of mutation, were discovered in the USA, and a stud breeding these fertile mules has now been established.

At one time it was thought that a particular frog species, *Ranidella signifera*, was found both along the south-eastern coast and in the south-western corner of Australia. Morphologically these frogs were so similar that it was virtually impossible to distinguish between them. Experiments in breeding frogs from the east and west, however, resulted in sterile offspring. The western frog was then renamed *R. insignifera*. This division was further ratified with advances in audio-technology where the calls were found to differ.

Selective hybrid elimination

The members of two closely related populations may be able to cross and produce fertile offspring. If these offspring and their progeny are as vigorous and well adapted as the parental forms, the two original populations will combine to form a common gene pool. If, however, they are less well adapted than the parental forms, they will soon be eliminated, and the gene flow between the two populations will decrease. Usually, if these populations are sympatric, each will rapidly evolve more effective isolating mechanisms. There will be selection for correct mating and selection against incorrect mating.

Parthenogenesis

Parthenogenesis (= virgin birth) refers to a variety of processes where a female can produce young without fertilisation of the egg. The processes by which this may be achieved were described in Section 17.5.2, page 447).

Elimination of the male from the reproductive process decreases genetic variability and may result in genetic drift in isolated populations. This can lead to rapid divergence of characteristics within a population, and thus speciation.

Case study 23.2: Parthenogenesis in an Australian gecko

Geckos are an ancient and successful group of lizards distributed through the tropics.

A study of geckos has revealed that six of the approximately 800 species are parthenogenic. They tend to have the following features:

- broad geographic range—usually larger than their sexual relatives
- common in disturbed environments, often in association with human activity. For example, the only Australian parthenogenic species, Bynoe's gecko (*Heteronotia binoei*), is found in homestead rubbish tips in arid areas.

Chromosome studies of Bynoe's gecko have shown that what was thought to be one species, on the basis of morphological characteristics, is in fact several, with at least four sexual species. This species is triploid; that is, it has three of each type of chromosome.

The formation of the parthenogenic triploid forms probably resulted from mutation in a female so that she produced diploid eggs which were then fertilised by a male. From the onset of parthenogenesis there was no further mixing of genes, and they can therefore be considered as permanent hybrids. Further reproduction by parthenogenesis freezes the diversity from both of the sexual parent species.

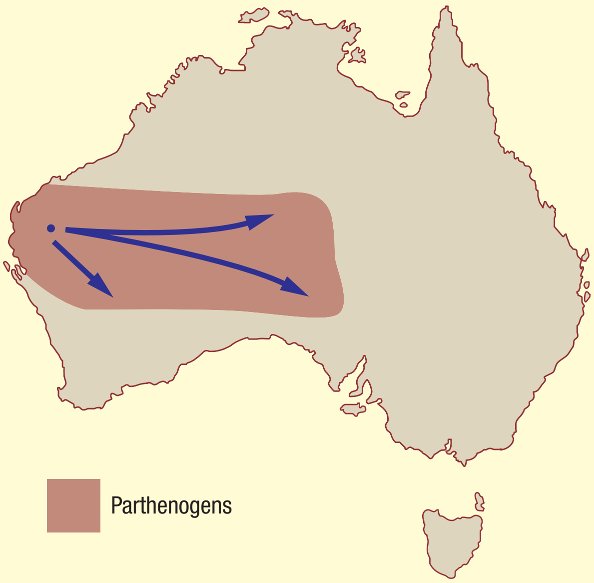


Figure 23.9 The origin and present geographic distribution of the various parthenogenic types of Bynoe's gecko in Australia

Through chromosomal and mitochondrial DNA examinations, the site of the original hybridisation was determined as the western goldfields of the Hamersley Ranges in fairly recent evolutionary times. From there the parthenogens have spread eastward to central Australia.

SUMMARY

Natural selection results in the change of a species. Since different populations of a species have at least one of the following structural elements:

- clinal variations
- geographic isolates
- hybrid belts,

the variability exhibited lays the groundwork for evolution to occur.

Races are groups of natural populations within a species that differ genetically, and are partly isolated from each other reproductively because they have different ranges.

Divergent speciation is usually initiated when populations become geographically isolated. Each population adapts to the local conditions. Allopatric species are those which have different ranges; that is, are kept separate by some geographic barrier. Sympatric species share the same range but have different gene pools.

If the external barrier breaks down within a short time, the populations will rejoin. However, if adequate time for the evolution of intrinsic isolating mechanisms has occurred, the populations will not rejoin if the external barrier is removed—the populations have become sympatric species.

Several different types of intrinsic isolating mechanisms can prevent or inhibit mating between closely related groups. The mechanisms may operate in the parents so that fertilisation is prevented or unsuccessful, or they may operate in the hybrid and so prevent its success. Parthenogenesis refers to a variety of processes where a female can produce young without fertilisation of the egg. This method of reproduction has been shown to have brought about speciation.

Review questions

23.10 Differentiate between clinal variation, geographical isolates and hybrid belts.

23.11 Define a species.

23.12 Can a population have more than one cline? Explain.

23.13 Many species can have several races. Explain what this means and how it comes about.

23.14 Distinguish between the following pairs of terms:
(a) divergent and convergent evolution
(b) allopatric and sympatric species.

23.15 Discuss means by which divergent speciation may occur.

23.16 Give an example of convergent evolution.

23.17 Describe, giving examples, four intrinsic mechanisms which prevent interbreeding between different populations.

23.18 Two populations of a species are separated for a long period of time by a physical barrier; that is, they are allopatric. Under what conditions can they be nominated as different species?

23.4 Coevolution

Coevolution results in simultaneous adjustments between community members which interact so closely that each species exerts a strong selective force on each other. As noted in Chapter 4, the first truly terrestrial animals were insects. They depended upon plants for their nutritional requirements. The evolution of insects, therefore, was intimately connected with that of plants, particularly the angiosperms.

Plants responded to the selection pressure of being eaten by evolving powerful defences against animal predators. These adaptations include thorns, glass-like bristles on leaf surfaces, and bad-tasting or toxic substances in their tissues. Quinine, nicotine, caffeine, mescaline, opium and cocaine are all plant products which are believed to have evolved in response to predation. Those plants in which a random mutation occurred that provided such protection had an advantage over other members of their population without the characteristic. The energy previously used to grow more structures to replace those eaten by animals could be directed into reproductive effort. For each defence mechanism, however, chance mutations within the predators allowed some of them to overcome the restraints imposed by the plant.

Case study 23.3: Koalas and eucalypts

It is surprising that any animal can exist on a diet of eucalypt leaves. Although the leaves have a high water content (approximately 50 per cent), fibre (18 per cent) and tannins (13 per cent), the low levels of fats, carbohydrates, proteins and minerals (a total of 19 per cent) provide very little nutritive value. In addition the leaves produce toxic oils and other substances. For example, prussic (hydrocyanic) acid is released by young leaves of some species at certain times. The high levels of fibre (particularly lignin) make the leaves highly indigestible.

The koala is a specialist feeder on eucalypt leaves. The types of eucalypts that koalas utilise, however, are limited by their tolerance to specific plant poisons. Although there is legal protection of the koala, this same protection has not extended to its food trees. Many forest habitats therefore do not contain adequate numbers of food trees for the survival of this unique animal.

The coevolution of the koala with eucalypts has resulted in:

- tolerance of, or the ability to detoxify, poisonous defence chemicals produced by some species of eucalypt
- slow rate of passage of chewed and partially digested food, allowing microbial digestion of fibre
- very enlarged caecum and proximal colon, maximising microbial digestion
- selective retention of fluids and fine particles in the proximal colon for absorption and elimination of the coarse, less digestible particles.

In spite of these adaptations the koala can still absorb only 25 per cent of the fibre. The tannins in the leaf bind to carbohydrates and proteins, making them less available for absorption. In order to survive on this specialist diet, therefore, an adult koala must consume at least one kilogram of its preferred foliage each day.

The koala's low intake of essential nutrients, and the necessity for slow digestive processes, are probably the reason for this animal's essentially sedentary nature. The brain is a highly energy-consuming organ. Another adaptation of the koala to its poor quality diet has been reduction in brain size.

Coevolution often provides positive results for all of the organisms involved in the interaction. Animal pollination provides flowering plants with a reproductive advantage over those relying on the whims of the weather. Selection pressure to provide more attractive flowers, flowers which mimic a particular insect pollinator, flowers with nectaries, or larger amounts of pollen improve the chance of cross-pollination and thus genetic variability. Richer and more abundant sources of food (pollen and nectar) benefit the pollinating animal. In a similar way there has been coevolution between fruit formation and animal dispersal agents.

Mimicry is an example of coevolution. The white sap of the cotton bush (*Asclepias*), for example, contains toxic substances (heart poisons in vertebrates) which deter predators. The wanderer butterfly has evolved enzymes that enable the caterpillar to feed on the cotton bush without being poisoned. These chemicals are stored in its body and thus present in the adult form. Predators of these distinctively marked butterflies become very ill and rapidly learn to avoid them: the plant deterrent has now become a deterrent at the next level of the food chain. Another, smaller, butterfly has coincidentally evolved a similar colour pattern to that of the wanderer (*Danaus plexippus*). The lesser wanderer (*Danaus chrysipus*) has a similar distribution pattern and also feeds on cotton bushes. It is thought that the two species reinforce the unpalatability of the other for predators. The female of another species, *Hypolimnas misippus*, has the same colour patterns as the wanderer but does not contain the toxic chemicals. Since these butterflies inhabit the same areas in northern Australia, protection is afforded to the non-toxic females.

SUMMARY

Coevolution refers to the adaptations resulting from selective forces exerted by interacting species of organisms on each other. Mimicry is an example of coevolution.

? Review questions

23.19 Define the term 'coevolution'.

23.20 In what ways does coevolution differ from convergent evolution?

23.21 Why is mimicry described as an example of coevolution?

23.22 Give three specific examples of coevolution between plants and animals.

23.5 Rapid evolution

Most evolutionary biologists believe that evolution is a gradual process, based on divergence of populations which are, at least initially, geographically isolated, i.e they are allopatric.

Sometimes this isolation is only for a short period of time and yet new species have arisen. It has been proposed that this has resulted from chromosome rearrangements. The short isolation was adequate for the chromosomal mutation to become established in the population.

In other cases, speciation has resulted even when the populations are sympatric. This most commonly occurs in plants by polyploidy, the doubling of the chromosome number. Examples of polyploidy were described in Chapter 21. Parthenogenesis also brings about rapid divergence in sympatric populations. This has been recorded in Bynoe's gecko, and also in the Australian morabine grasshopper (*Warramaba virgo*). This grasshopper is diploid. Traditionally these sorts of examples have been considered to be uncommon.

If the population has the same range, gene flow should maintain a single species and a common gene pool. Recent studies, however, suggest that sympatric speciation may be more significant than previously thought. Within any population many characteristics can have different, alternative phenotypes. When considering all of the possible combined phenotypes, there is great variation between individuals in a population. Thus the homogenising gene flow that maintains the group as a single species can be readily disrupted by any instability in the population. Just a stick bent by strong forces becomes unstable and snaps into two smaller but stable pieces, so too do populations.

For a population to be stable, small changes in structure or behaviour are damped out in following generations. If this does not occur, and those small changes are amplified in the gene shuffling that occurs in sexual reproduction and then natural selection occurs against less adapted combinations, the population becomes unstable. Instability in the population occurs when small but critical changes in the common environment (e.g. food availability) favour new gene combinations over existing ones. This does not require mutations, only different combinations of existing genes. Thus species diverge because of unmanageable loss of stability.

This model of sympatric speciation, supported by mathematical models based on physical phenomena, explains, for example, the evolution of the diverse group of finches on the Galapagos Islands from one original species. As a result of natural, small random variations in a particular feature such as beak size, any slight change in the available food supply would have conferred an advantage on birds with beak sizes either above or below the average size. The birds will divide into two distinct types that avoid competition by utilizing different food sources. Selection pressure for resource partitioning will ultimately result in different gene pools; that is, new species.

Support for this model includes the following observations in natural populations:

- Populations usually diverge into two rather than three or more distinguishable types.
- The split usually occurs rapidly.
- The two new species evolve in opposite directions; for example, if one evolves large beaks, the other evolves small beaks.

Research into 'heat shock proteins' (hsp) also adds support to the idea that most evolution occurs in sympatric populations under stress. It has long been known that a group of proteins (called hsp90s) are abundant in animals, plants and fungi. They are known to bind to unstable proteins, preventing their break-down in environmental disruptions such as high temperature by maintaining their shape. Evidence from a variety of organisms suggests that hsp90s have a much larger role in maintaining species homogeneity. They are able to prevent the expression of a number of mutations, including those of regulatory genes. Thus an organism can, over many generations, accumulate many hidden minor mutations.

When a population experiences environmental stress, however, it seems probable that the hsp90s are unable to deal with all of the faulty proteins and thus some hidden mutations are unmasked. If any of these mutations are in a regulatory gene and the stress occurs during the developmental stage of the organism, abrupt changes in shape and form emerge. Axolotls are salamanders which have not metamorphosed into the adult terrestrial form like other amphibians. They retain the gilled, larval body plan. If experimentally given the hormone thyroxin, they will develop into the adult air-breathing form. Thus a mutation of a regulatory gene has resulted in a sexually reproducing 'juvenile'. This **developmental neoteny** can bring about rapid speciation.

This ability of hsp90s to store and release mutations helps to explain how species can make the rapid transition from one body form to another; that is, to jump dangerously maladapted intermediate forms.

Proponents of the theory of punctuated evolution suggest that these types of changes are the basis for evolution. Species, therefore, remain constant for very long periods of time. At some particular point, probably stimulated by environmental pressure or random genetic drift, sudden and dramatic change leads to the development of new species.

SUMMARY

Several examples of rapid evolution exist, such as polyploidy in plants, parthenogenesis, and changes in regulatory genes. In these cases, new species may come into existence over a matter of generations. Proponents of punctuated evolution theory view this as the normal situation rather than unusual.

Review questions

23.23 Explain how the development of parthenogenesis may lead to rapid evolution of a new species.

23.24 In which types of organism is polyploidy most common?

23.25 How can changes in regulatory genes lead to rapid evolution?

23.26 How does the theory of punctuated evolution explain the rapid emergence of new species?

23.6 The biological evolution of humans

23.6.1 Primate and human features

Human beings are a species of animal, *Homo sapiens*. They are classified in the class Mammalia, order Primata. They share the following characteristics with all primates:

- They retain the simple five-digit foot. All digits, with the exception of the first (toe or thumb), have three jointed segments which allow independent movement and thus flexibility. The first digit of the forefoot is divergent. It can be brought into opposition with the forefinger, which greatly increases gripping power and dexterity. The whole hindfoot touches the ground (i.e. it is plantigrade).
- In the forelimb, the radius can slide over the ulna. This allows the hand to be rotated through a full semicircle without moving the elbow or upper arm.
- The collarbone (clavicle) is well developed. The upper arm, therefore, can move freely in its socket and rotate in a wide arc.
- Most primates have nails instead of claws, providing a highly sensitive tactile digit area for exploration and manipulation.
- The eyes are directed forwards. Sharp visual acuity is achieved by stereoscopy and areas of highly packed photoreceptors. Most primates have colour vision.
- The nose and jaws are short.
- The premolars are bicuspid.
- The brain is enlarged, particularly the forebrain which contains higher control centres. This allows increased memory to 'map' and relocate food sources.
- Births are usually single and parents take care of the young for a long period of time.
- All are capable of an upright posture, particularly when sitting. This is associated with a change in head orientation, allowing the animal to look ahead when upright.

The human species has features which are unique. These include:

- decreased body hair
- a chin, which binds the lower jaws together
- reduction in the size of the canine teeth, associated with a more omnivorous diet
- rotation of the pelvis to allow a permanent upright stance. Large buttocks (gluteus maximus muscles) maintain the position of the pelvis and provide a major force to drive the legs. This has also resulted in a further change in the orientation of the head, and development of arches in the foot.
- double curvature of the spine, presenting an S-shape (That of apes is C-shaped.)
- loss of the opposable big toe
- legs that are longer than the arms
- larynx, with associated areas in the brain, allowing speech.

23.6.2 Primate evolution

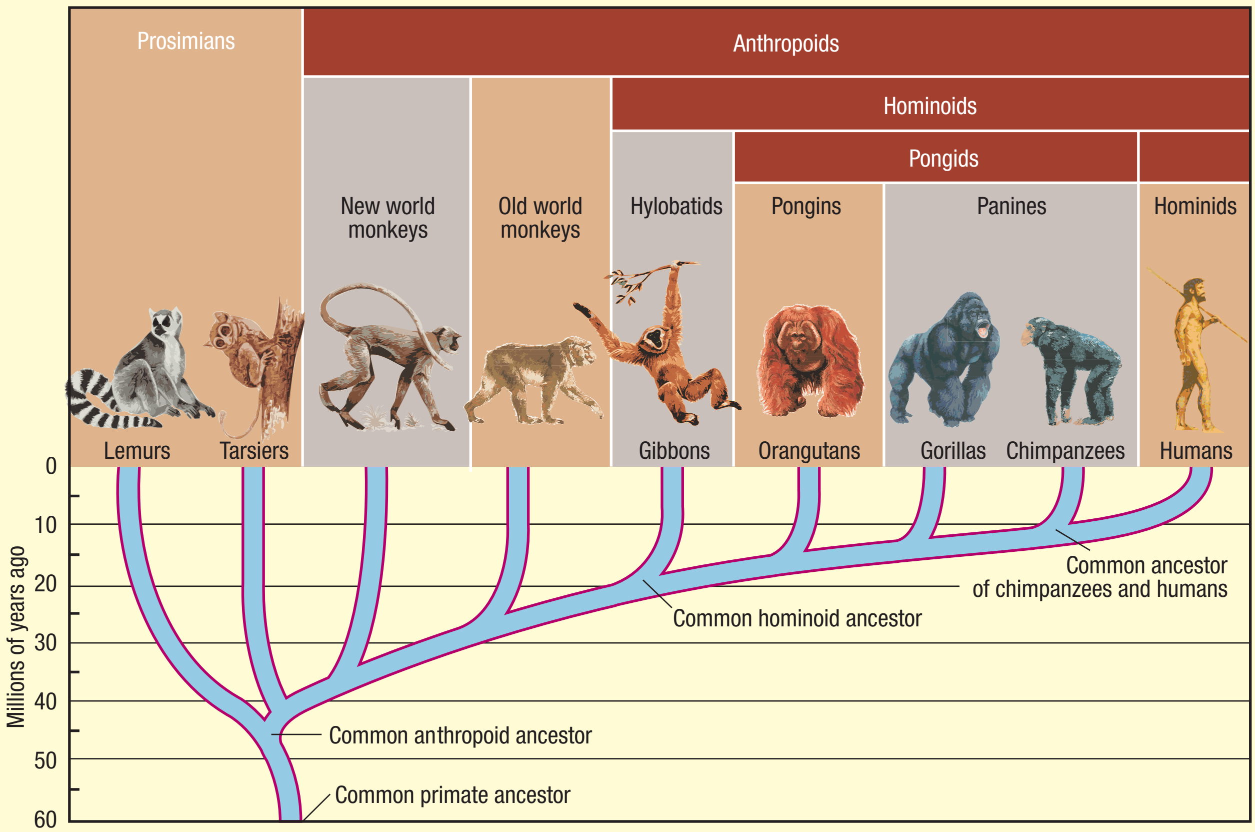
According to fossil evidence, two main lines of primates diverged early in their evolution: the 'prosimians', and the monkeys and anthropoids.

The prosimians include the lemur and loris, which have a nose pad with a marked median slit attached to the upper gum, and crescent-shaped nostrils. The monkeys and anthropoids have a hairy nose. This group is further divided. The flat-nosed, New World monkeys of South America have nostrils far apart, earholes not associated with tubes, and many have a prehensile tail. The Old World monkeys and anthropoids of the Ethiopean, Oriental and Australian regions have nostrils that are close together and earholes associated with tubes.

Humans are as much a product of evolution as any other organism. The gradual emergence of being 'not merely animal', and the forces that brought about this evolution, are by no means understood. This topic is the source of much controversy, in part because the reconstruction of human phylogeny is still largely a matter of guesswork. Fossil evidence of the evolution of the primates, and particularly of the emergence of the human species, is sparse. This is partly because the main time of evolution occurred during a long period of drought, when the rainforests were retracting and large savannah plains were developing. These conditions are not conducive to the formation of fossils.

Comparative anatomical studies confirm the great similarity between humans and the anthropoid apes. The traditional classification of these groups is:

Order Primata
Superfamily Hominidae
- Family Pongidae
  - Living great apes
    - *Hylobates* (gibbon)
    - *Pan* (chimpanzee)
    - *Pongo* (orangutan)
    - *Gorilla* (gorilla)
  - Extinct great apes
    - *Dryopithecus*
    - *Silvapithecus*
    - *Gigantopithecus*



The approximate evolutionary relationships and times of divergence of today's major groups of primate — the main uncertainty in this scheme is the place of the tarsier; some claim that its closest affinities are with the lemurs and lorises, rather than with the 'anthropoids', as shown here; many other details of primate evolution also remain unresolved.

Figure 23.10 A possible evolutionary tree of the primates

Living humans
Homo sapiens
Extinct humans
H. habilis
H. ergaster
H. erectus
H. heidelbergensis
H. neanderthalensis

23.6.3 Evidence of human origins

Relationships with the apes

Fossils show that the divergence of the gibbons from the ancestral form occurred very early, and that the brachiating adaptations (swinging from one arm to the other with bodies upright) of all the living apes are due to similar arboreal habitats. Fossil evidence, as well as haemoglobin, serum protein and DNA analysis, strongly suggest that the hominid line branched off from the line of African apes at a comparatively recent date.

Further support comes from DNA studies. The chimpanzee has forty-eight chromosomes while humans have forty-six. Banding studies of these chromosomes indicate that at least ten large inversions and translocations and one chromosomal fusion have occurred since the two lineages diverged. It was found, however, that human and chimpanzee DNA differs in nucleotide sequence by only 1.1 per cent. In other words, a strand of human DNA 3000 nucleotides long (and capable of coding for a sequence of 1000 amino acids) differs in nucleotide sequence at about thirty-three sites (eleven amino acids), from the equivalent chimpanzee strand.

These changes, however, cannot account for the tremendous differences between the two species at the organismal level. It has been postulated that the genetic differences are, therefore, in a few regulatory genes which could then bring about dramatic changes in the production of enzymes. The conclusion drawn is that the human and chimpanzee genes are so remarkably similar because the two

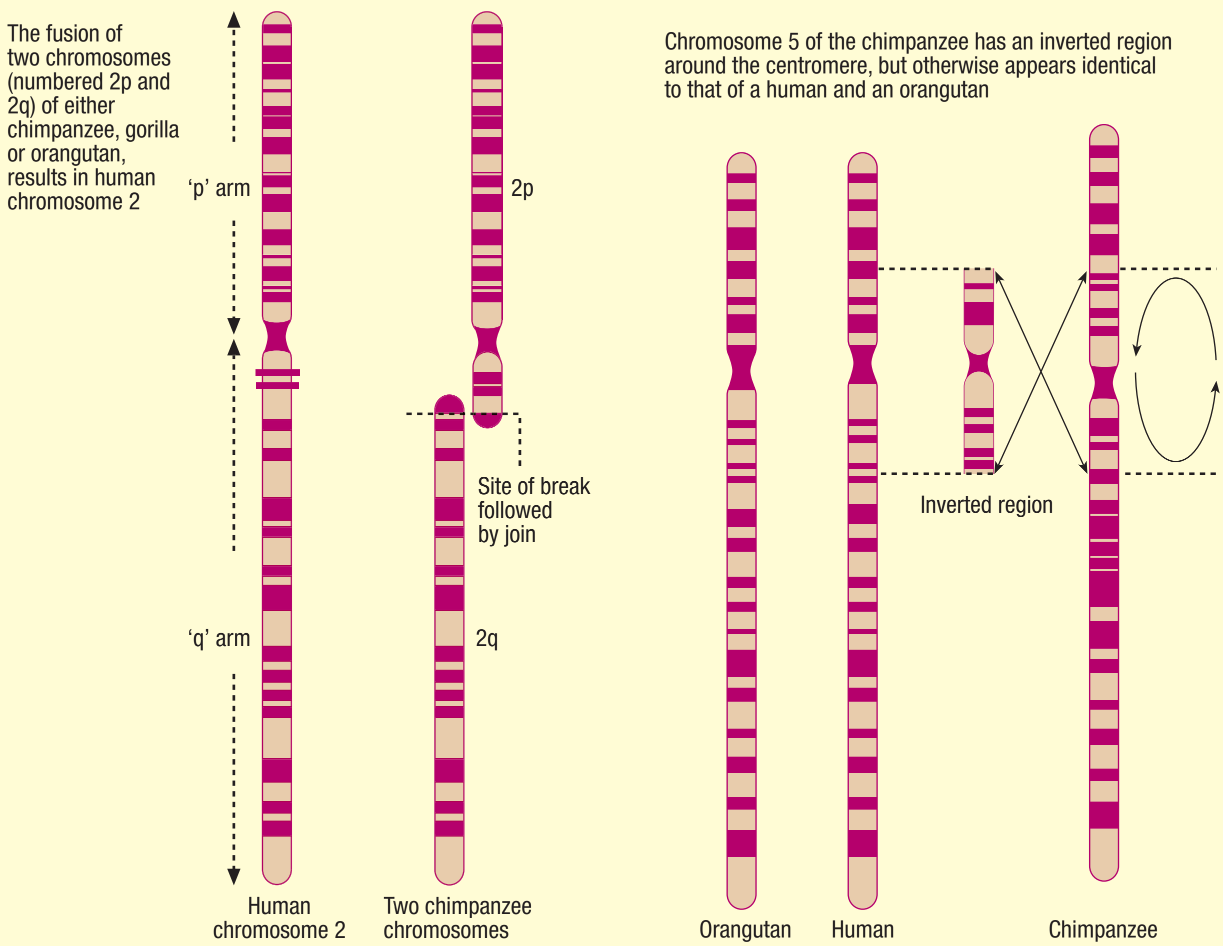


Figure 23.11 Likely chromosomal mutations resulting in the human karyotype

species diverged rather recently and the large organismal differences are due to a rapid evolution of regulatory genes in the human lineage.

Behavioural studies of the chimpanzee (van Lawick-Goodall) and gorilla (Schaller) also support this view. Both researchers report an amazing similarity of behaviours of these animals and humans in certain situations. The renowned chest-beating behaviour of the gorilla and the behaviour exhibited by people at, for example, a football final bear great similarities in structure and both appear to arise from a conflict situation. They express communication and intimidation of the opponent. Both the gorilla and chimpanzee show similar emotional expressions to people. They frown, smile, bite their lips if uncertain and youngsters have temper tantrums if thwarted. The social interactions of members of the group are close and affectionate. They seek reassurance in stressful situations by physical contact with another individual, and show greeting behaviour. Their mating system is polygamous, a type found in several human cultures. They use and make primitive tools.

A further comparison of chimps and humans shows the following developmental patterns:

	Chimpanzee	**Human**
First (milk) teeth	3–12 months	6–24 months
Second teeth	3–10 years	6–20 years
Sexual maturity (female)	9 years	13 years
Gestation	34 weeks	40 weeks

Human beings look and are like chimpanzee babies (baby chimps, unlike the adults, do not have opposable big toes). Human rates of development are those of a baby chimp and stay that way for longer. Almost all human development seems to have slowed down except for the period of gestation which, if extrapolated (using the figures above), should be approximately 95 weeks. The result of the speeding up of gestation is the birth of an extremely helpless human baby (equivalent to a chimpanzee fetus).

Becoming bipedal involved changes in the structure and size of the pelvis. These changes correspond in fossil evidence with increased brain sizes. Females with hereditary large pelvises are able to bear large-brained children. There is, however, a limit to the size of the pelvis and the ability for the woman to successfully walk. A retracted gestation period (necessitating the birth of a 'fetal' stage) allowed an increase in brain size.

From the above data it has been suggested that one of the genetic differences between chimps and humans is the retention of the juvenile body form into sexual maturity; that is, the loss of a regulatory gene which does not bring about the 'metamorphosis'. This developmental neotony appears to be accompanied by a **behavioural neotony**. The human species has a persistently 'juvenile' character in respect to behavioural flexibility. Exploratory behaviour—the maintenance of active, creative interaction with the environment—is restricted in animals to a brief developmental phase, whereas in humans it persists until the onset of senility.

On the basis of this evidence, it is obvious that there is a strong evolutionary relationship between gorillas, chimpanzees and humans. It has been suggested, therefore, that the classification system should more strongly reflect this relationship and thus family Hominidae should include the great apes, in the tribe Homini:

Family Hominidae	gibbon orangutan
Tribe Homini	gorilla chimp human

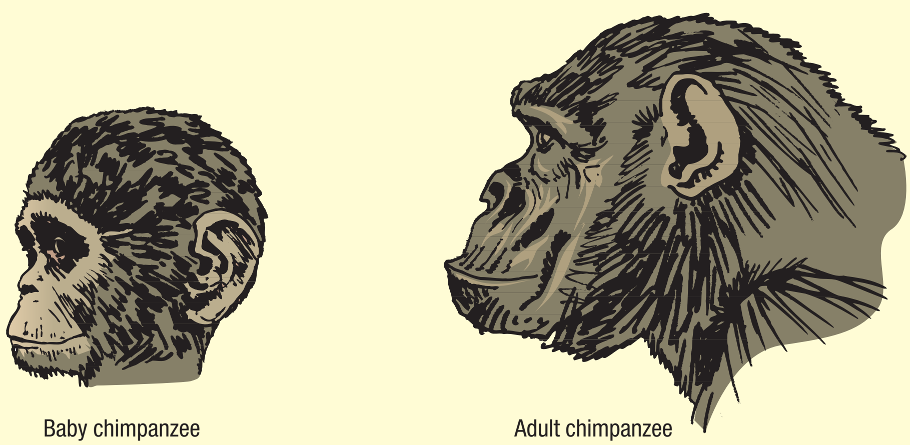


Figure 23.12 Comparison of facial features of juvenile and adult chimpanzees

The fossil record

There is a a long gap in the fossil record between the early Miocene (25 million years ago) of eastern Africa, and the rich fossil deposits of the early Pleistocene (3 million years ago). The anthropoid fossils of the intervening 20–25 million years are either fragmentary (*Ramapithecus*) or definitely ape-like. It is consequently not known through what stages the 'human' line went in the Miocene and Pliocene. Considering how primitive the earliest known Pleistocene hominids are, it can be concluded that their evolution in this period was rather slow.

Current knowledge of human ancestry (from both increasing fossil finds and techniques for extracting and analysing DNA from fossil bones) suggests that there was not a single evolutionary pathway with simple progression from one species to another. Rather the evidence suggests that there were many diverging branches, many of which rapidly led to deadends. Adaptive radiation of the common ancestor of both chimpanzees and humans was a response to global cooling 8 million years ago. Contraction of the forests and expansion of grasslands that accompanied this cooling made early human ancestors vulnerable to predation by large carnivores. This would favour divergent evolution of phenotypes that employed different strategies to avoid being eaten while ensuring provision of their own requirements. Some of these phenotypes were more successful than others and existed for longer time periods than other less adaptive phenotypes.

It is considered that the proto-human, chimpanzee and gorilla groups probably evolved from a stem ancestor, possibly *Aegyptopithecus zeuxis*, which existed 30 million years ago. Fossils of *Australopithecus africanus* (from South Africa), and *A. afarensis* (from Ethiopia), aged between 3.5 and 1 million years old, had an upright stance. Brain capacities with an average of 500 mL and 400 mL respectively are comparable in size to modern apes. There is no evidence that either group used tools. Thus the erect posture was probably an adaptation to easily viewing predators in savanna grasslands. Towards the end of this period the australopithecine brain had enlarged to 650 mL.

An overlap occurs with *A. africanus* and fossils of *Homo habilis* (= handy man), a toolmaker with larger brain and reduced jaw, about 2 million years ago. It is believed that *H. ergaster* (= working man) evolved from *H. habilis* and that adaptive radiation of this species resulted in both *H. erectus* and *H. heidelbergensis*.

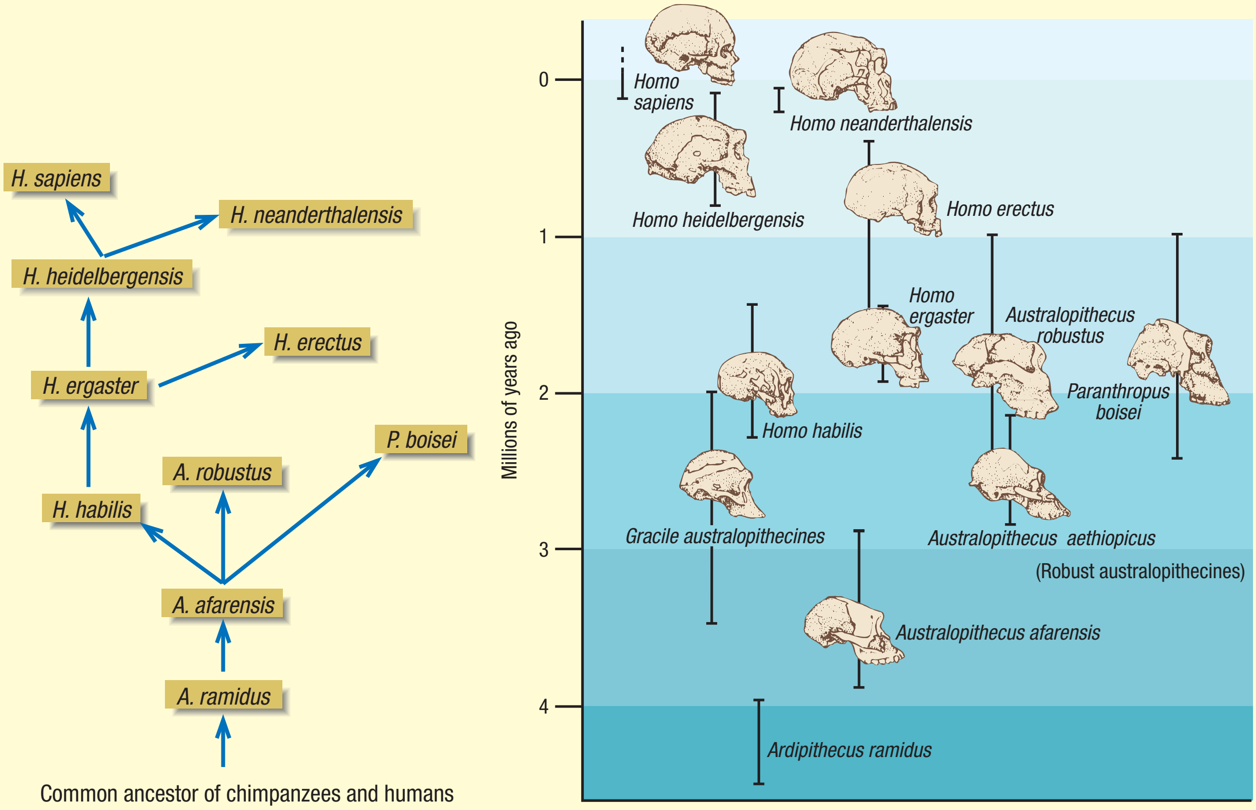


Figure 23.13 (a) One interpretation of new fossil discoveries; (b) time ranges for hominid ancestors

The first *Homo* fossils found outside Africa, in Europe and Asia, occurred between 1.5 million and 300 000 years ago and were named *Homo erectus* (= upright man). These fossils were given the common names of Peking Man and Java Man. Over this period of time there was a gradual enlargement of the brain to 1000 mL capacity and a much more sophisticated use of tools. Between 2 and 1.4 million years ago, there were also other species of *Homo* which existed for only a relatively short period of time. One of these, *H. heidelbergensis*, also evolved in Africa and also colonised Europe and Asia. Due to greater sophistication in tool making they were competitively superior to *H. erectus* and thus supplanted the earlier colonisers. Proponents of the punctuated equilibrium theory suggest that selection among these species fits the evidence better than a gradual change from one species to another.

It is possible that adaptations of *H. heidelbergensis* to their differing environments (e.g. Africa and Europe) led to two different new species—*H. neanderthalensis* in the Middle East and Europe, and *H. sapiens* in Africa. Neanderthals evolved between 150 000 and 200 000 years ago and only existed for around 30 000 years. The earliest modern human fossil (from Omo in Africa) is dated at about 130 000 years. Since the evolution of *H. sapiens* (with mitochondrial DNA different from all other hominids), modern humans colonised all inhabited parts of the world. Through competitive superiority associated with enhanced intellect and abstract thinking, they were able to supplant the only other contemporary human species, the Neanderthals.

Steps in the evolution of modern humans

Bipedalism is a relatively inefficient form of locomotion for mammals but has two advantages. It opens up the terrestrial habitat for a previously arboreal creature and frees the forelimbs for other purposes such as the use of tools. The evidence suggests, however, that bipedalism evolved more than a million years before the appearance of simple tools.

It has been argued that the skilful use of tools is a strong selection pressure for increased brain size and subsequent manufacture of tools. However, studies of sea otters, chimpanzees, baboons and one of the Galapagos finches shows that the use of tools is not primarily a hominid feature. Humans, however, are the only mammals that are continuously

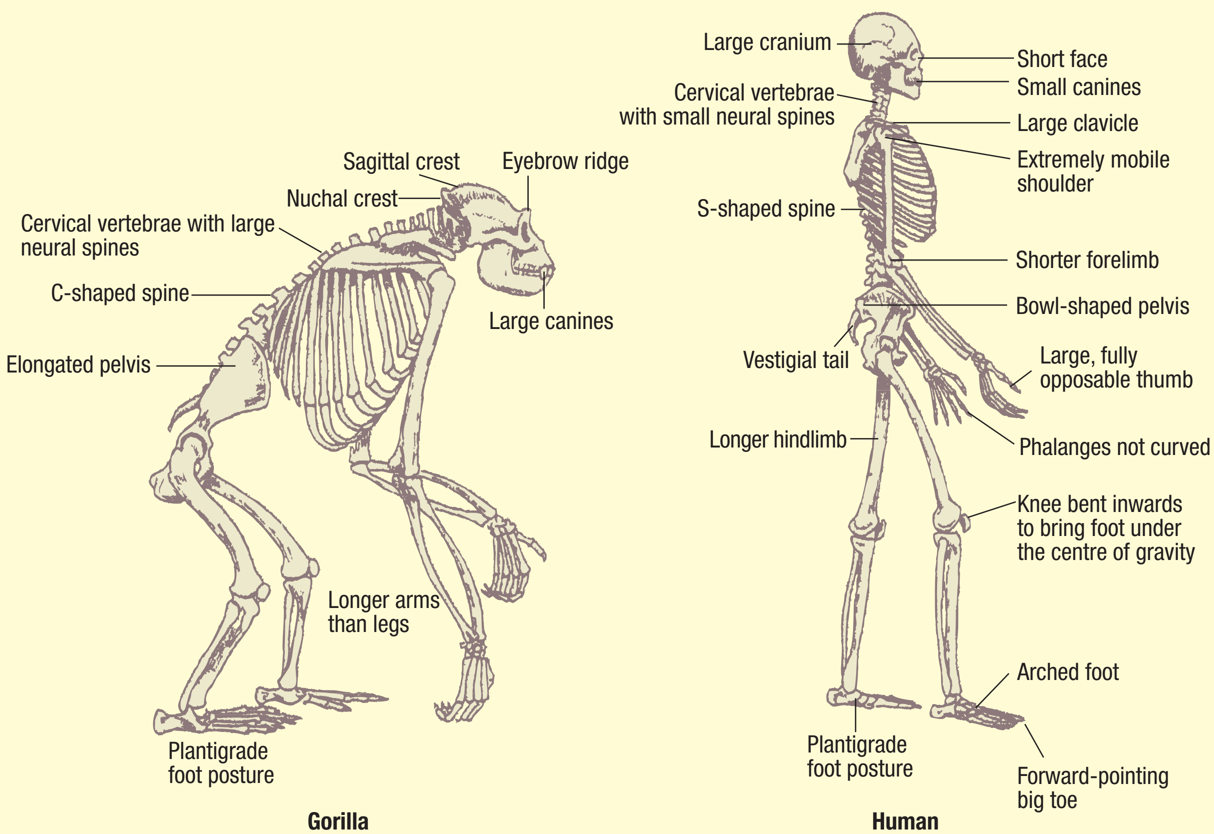


Figure 23.14 Comparison of the stance of gorilla and human (see page 635)

dependent on tools for survival. This dependence on the learned use of tools involves the development of previously unexploited behaviour potential, and thus releases entirely new selection pressures.

It seems likely that the ability to make tools contributed far less to selection pressure for increased brain size, with its associated memory, than did the need for an efficient system of communication. Foresight and capacity for leadership must have been greatly enhanced by an ability to speak. Many aspects of intelligence and planning would have little survival value without a medium of communication far more efficient than that of the anthropoid apes. Neither the chimpanzee nor the gorilla has the potential for speech, so verbal communication as opposed to communicative sounds (grunts, shrieks etc.) are unknown in these species.

It seems that gorillas do not vocalise for the sake of it. No baby gorilla babbles as do human babies. Their ability to impart information is confined entirely to the situation at hand. They coordinate their behaviour within the group primarily by employing certain gestures and postures. It has been suggested that the gorilla has not developed further because of the ease with which it can satisfy its needs in the forest. There is no need to make, carry and use a tool if food is abundant everywhere and at all times, and no preparation for this food is required beyond stripping and shredding it with teeth and fingers. Thus there is no pressure to develop a system of communication involving past and future.

The need for tools and for new additions to the diet are more likely in a harsh marginal habitat where a premium is placed on an alert mind and new modes of fulfilling bodily requirements. These are the conditions under which it was believed *Australopithecus* evolved, in the dry conditions of the early Pliocene where there was a dramatic reduction of the forests. The anthropoids became trapped in the surviving forests in the Congo, hills of India and jungles of southern Asia, to become specialists of a single habitat. The protohumans became generalists and thus were able to utilise a diverse range of habitats.

The relationship between the need to use tools and speech appears to be very fundamental. Although recent studies have shown that apes tend to use a particular hand for specific functions, they are still very ambidextrous. Split brain experiments indicate brain lateralisation. In humans, the rational, logical thought expounded by language occurs in the left cerebral hemisphere and 'intuitive', creative thought processes are located in the right. Fetal human brains show greater development of the left hemisphere, and this continues throughout life.

Although it is considered genetically that the propensity for left- and right-handedness should be equal, this is not the case. The vast majority of people are right-handed. Although many left-handers still have their speech centre in the left hemisphere, considerable evidence suggests that they are more likely to have problems with reading, writing, speaking and arithmetic and may be more adept at pattern recognition and general creativity—right hemisphere functions. There is evidence from skull fractures in kills that handedness was selected for early in human development. *Australopithecus* appears to have been right-handed. Castings of fossil skulls have

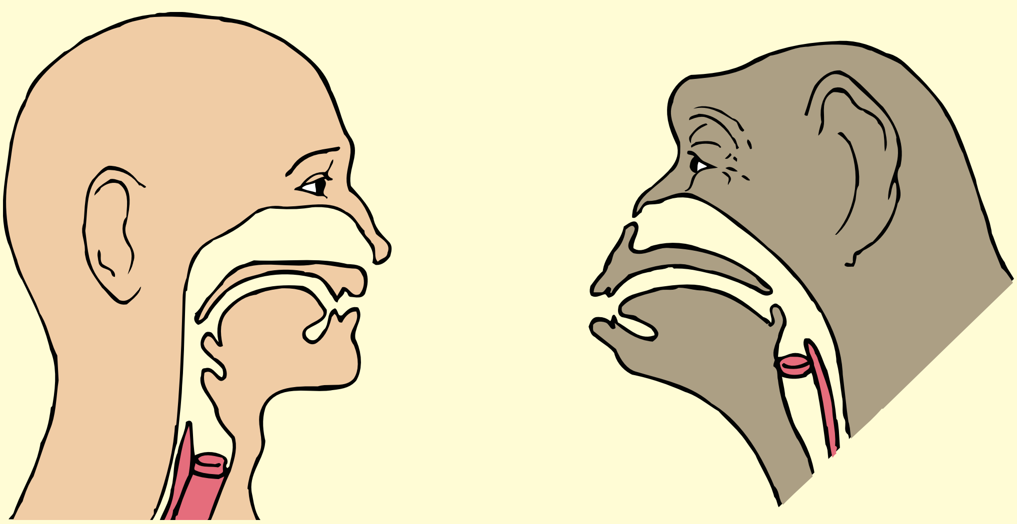


Figure 23.15 Human and ape vocal apparatus

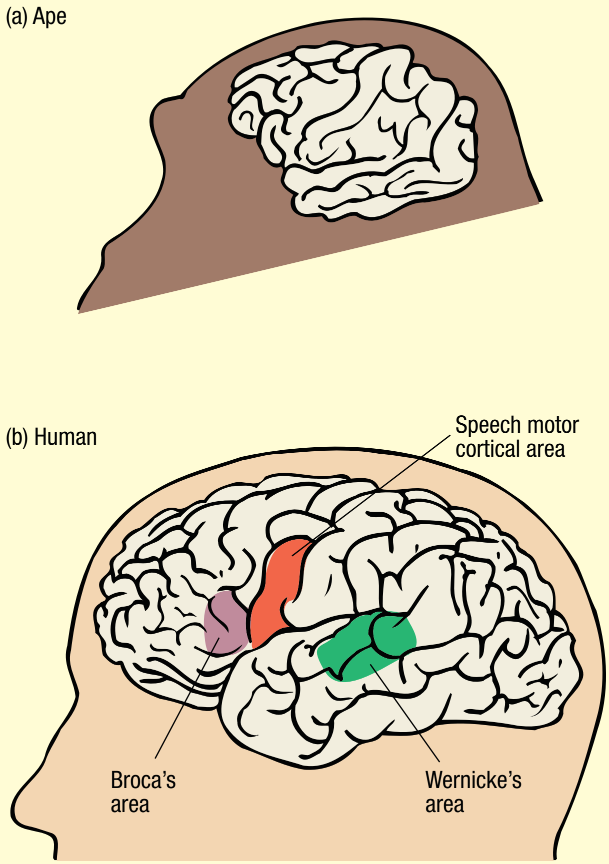


Figure 23.16 Comparison between brains of ape and human

shown that *Homo habilis* displayed Broca's area, one of the several centres required for speech development. Handedness and speech, therefore, appear to have evolved in parallel.

It is not through lack of intelligence that apes are unable to speak. Hand-reared chimpanzees at the University of Nevada (the most famous being Washoe) were taught to communicate using deaf-and-mute sign language. At five years of age Washoe could understand 360 symbols and use 180 of them correctly. The conceptual development of the chimpanzee was demonstrated when, presented with unseen articles for identification, she correctly identified a brush as a comb. Similar results have also been found for the gorilla.

It is a puzzle to researchers why the non-human primates do not make greater use of their ability to learn a complex gestural language. It has been suggested that humans may have exterminated any other primates that displayed signs of intelligence. If this is so, humans may have been agents of natural selection by suppressing competition.

The development of speech is considered to have had the greatest bearing on human increased brain size, which led to a complete reconstruction of the skull. This development was favoured by the forward shift of the skull support in connection with upright posture, and the lessening of the selection pressure in favour of strong jaws and big teeth, with the preparation of food made possible by the enlarged brain. This resulted in the reduction of jaws, the teeth and the entire facial part of the skull, while simultaneously the cerebral part of the skull enlarged. It resulted also in the reduction of facial muscles and their associated bony crests and ridges.

The evolution of the human phenotype, therefore, is exactly what one might expect as a compromise between various selection pressures. The development of the human form was gradual, and as such it is virtually impossible to pick a stage in the continuum which can be designated as the 'real origin' of humans.

Homo erectus was, from fossil evidence, a hunter–gatherer as were the Neanderthals and early *Homo sapiens*. The evolution from one species to the other was not a major one structurally but, since the appearance of *Homo neanderthalensis*, enormous cultural changes have occurred which in themselves have acted as selection pressures.

Neanderthal humans were more heavily built and muscular than modern humans. Fossil reconstruction shows that they had a long, massive skull, and a protruding face with a low forehead and heavy brow ridges. This species had more sophisticated tools than its predecessors, and a well-developed culture which included burial ceremonies and art. They were, however, fairly rapidly supplanted by modern humans (*Homo sapiens*), and were no longer in existence 30 000 years ago.

23.6.4 Theories of the evolution of modern humans

There is general consensus that *Homo sapiens* arose from a line in which *Homo erectus* was involved, but there are two main theories of the evolution of modern humans. Proponents of the multiregional, or candelabra, theory state that there were multiple early migrations of *H. erectus* out of Africa about 1 million years ago. Different regional populations evolved adaptations to their environmental conditions, which resulted in racial differences, and gene flow between adjoining populations ensured continuity of a single species. Thus modern humans arose almost simultaneously in different parts of the world from races of *Homo erectus*. Evidence for this theory is based on the fact that Neanderthals were found in Europe, the Near East and Central Asia. It points to racial differences having ancient genetic roots reaching back 2 million years.

The second, single-origin, theory has been dubbed the Noah's Ark, Out of Africa or Mitochondrial Eve model. This states that modern humans evolved fairly recently in Africa and rapidly colonised the whole world over the past 100 000 years. The earliest known complete *Homo sapiens* fossils, dated at 90 000 years old, have been found in a cave in Israel, although earlier fragments (130 000 years old) have been found in Africa. Mitochondrial DNA studies from diverse human groups indicate great uniformity in DNA sequences. It has been suggested that this DNA can be traced to a small population in Africa some 170 000 years ago. This is not necessarily the only genetic line since in order to ensure continuity of the female inheritance, each female in the link must have had at least two daughters. Other genetic lineages cannot be established if, at some point, the daughters died before childbirth, had no children or only had sons. According to this model, modern racial features arose recently and are therefore genetically superficial.

The multiregional theory is based on fossil evidence only, but the single origin theory also incorporates intensive studies of mitochondrial and nuclear DNA. A major flaw in the multiregional theory is that it relies on the maintainence of gene flow throughout the various populations of the whole world. This is highly improbable, since the total world population of humans was unlikely to be great enough to ensure this.

The demise of the Neanderthals was associated with the rise of modern humans, but the exact cause is not known. It may be that they succumbed to diseases to which their successors were resistant, they may have been less able than their more modern counterparts to compete for resources or they may have been systematically destroyed by *Homo sapiens*.

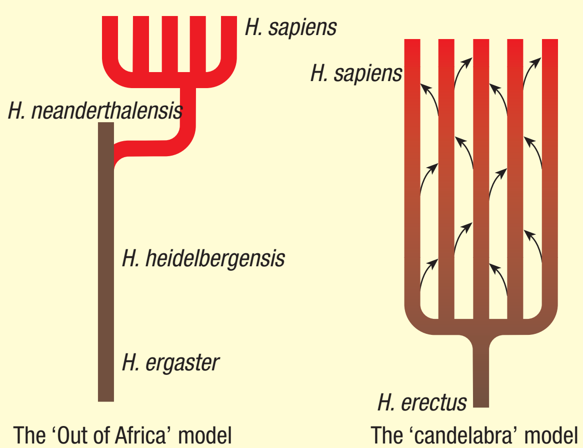


Figure 23.17 Two models of the evolution of modern humans

There has been an enormous expansion of humans throughout the world since the last ice age (approximately 35 000 years ago). Apart from refinements of the basic form, the evolutionary process has been, and continues to be, basically cultural. This is believed to be based on the social and technological foundations which were initiated by the species.

SUMMARY

- Chimps have forty-eight chromosomes; humans have forty-six, possibly as a result of fusion of two chromosomes.
- Chimp and human DNA differs in nucleotide sequence by only 1.1 per cent.
- Chimps and humans have similarities in expression of conflict behaviour and social interactions.
- They also have similar developmental patterns.

It is suggested that chimps and humans evolved from a common ancestral line (*Aegyptopithecus*), and that there were several stages in the evolution of humans from then to the emergence of modern humans (*Homo sapiens*). Humans are believed to have evolved in fairly recent times (within the past 150 000 years) in Africa. Members of this species migrated to the rest of the world and supplanted previous species of *Homo* as they went.

Several modifications, such as change in the structure of the chin, position of the pelvis, foot structure, development of buttocks, larynx etc. resulted in a hominid line. It is suggested that these changes resulted from regulatory rather than structural genes. Relatively minor structural changes occurred in the evolution of modern forms from the human prototype (*Australopithecus*); most of these changes seem to be related to the development of speech.

Since the emergence of modern humans, the greatest changes have resulted from cultural evolution.

Review questions

23.27 How would a prehominid fossil differ from a hominid fossil?

23.28 Suggest reasons for the limited fossil record of the human ancestral line.

23.29 Chimpanzees and humans are believed to be closely related. What evidence supports this?

? **23.30** Why have biologists concluded that *Australopithecus* was more like humans than apes?

23.31 On what basis do biologists believe speech to be a greater determinant in the evolution of modern humans than the use of tools?

23.32 How does the multiregional theory differ from the single origin theory of the evolution of modern humans?

EXTENDING YOUR IDEAS

1. IB Tongue-rolling (the ability to roll the tongue longitudinally into a U-shape) is caused by a dominant allele. Tongue-rollers are either homozygous for this allele or heterozygous. Non-rollers are homozygous recessive.

   In a survey carried out in a city it was found that of 5000 people, 3200 could roll their tongues whereas 1800 could not.

   (a) What percentage of persons in this city sample are homozygous recessive for tongue rolling?

   (b) Calculate the frequency of the recessive allele in the population.

   (c) Calculate the frequency of the dominant allele in the population.

   (d) What percentage of persons in this sample are homozygous dominant for tongue rolling?

   (e) What percentage of persons are heterozygous for tongue rolling?

   (f) Would you expect the same percentages (a, d, e) in the next generation? Explain fully.

   (g) What is the relevance of all this to the mechanism of evolution?

2. UB Figure 23.18 shows three basic types of natural selection. The shaded areas marked with arrows show the individuals in each population which are being selected against.

   (a) Name the type of selection exhibited in each graph.

   (b) Explain the consequences for future generations as a result of the type of selection shown in:

      (i) graph B

      (ii) graph C.

3. UB Rock wallabies of the genus *Petrogale* are small marsupials which live in tight social groups on rocky outcrops. There are at least twenty chromosomally and genetically different forms, eleven of which are classified as different species within Australia. Some species hybridise where their ranges overlap. Figure 23.19 shows the distribution of rock wallabies in Australia.

   Using the information in Figure 23.19, explain why the evolution of rock wallabies in Australia is considered to have been a result of allopatric speciation.

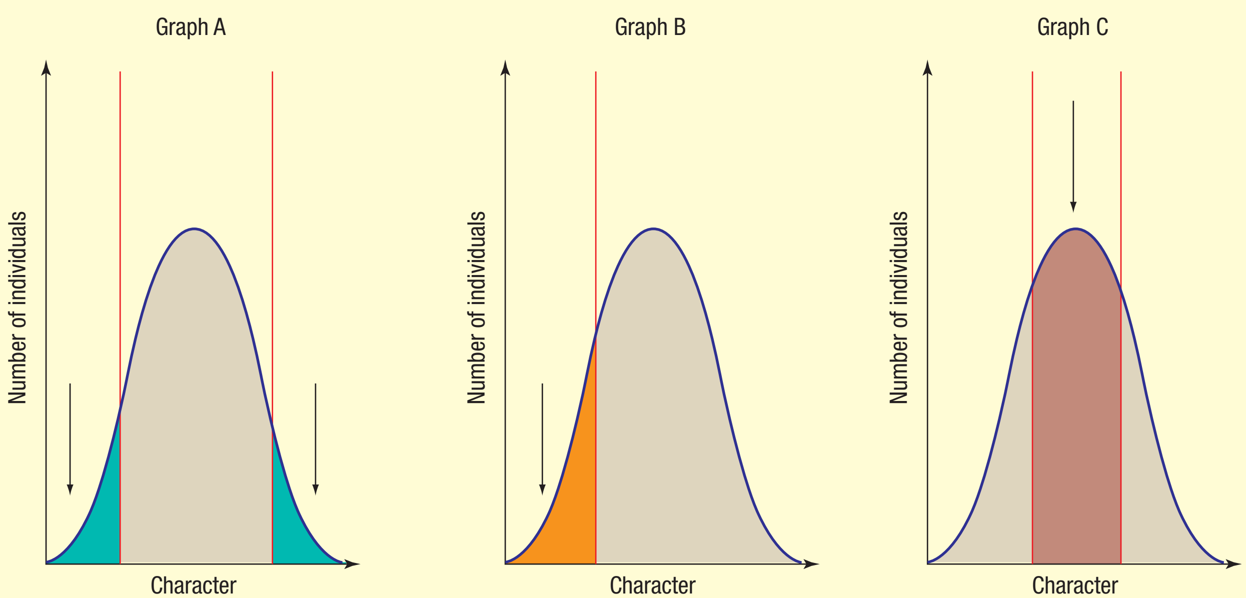


Figure 23.18

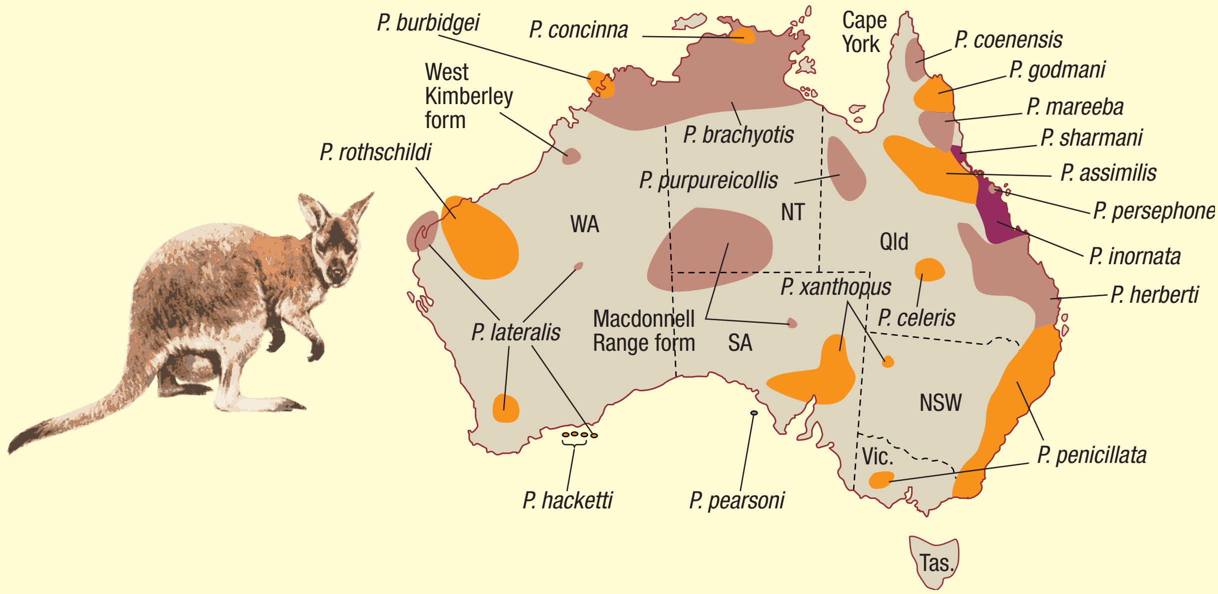


Figure 23.19 Distribution of rock wallabies of the genus *Petrogale*

4. UB The northern green ant (*Cacophylla virescens*) is commonly found in trees and shrubs in wet areas of northern Queensland. They characteristically weave leaves together to form a nest. The leaves are glued together by a silk which is released in fluid form by larvae. Although they feed on aphid and scale insect excretions, they are aggressive protectors of their nest. Their large mandibles can pierce and inject formic acid into large animals.

   One species of blue lycenaenid butterfly lays its eggs on trees inhabited by green tree ants. The larvae feed exclusively on ant larvae in the nest but are themselves protected by a smooth tough skin and the ability to press themselves firmly against the nest surface. Although the adult ants attack the butterflies as they emerge from the pupae, they are unable to damage them. The butterfly has a dense covering of easily detached scales which clog the ant's mandibles sufficiently to allow escape.

   The main predator of the green ant is a crab spider, *Amycina albomaculata*. It mimics both the colour patterns of the green ant and some of its behavioural characteristics. The spider's abdomen sports two black spots similar to the ant's eyes, so that even from the rear it resembles its model. This tiny spider, attached by a thin thread of silk, positions itself on a branch and allows ants to pass by. It even waves its first pair of legs, in imitation of the ant's antennae, as they pass. The spider pounces on an ant from the rear, sinking its fangs into its victim's neck or back. A powerful venom injected from the fangs instantly incapacitates the ant. Thus the spider avoids any counter-attack from the ant. The victim is immediately dragged off the branch where, suspended from the silk thread, the spider can eat its prey in safety.

   (a) Draw a concept map showing the relationships between the green ant, the lycenaenid butterfly and the crab spider.

   (b) Name all the relationships which exist between:

      (i) the green ant and the butterfly

      (ii) the green ant and the crab spider.

   (c) In what ways has there been coevolution between these organisms?

5. UB The two-spot ladybird exists in two different colour forms, red and black. In Britain there is a difference in the frequencies of the black form (controlled by the allele *B*) and red form (controlled by the allele *b*). In northern regions, the frequency of the black form is as high as 97 per cent, whereas in southern regions it is below 10 per cent.

   Suggest a reason why it is not appropriate to use the Hardy–Weinberg formula to find the frequency of heterozygous black ladybirds in Britain. Explain why you have selected this reason.

6. EBI Write an essay on the following topic:

   'The effects on parasites, pests and pathogens of human attempts to control them'.

   In your essay, ensure that you mention the variety of control methods currently employed and the methods by which organisms respond to them.

7. Two populations of *Drosophila,* initially containing an equal number of wild type and of individuals having the gene for ebony (dark body colour), were kept in two containers and under different conditions of temperature.

UB

Figure 23.20 shows the changes with time of the relative proportions of ebony flies. Comment on these results.

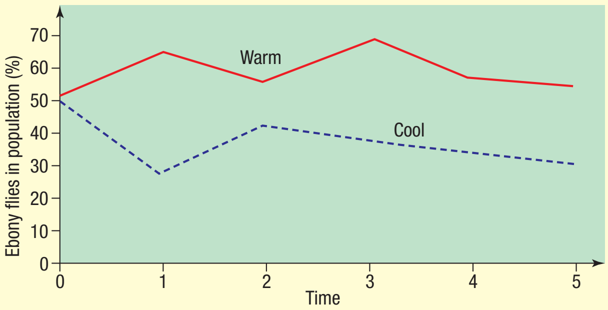


Figure 23.20

8. Some opponents of evolution have exclaimed, 'I just can't believe we came from a chimpanzee!'. What is their misconception about evolution?

UB

9. Considering that many species are associated with the ancestral human lineage, explain how punctuated evolution could explain an overall trend towards larger brains in human evolution.

UB

10. Discuss the differences in brain size, and the implications for behaviour, between *Homo habilis*, *Homo erectus* and *Homo sapiens.* (See Figure 23.21.)

UB

11. Evolutionary biologist Stephen Jay Gould states: 'Mankind stood up first and then got smart.' Discuss, citing evidence, the basis of his statement.

UB

12. The oldest DNA recovered from human remains has been extracted from a 60 000-year-old fossil (Mungo Man) found on the shores of Lake Mungo in south-eastern Australia. While anatomically similar to other *Homo sapiens*, the DNA suggests that this group of people descended from an extinct genetic lineage. Allan Thorne of the Australian National University is one of the founders of the multiregional model of human evolution. He claims that Mungo Man DNA supports this theory. Proponents of the 'Mitochondrial Eve' model disagree.

UB

Using your understanding of these two models of the emergence of modern humans, argue a case for one of these two views.

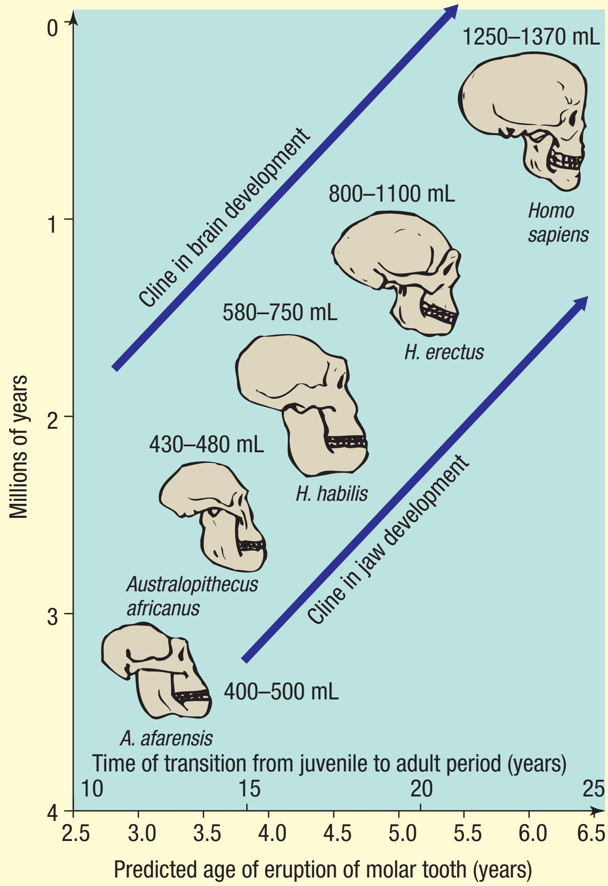


Figure 23.21

13. It is thought that the early ancestors of mammals did not have sex chromosomes. The gender of the offspring, like those of modern reptiles, was probably determined by the environmental temperature during development. It has been determined that about 300 000 years ago a gene mutation happened on one of the chromosomes (now termed X chromosomes) that automatically determined gender. Those organisms inheriting this mutation (gene *SRY*) developed as males by binding with proteins that inhibited femaleness. The chromosome on which this occurred also underwent mutation—first one and then another inversion and finally deletion of some sections. This meant that during cell division, these two chromosomes could no longer recombine—the Y chromosome came into being. The human Y chromosome now carries codes for only forty genes as compared with 1500 genes on the X chromosome.

EBI

Recombination is one way in which a species can eliminate harmful mutations. Since its inception the Y chromosome has been collecting mutations that are slowly destroying other genes while enhancing those related to male features. Thus human Y chromosomes now have a large number of 'parasitic' repetitive segments that, like viruses, try to copy themselves as often as possible at the expense of legitimate genes. These repetitive elements can cause sections of the Y chromosome to be deleted. Studies have shown that 15 per cent of infertile men have lost a group of genes (*AZF* group) that are essential for sperm production. Given the rate of gene loss in the Y chromosome over the past 300 000 years, it has been estimated that the Y chromosome could disappear altogether in 5 to 10 million years. If this scenario eventuates, the male and thus the species will no longer exist.

Using your knowledge of the process of evolution, predict possible alternatives to the suggested demise of the human species. Justify your response with 'known' examples of evolutionary patterns.

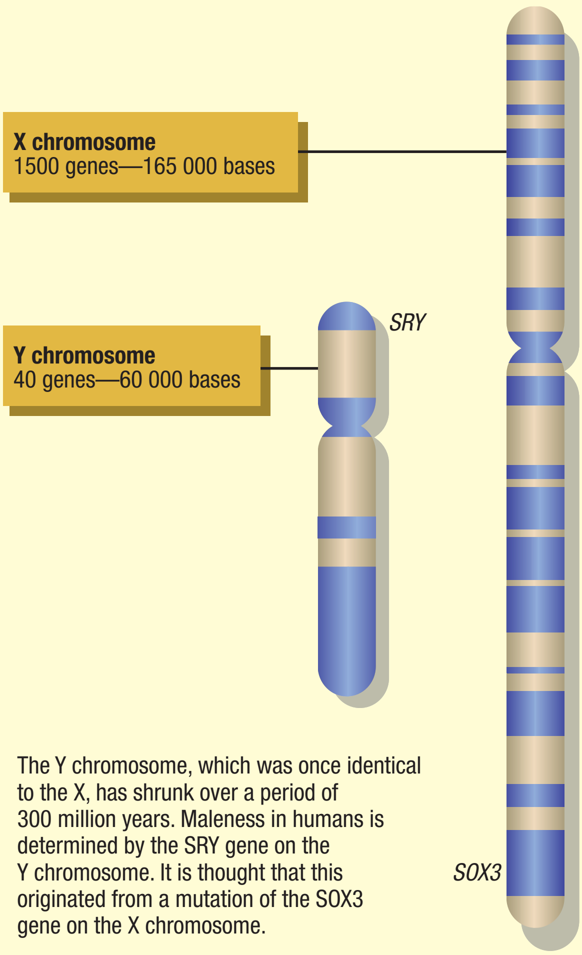


Figure 23.22

UNIT 9

Biotechnology

Biotechnology, the application of biological knowledge to the production of organisms or their products useful to humankind, has been used for thousands of years. Many of the foods that are taken for granted have been produced using artificial selection and breeding of organisms with desirable characteristics. Fermentation processes by yeasts and bacteria have been utilised in food production. The medications taken to prevent or alleviate symptoms of disease have first been isolated and identified from other organisms, even though the active chemicals may now be produced by synthesis techniques.

Genetics impacts on human life, not only directly but through the application of genetic principles in such fields as animal and plant breeding and health care. Genetic principles and techniques have been applied to many commercial enterprises, such as genetic engineering of drug and food-producing organisms, as well as manipulation of some genetic diseases and cloning of individuals. This has created considerable public debate about the safety of such procedures, as well as their ethical application. DNA 'fingerprinting' is becoming an important technique in forensic science, as well as providing valuable clues to evolutionary pathways.

Key concepts

- Cells are the functioning units of living things.
- Multicellular organisms are functioning sets of interrelated systems.
- There are mechanisms by which characteristics of individuals in one generation are passed on to the next generation.

Key ideas

- There are different types of cells and the ways they are organised influences their functioning.
- Cell division is an integral part of growth and reproduction.
- Systems of the body work together to maintain a constant internal environment.
- Malfunctioning of one system or part of a system may affect the whole organism.
- Living things employ a variety of reproductive strategies.
- Human understanding of the mechanisms of reproduction and DNA structure and function have led to intervention in natural processes.

24 BIOTECHNOLOGY

The term *biotechnology* conjures a variety of images that may include

- controlled human societies where individual 'castes' have been genetically engineered to perform specific roles
- people locked into suspended animation, awaiting the discovery of a cure for diseases
- the development of the 'fountain of youth'—the control of aging processes
- human clones.

Many of these images have been the result of futuristic novels and movies that examine the possibilities of current scientific understanding and generally focus on the negative aspects of their further development. Most of our conceptions, however, do not begin to hint at the huge impact that biotechnology has on the quality of human life.

Biotechnology is defined as the use of biological knowledge for the development of industrial processes and the production of useful organisms and their products.

24.1 TRADITIONAL USE OF BIOTECHNOLOGY

Many things taken for granted in modern society—food, clothing and many medicines—are based on applications of biological knowledge. Often the processes were used prior to the understanding of why and how it occurs. As seen in Case study 13.1 (page 339), linen was one of the earliest textile materials produced. In order to release the cellulose fibres, partial bacterial decomposition of the bark is necessary. The early manufacturers would have been unaware of the existence of bacteria, let alone their function in the retting process. But they did know that soaking the flax bark for a period of time was an essential part of linen production.

24.1.1 SELECTIVE BREEDING

Human agriculture is thought to have developed about 10 000 years ago. The ability to grow crops and domesticate animals had a major impact on the survival of *Homo sapiens*. Small groups of people were able to settle in one place and have a reasonably reliable food supply, ensuring a safer environment for pregnant women and young children.

It is likely that the first crops resulted from general collection and planting of wild seed. With time it was probably discovered that certain plants produced bigger seed than others. When these were collected and grown separately, most of the next generation seeds were also larger. Thus began the process of **artificial selection—**a process that continues to be a major force in plant and animal breeding today. A general understanding of the reproductive process developed and the next step in the artificial selection process (where humans, not natural environmental conditions, determined which characteristics had a selective advantage) was the deliberate interbreeding of organisms that displayed desirable characteristics.

The evolution of common wheat is a good example of how agriculture has impacted on plants. There are several species of wild wheat (*Triticum*) and it is known that these were harvested in the Middle East, especially *T. monococcum*. Most species have mechanisms that prevent interbreeding between them. Some species are very closely related, however, and reproduction between them can occur. It is likely that some of these close species of wild wheat interbred to form hybrids. Most hybrid plants, however, have variable numbers of chromosomes that do not form pairs and so are unable to form gametes. They are infertile. It is thought that *T. monococcum* (with fourteen chromosomes) interbred with another wild wheat (also with fourteen chromosomes) to form a hybrid with two dissimilar sets of seven chromosomes, each of which duplicated. This hybrid, called Emmer wheat (*T. turgidum*) now had fourteen pairs of chromosomes (seven pairs from each 'parent' type) and was fertile. The seeds (grain) of this species were not only larger (and thus contained more nutritive endosperm), they were more readily dislodged from the ear and so more easily dispersed by wind than those of the parent species.

It is highly likely that the first cultivated species was Emmer wheat. About 8000 years ago another significant hydridisation occurred between *T. turgidum* and another species of wild wheat (*T. tauschii*) with fourteen chromosomes. As in the

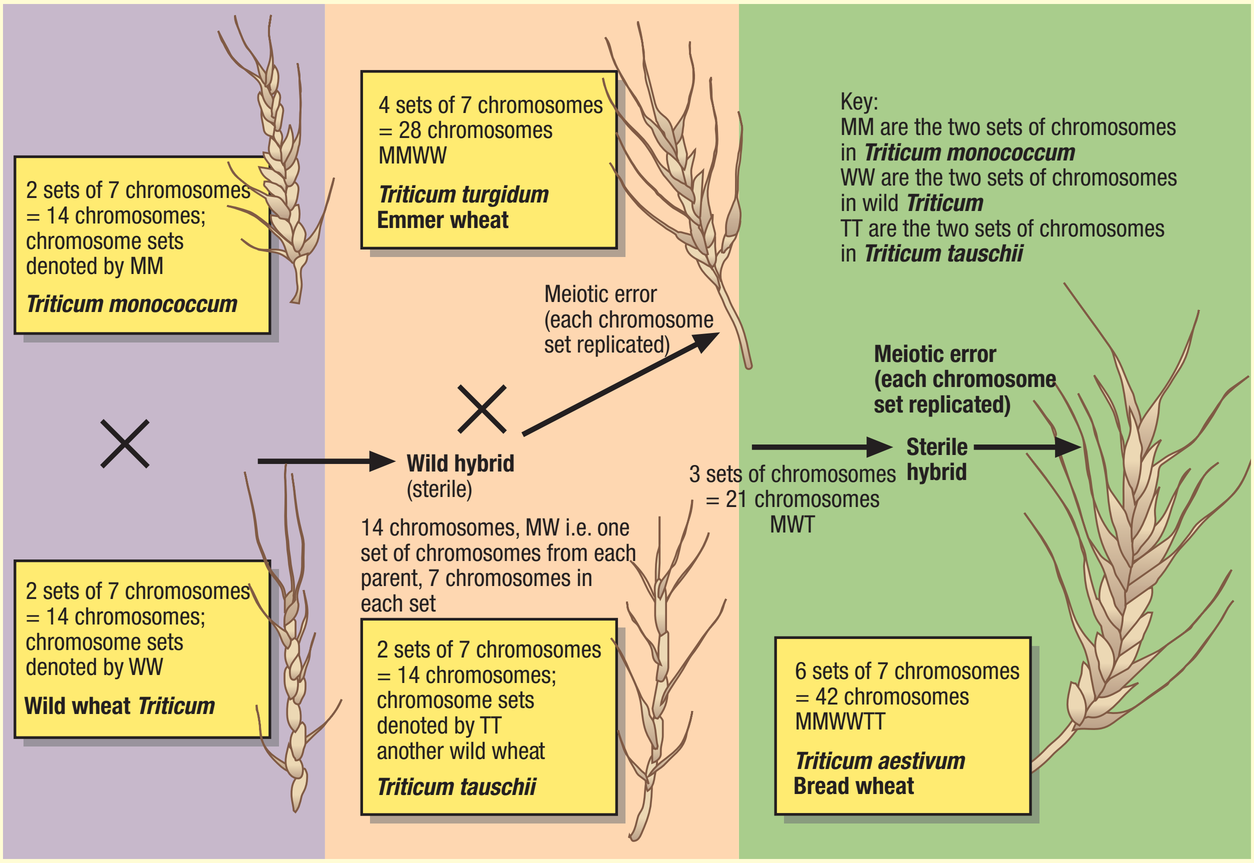


Figure 24.1 The evolution of wheat

formation of Emmer wheat, this hybrid also underwent a complete duplication of chromosomes and so was fertile. *T. aestivum* (modern bread wheat) came into being. Its forty-two chromosomes comprised seven pairs of original wild wheat, seven pairs of *T. monococcum* and seven pairs of *T. tauschii*. In this new species, the grains were strongly attached to the stalk and so were not readily wind-dispersed. They needed to be manually planted.

The evolution of bread wheat is shown in Figure 24.1. Over time different varieties of bread wheat would have evolved in different growing conditions. By crossbreeding these varieties, thereby eliminating harmful recessive genes and increasing genetic diversity, the quality of wheat seed was improved.

Although bread wheat evolved naturally, it is unlikely that it would have survived without the intervention of cultivation, since its seed did not easily spread. Natural selection was then replaced by artificial selection as farmers selected the best varieties of seed to grow and encouraged cross-fertilisation between specific varieties in order to achieve a strong plant that produced good grain. Today there are only four species of wheat commonly grown around the world.

Humans have modified useful species over many generations by selecting individuals with the desired characteristics as breeding stock. The plants and animals we grow for food bear little resemblance to their wild ancestors. For example, broccoli, cauliflower, cabbage, kale and brussel sprouts all have a common ancestor in one species of wild mustard.

Figure 24.2 Artificial selection of a common mustard species has resulted in a variety of food plants such as the cauliflower, cabbage and broccoli.

Breeders have selected different parts of the plant to accentuate in producing these divergent results.

The first domestication of animals was a more difficult process than cultivation of plants. Few wild animals have the necessary attributes for successful farming. They needed to be able to live together in a fairly confined space and thus needed to be herd animals of a naturally placid disposition. In addition they needed to have a relatively fast growth rate with easily obtained feeding preferences. Herbivores are more efficient in converting available food into flesh than are carnivores and, due to their social structure, are much more placid. Few species fitted all criteria, and apart from a few regional species (e.g. camels in the Middle East and llamas in Peru) the only mammals domesticated worldwide are cattle, sheep, goats, pigs, dogs and horses.

The first cattle that were domesticated about 6000 years ago were aurochs. There were two varieties of this animal—the humped auroch found in Asia (a few wild auroch are believed to exist in Indonesia) and humpless auroch of Eurasia and North Africa (now extinct). They were independently domesticated at about the same time. For centuries the main criterion for breeding was the selection of mating stock that were docile and easily looked after. The original aurochs were hairy animals able to withstand the extremes of weather they would experience in the wild. With domestication and provision of shelter, short-haired varieties became more common.

European expansion into other parts of the world in the eighteenth century (e.g. to America and Australia) and a growing demand for increased food production saw the selection of cattle based on other characteristics, such as milk and meat production. European breeds were less able to survive in many parts of Australia and America. Varieties were developed that had longer legs and could efficiently travel vast distances seeking pasture and water.

By the nineteenth century, graziers had a greater understanding of artificial selection, even if the genetic basis was still unknown, and careful records were made of breeding programs. With the expansion of cattle into north Queensland and the Northern Territory, the long-legged shorthorn cattle were found to be susceptible to tick fever. In the mid-1900s humped cattle (Brahmans) from India were introduced and crossbred with European stock. These hybrids (e.g. Santa Gertrudis, Brangus, Droughtmaster) have the more docile characteristics and meat production of the European breeds but the greater tolerance to heat, high humidity and ticks of the Indian breed.

Similar artificial selection of sheep, goats and pigs took place. There are many varieties of sheep, some used predominantly for fine wool production (e.g. the Australian merino) used in clothing, others for carpet wool production and others for meat production.

Two methods of artificial selection are commonly used by breeders. **Inbreeding** is a process where consistency in particular characteristics is maintained by mating close relatives. This is easily achieved in plants that self-pollinate. In animals, closely related males and females are mated. Although this method increases the number of organisms in a stock that are homozygous for a particular characteristic it also tends to increase the chances of harmful recessive genes occurring together in the offspring. Dwarfism in Hereford cattle, deafness in Dalmatian dogs and hip dysplasia (faulty development of the hip bone structure) in German shepherd dogs are examples of recessive genetic traits that commonly occur as a result of inbreeding.

Outbreeding is the mating of different varieties or closely related species. Corn, for example, is usually grown from seed produced by hybridising two different pure-breeding varieties, each selected for a superior characteristic. One parent plant may exhibit strong disease resistance while the other produces a sweet taste. The parent plants have to be grown under controlled conditions and artificially cross-pollinated. The resulting seeds produce plants which display **hybrid vigour**, i.e. have better overall characteristics than either parent plant. The seeds that these plants produce, however, have great variability. Thus new hybrid seed has to be purchased each growing season to ensure consistency. In the development of animal varieties with desirable characteristics that breed true, outbreeding is followed by a program of inbreeding.

Aquaculture is another method of ensuring a regular supply of food. Although most organisms reared in this way are animals, some plants, such as water chestnut and seaweed, are also produced. Fish farming originated 6000 years ago in China—different varieties of carp, each eating a different food source such as plankton, floating plants and detritus, were kept in garden ponds. In ancient times human waste disposal into the ponds provided water plants and some carp species with nutrients. This practice also aided the dispersal of human liver flukes (*Clonorchis sinensis* and *Opisthorchis felineus*) since the snail and freshwater fish are intermediate hosts.

The early Romans practised oyster farming, using a method of culture little changed today. The eggs of oysters hatch into planktonic larvae which eventually settle onto a stable substrate (rocks in nature) and develop into the attached, shelled adult.

By providing artificial substrates with a large surface area, many oysters can be grown in a relatively small area and easily harvested. While the Romans farmed oysters for food, the Japanese developed the technique for culturing pearls at a very early time. They carefully opened the oyster shell and inserted a small piece of mussel shell inside. The oyster secretes a solution of calcium carbonate around the foreign matter that eventually hardens into pearls. In natural conditions pearls are formed in response to grains of sand.

There is some evidence that early Australian Aborigines carried yabbies (freshwater crayfish) from one water hole to another. Coastal tribes, as seen from their midden heaps, certainly harvested oysters, mussels and other shellfish.

There is currently a growing aquaculture industry in Australia with fish (such as barramundi and trout), crocodiles, yabbies, prawns, crayfish, oysters and mussels being farmed around the country.

Figure 24.3 Oyster farming on North Stradbroke Island, Queensland

SUMMARY

With the beginnings of human farming, characteristics of crops and domestic animals have changed through both natural and artificial processes. Genetic variations within wild populations resulted in different characteristics which were acted upon by regional natural selection. Hybridisation between related species, coupled with chromosomal duplication, sometimes resulted in new species. Further phenotypic changes appeared through the deliberate selection of breeding stock by farmers. Through artificial selection a great number of plant and domestic animal varieties have arisen, each maximising production and suited to its growing conditions.

Two major processes are involved in artificial selection—inbreeding within family groups of the same species to achieve a high degree of morphological similarity, and outbreeding to produce different varieties.

Review questions

24.1 Define the following terms:
(a) artificial selection
(b) inbreeding
(c) outbreeding.

24.2 Explain why it is unlikely that bread wheat would have survived had human agriculture not developed.

24.3 Suggest why carnivores are not suitable animals for domestication.

24.4 Why is artificial selection a more rapid process than natural selection?

24.1.2 Traditional uses of micro-organisms in biotechnology

Food processing

A large number of common foods (e.g. certain cheeses, yoghurt, leavened bread), condiments (such as vegemite) and alcoholic drinks are manufactured using biotechnology. Many of these products are formed from the anaerobic respiration of micro-organisms, particularly yeasts and bacteria. Many yeasts produce alcohol and carbon dioxide during anaerobic respiration and this is commonly called fermentation. Other microorganisms produce lactate. Anaerobic respiration was fully described in Chapter 14 and is summarised in Figure 24.4 on page 650.

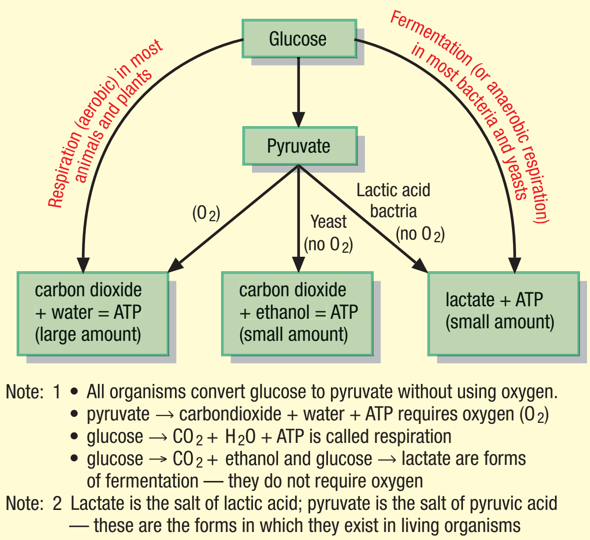


Figure 24.4 An overview of respiration and fermentation

Many of these procedures date back several thousands of years, before knowledge of the organisms or processes involved. Observations that honey and sugar-rich fruit juices fermented to produce alcohol or acetic acid (the main component of vinegar) were the first steps in deliberate production of these substances. Beer was produced from fermenting germinating cereal. The Sumerians and Babylonians were producing beer in 6000 BC. The carbon dioxide released during fermentation of yeast in flour dough was found to cause the dough to rise. The bubbles of gas are trapped inside the dough when it is cooked, making the bread rise. Leavened bread was made by the Egyptians in 4000 BC. Other observations led to the production of yoghurt (bacteria in the milk release lactic acid, causing the milk to sour slightly and become creamy in texture) and cheese (the stomach enzyme rennin separates the solids or curds, from the liquid portion, whey, of the milk). In the latter case it could be hypothesised that this was discovered when the stomach of a calf was used as a storage container for milk.

Further refinements of the initial observations and increased knowledge of exactly which micro-organisms were involved in any particular reaction, particularly in the nineteenth and twentieth centuries, produced products of standard quality and a predictable taste.

Today a great number of products are made using anaerobic respiration of microorganisms. The most commonly used bacteria are *Acetobacter* (vinegar from alcohol), *Lactobacillus* (butter, cheese and yoghurt from milk) and *Clostridium* (acetone and butanol from molasses). Other lactic acid bacteria are used in the production of sauerkraut and in the preservation of olives and cucumbers. The material to be preserved is mixed in salt water and pressed into containers excluding air. The bacteria thrive in these conditions, producing lactic acid which reduces the pH to between 4 and 5 and this prevents survival of other microorganisms. A variety of yeasts are used to produce different wines and beers (the yeast sludge from beer making is used in the manufacture of Vegemite). At concentrations of approximately 12 per cent, the alcohol kills the yeasts and so no further fermentation occurs. The alcohol acts as a metabolic poison.

Fungi are also used to give different cheeses their distinctive flavours such as roquefort (*Penicillium roquefortii*) and camembert (*P. camembertii*). The mucilaginous coating on both coffee and cocoa beans is removed by allowing fermentation by naturally occurring microflora (bacteria and yeasts) to act on mounds of beans. The heat generated during fermentation kills the seed embryos and so prevents germination. Once this is completed the beans are then dried and ready for transport. *Aspergillus oryzae* is used to ferment soya beans and wheat to manufacture soy sauce.

A large variety of enzymes are used in the commercial preparation of foods. The nature and properties of enzymes were discussed in Chapter 12. Without the addition of the enzyme pectinase to fruit juices, for example, the naturally occurring pectins in the fruit make the juice cloudy and cause the colour and flavour to deteriorate. Table 24.1 lists some of these enzymes, their sources and uses.

With increasing concerns over the use of petroleum (a non-renewable resource) in motor cars and the discharge of greenhouse gases as a result of its combustion, the use of alcohol as a fuel has become more significant. Usually the alcohol is produced by the fermentation of molasses. Sugar cane is crushed to release its fluids. Molasses is the syrup remaining after sugar has been crystallised out. Dilute alcohol is derived from the fermentation of the molasses by *Saccharomyces cerevisiae*. The alcohol is distilled to yield pure ethanol.

Many of the fermentation processes are now undertaken in very controlled conditions in large industrial fermenters. This method was described in Case study 5.1 (page 114).

Useful decomposition reactions

Many bacteria and fungi are important decomposer organisms. They obtain their nutrients from organic matter (predominantly dead organisms) and, in doing so, release simple inorganic compounds back into the environment and make them available for

Table 24.1 Some enzymes produced by microorganisms used in the commercial production of food

Enzyme	Microorgansim from which obtained	Application
α-amylases	*Aspergillus oryzae*	Conversion of grain starch to sugar in beer production Preparation of glucose syrup Thickening of canned sauces
β-gluconase	*Bacillus subtilis*	Conversion of sugar to glucose in beer production
Glucose isomerase	*Bacillus coagulans*	Sweetener for soft drinks
Lactase	*Kluyveromyces*	Sweetener for milk drinks
Lipase	*Candida*	Development of flavour in cheese
Pectinase	*Aspergillus*	Clearing of wines and fruit juices
Protease	*Bacillus subtilis*	Meat tenderiser
Pullulanase	*Klebsiella aerogenes*	Soft ice-cream production
Sucrase	*Saccharomyces*	Manufacture of confectionery

use by producer organisms. Many decomposer bacteria and fungi are used as biodegradation agents; for example, to clean up oil spills and in toxic organic-waste dumps.

Methanogen bacteria are utilised in a variety of processes. Domestic rubbish, sewage or agricultural waste, placed in a container (a digestor) and inoculated with these bacteria, is broken down to form humus and methane gas. The gas is collected and used for cooking, lighting and heating. Such digestors are used domestically in China, India and New Guinea. In Australia, many authorities are now using methane released from rubbish tips to generate electricity. Bacteria and other microorganisms are also used in the industrial treatment of sewage.

Bacteria are also used to decompose pectin, the chemical which holds the cellulose fibres in hemp and flax together. The freed fibres are used to make linen, other textiles and rope. Other bacteria are used in tanning leather and curing tobacco.

Production of medicines

Most **antibiotics** are chemicals released as a metabolic waste product by certain bacteria and fungi that prevent the spread of other microorganisms. Since their discovery and techniques of isolating and purifying the active substances, many antibiotics have been artificially synthesised. Of approximately 5000 antibiotics that have been isolated, only about 100 have been found to be effective in treating human and domestic animal diseases. Most antibiotics inhibit growth rather than kill the pathogens on which they act.

One of the first antibiotics used in human treatment was discovered accidentally. Prior to going on holidays Scottish scientist Alexander Flemming, by chance, left an agar plate inoculated with the bacterium *Staphylococcus aureus* (golden staph) on a bench rather than placing it in the incubator. On his return he discovered a mould growing on the plate. Further, bacterial colonies close to the mould appeared to be breaking down. He reasoned that the mould released a chemical that prevented the growth of bacteria.

Flemming was able to identify the mould (which would not have actively grown in the moderate temperatures of the incubator) as *Penicillium* and showed it did release a chemical (which he named penicillin) into the agar medium. He did not, however, purify this chemical even though experiments on the impure form were found to kill a number of Gram-positive bacteria. Further work on penicillin was continued by colleagues Howard Florey (an Australian) and Ernst Chain at Oxford University. They were able to extract a highly concentrated preparation of penicillin and, from animal testing, found that it cured all staphylococcus infections which were not able to be treated by the existing sulfa drugs. Commercial production was in place by 1941.

Penicillin is an example of a **narrow-spectrum antibiotic**, since it is effective on only a few bacteria.

Other antibiotics, such as chloramphenicol, are **broad-spectrum antibiotics** and inhibit the growth of a large number of pathogens.

The commercial production of penicillin (and many other antibiotics) is done in a stirred-tank fermenter, as described in Case study 5.1, in which either *Penicillium notatum* or *P. chrysogenum* is grown under optimal conditions. Penicillin production reaches a maximum after 4 days and usually ceases after 6 days. Since this is an excreted waste product, the fungus mycelium is filtered off and discarded and the pencillin is extracted from the filtrate and purified as a crystalline salt using appropriate solvents.

The production of viral vaccinations is undertaken in a different manner. Since viruses cannot reproduce out of a host cell, they must infect another cell in order to multiply (see Case study 1.2, page 12). Hen eggs are normally used in this process. The viral particles are then collected, killed and concentrated. The dead virus causes a similar immune response to a live virus when injected into a

A large bioreactor being erected in Britain to grow bacteria on methanol

A fermentation tank (bioreactor)

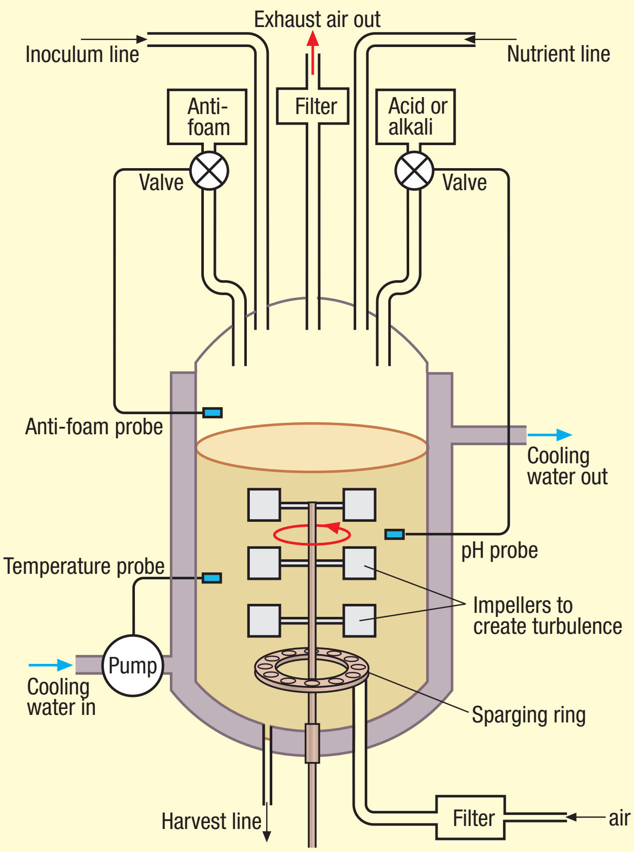
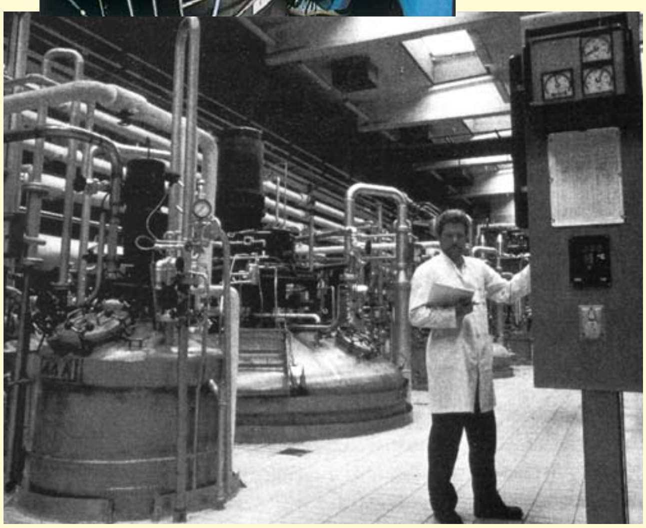


Figure 24.5 Stirred-tank fermenter



A fermentation plant at Novo, Denmark, used for the production of enzymes person but without the development of the disease symptoms. The antibodies formed in this response give the person immunity to the viral disease for a period of time.

Germ warfare

Many infectious diseases can have an effect on bone metabolism in some way and thus fossil bones can give an indication of the extent of pathogenic infections at particular times in history. Using this as an indicator, it would appear that early humans who took up farming were more likely than the hunter–gatherer groups to have suffered from bacterial and viral diseases. This is not surprising since the development of farming allowed the development of sedentary societies, not all members of which were involved in food production. Consequences of farming include:

- By selecting and growing those few species of plants and animals that we can eat, a particular area could support between ten and 100 times more people than the same area dependent on hunting–gathering of food where edible material competes with non-edible.
- Domestic animals provide meat, milk for food, hair and hides for clothing, fertilisers for crops and manure as a construction material and fuel. They can pull ploughs to aid cultivation and are a means of transport.
- Excess food can be stored. Thus non-food-producing specialists can be supported
- Because the group did not have to constantly travel, women could space their children at more regular 2-yearly intervals rather than the 4 years typical of hunter–gatherers. Population density therefore increased in farming areas.
- Many pathogens of domestic animals evolved mechanisms enabling them to infect their human hosts. Thus pathogens causing smallpox, influenza, tuberculosis, malaria, plague, measles and cholera all had an origin in an animal host. Because of the higher human population density in farming communities, these diseases could spread more rapidly than in nomadic groups with their isolated, small populations.
- With congregations of people in a permanent place, disposal of human sewage into waterways and as a fertiliser for crops became the norm. This maintained high levels of pathogens within an area. As towns and cities developed based on the agricultural community supplying food, this problem became even greater.
- Many animals such as rats were attracted to food-storage areas. Similarly, mosquitoes accumulated in cleared areas, particularly where crops were irrigated. These and other animals are capable of transmitting human disease.

As described in Chapter 5, infectious diseases are invariably counteracted by the immune system. The body is able to recognise proteins (antigens) on the pathogen's cell surface and other proteins (antibodies) specific to the antigen are formed which activate a number of responses culminating in the destruction of the pathogen. In addition, some of these antibodies remain in the system for many years ready to strike a further infection. In some cases, a person dies before the immune response counteracts the pathogen. Some members of the population are not affected due to their particular genetic disposition. Over time in any particular population, the combined effects of the immune system and natural selection result in a fairly strong resistance to pathogens to which it is repeatedly exposed.

Natural selection of particular genes can, however, differ from place to place. As seen in Chapter 20, sickle-cell anaemia is a fatal disease resulting from deformed red blood cells (and thus an inability of the haemoglobin to carry adequate oxygen) due to a recessive allele. A person with the homozygous recessive genotype will die at a young age as a result of the disease but a homozygous normal person is more likely to contract and die of malaria. A heterozygote, although suffering mild anaemia, does not get malaria because the slightly distorted red blood cells are not suitable for the malaria pathogen. Thus in those areas in which malaria is prevalent, there is a greater survival rate of heterozygotes for sickle-cell anaemia and thus the allele is maintained in the gene pool at a higher level than in malaria-free areas. A similar situation occurs for the allele for Tay-Sachs disease among Ashkenazi Jews against tuberculosis and that for cystic fibrosis in northern Europeans against bacterial diarrhoea.

During the eighteenth century the microbial nature of many diseases was established. As early as 1701, children in Constantinople were being inoculated with a mild strain of smallpox to induce resistance to more severe strains later in life. Later in that century, Jenner established that vaccination with cowpox also conferred resistance to smallpox. Thus the science of using germs to combat disease caused by germs was established.

The spread of pathogenic microorganisms, either accidentally or on purpose, has been significant in the outcome of conflict between opposing groups over human history. The early deliberate spread of human infectious diseases can only be hypothesised. Certainly the extent to which a few Europeans were able to subdue large numbers of indigenous peoples in their expansion throughout the world is well documented. Thus the Indian population of Hispaniola was decimated by disease from an original 8 million to zero over 47 years with the arrival of Columbus. Similarly the conquering of the Aztecs by Cortés in 1520 was largely the result of a smallpox epidemic. Apart from syphilis, there were few infectious diseases in the New World. This probably was because there were few animals that could be domesticated and so farming was mainly restricted to crops. Similar decreases in indigenous peoples are recorded with the colonisation of Australia and other Pacific islands.

The deliberate use of pathogens against an enemy goes back to the beginning of human civilisation. Scythian archers dipped their arrow-heads in manure and rotting corpses to increase the deadliness of their weapons. In the fourteenth century the Tartars threw corpses of plague victims over their enemy's city walls. Unfriendly Native Americans were given blankets previously used by smallpox patients as gifts. The Germans spread a horse disease among the mounts of the enemy during World War I. In World War II the Japanese dropped plague-infected fleas on Chinese cities.

Even though intentional biological warfare was condemned as unethical and inhumane, research and development into its use was carried out during the early twentieth century by Canada, France, Germany, Japan, the Soviet Union, the United Kingdom and the United States of America. They expended huge effort in the scientific development of pure cultures of virulent viruses and bacteria that could be readily dispersed through enemy territory. The difficulties lay not in the production of large numbers of the microbes but in processing them in such a way that they were both hardy and stable enough for efficient, wide dissemination that targeted the enemy only. Particularly virulent forms of *Anthrax* were developed and converted to dormant spores. Blights that would attack potatoes and rice, plague and tularemia were also explored. Scientists also were able to extract and concentrate the exotoxins of bacteria, among them botulinum toxin (the deadliest poison known), which causes complete muscle paralysis. This toxin would rapidly kill anyone in contact with it. As the actual pathogen would not be used, however, the disease effects could not be transmitted to others by those individuals initially affected by the toxin.

Success of the deliberate infection of rabbits with the myxomatosis virus in Australia and France in the early 1950s led the American research teams to investigate viruses (myxomatosis virus is very similar to the group of viruses causing smallpox) as an alternative to bacterial warfare. Part of the reasoning was that bacterial infections can be treated with antibiotics. Immunisation against viral infections can be made, so the advancing army could be protected and the unvaccinated enemy affected. In addition, most viral infections rarely killed their host. The effects experienced, however, would be such that they would tie up many enemy personnel and give the invading army an advantage. Over fifty different viruses were developed for possible use, including encephalitis, yellow fever and Q fever.

In 1976 the United States, the Soviet Union and more than 100 other nations signed the Biological and Toxin Weapons Convention that prohibited the possession of these agents except for research into defensive vaccines, detectors and protective clothing. Unfortunately this accord was only a pledge and did not limit the amount and types of organisms that could be kept for research.

With the ability to now manipulate and recombine the genes (see Section 24.3) of microorganisms, the ability to produce deadly biological agents of war at a faster rate than the development of vaccines is a real danger. The fear engendered by such possibilities is exemplified by the recent Gulf Wars. In 2003 America, backed by a coalition of forces, invaded Iraq on the suspicion, later found to be unverified, that the Iraqis were stockpiling biological weapons of mass destruction.

Not all germ warfare is pitched against our own species. A greater understanding of plant and animal pathogens has allowed the biological control of many pest species. *Bacillus thuringiensis*, for example, produces a protein which is highly toxic to insects. Contamination of the insect's food with this bacterium can help to control its numbers. Several exotic plants introduced into Australia (e.g. skeleton weed, blackberry and Paterson's curse) are being controlled by specific rust fungi that reduce the plants' growth rate and thus their spread. Nitrogen-fixing bacteria, *Rhizobium*, can be inoculated into soils along with their host seeds to combat low soil nitrate and thus ensure higher crop yields.

SUMMARY

Microorganisms have long been used in a variety of processes to benefit humans, even prior to the understanding of the organisms and the processes involved. They are used in food and beverage production, either directly accessing the products of anaerobic respiration (alcohol, carbon dioxide or lactic acid) or indirectly through extraction of enzymes used in the food industry.

Decomposition by bacteria and fungi has been utilised in the production of methane gas as a fuel, as biodegradation agents and in the industrial treatment of sewage. Many bacteria and fungi are plant and animal pathogens. Thus they can be used in biological control of human pests as well as weapons of war.

Review questions

24.5 Describe three food processes that have long used microorganisms.

24.6 How are methanogen bacteria used for the benefit of humans?

24.7 What is an antibiotic?

24.8 What is the function of an antibiotic for the organism producing it?

24.9 Distinguish between a narrow-spectrum and broad-spectrum antibiotic.

24.10 Discuss some of the inherent dangers of biological weapons.

24.2 Reproductive technologies

A whole array of technologies have developed over the past 75 years related to reproductive processes, including methods to:

- prevent conception
- aid conception
- assist difficult pregnancies
- screen embryos for congenital and genetic defects
- overcome infertility
- produce pure-line breeds of plants and animals.

While many of the biotechnologies developed originated from plant and animal research and were then applied to human reproduction, some were directed purely towards the human species. The general euphoria surrounding the new biotechnology of the early twentieth century (related to the production and life-saving effects of penicillin) sometimes led to applications that had extreme negative effects, some of which were not discovered for many decades.

While some couples wish to prevent conception, other couples have difficulty in conceiving or in maintaining a pregnancy. Case study 19.1 (page 526) describes some of these situations and the biotechnologies currently available to help rectify some of these problems. The current techniques used to determine possible embryonic defects are described in Section 19.3.3.

24.2.1 Hormone therapy

The way in which hormones interact in the development of the human reproductive system and the control of the cycle in females was described in Chapter 19. Initial work on the effect of hormones was undertaken in the early part of the twentieth century. After the identification and isolation of the major human reproductive hormones, their effects were tested on rats. Research demonstrated that during pregnancy normal levels of oestrogen were essential for the development of the fetus, although high levels could cause abnormalities due to disrupted sexual development.

In 1938 the first artificial hormone that acted in the body like natural oestrogen was synthesised. Known as DES (diethylstilboestrol), it was initially given to women experiencing problems during pregnancy. It was thought that miscarriage and premature birth resulted from lower than normal levels of naturally produced oestrogens. Ignoring the data from the rat experiments (dismissing them as irrelevant to humans), doctors prescribed this drug widely over the next two decades. Its use was expanded:

- as a supplement for normal pregnancies somewhat like a vitamin to produce bigger and stronger babies
- to suppress milk production after childbirth
- to alleviate hot flushes and other menopausal symptoms
- to treat acne, prostate cancer and gonorrhea
- to stunt growth in teenage girls who looked as though they were becoming unfashionably tall
- as a 'morning after' contraceptive pill.

Excited by the new technology, farmers also used DES and other synthetic chemicals as a food supplement or as a skin implant to increase the fattening of livestock.

It was not until 1971 that the true effects of DES came to light. A strong link was made between a rare vaginal cancer, malformed vaginal tissue and abnormal uterine structure in young women born of mothers who had taken DES during pregnancy. Shortly after it was found that males exposed to DES had one or more of the following conditions—abnormal sperm, immune system problems such as arthritis, undescended testicles, stunted penises and epididymal cysts and in extreme cases, testicular cancer. In both genders, there was a high incidence of depression and eating disorders. The significant feature of this example is the long time between cause and effect.

At the time that DES was introduced, little was really understood about the interactions between hormones, the effects of hormones on development or how hormones influenced cells to perform particular functions. The apparent success of DES, however, encouraged the development of further biotechnology.

During the early 1940s sheep in Western Australia, despite good rain and lush pastures, suffered extreme infertility. In the first years, there was an increasing number of stillborn lambs or the ewes failed to go into labour and the lambs (and often their mothers) died. In following years, in spite of repeated breeding to fertile rams, the ewes did not conceive. Research determined that the cause was clover. In previous years the farmers had worked at improving their pastures and soil nitrate levels by growing subterranean clover from the Mediterranean region. It took several years for scientists to isolate the chemical formononetin, a small molecule that does not break down in the sheep's intestine and that, like DES, mimics oestrogen. As the concentrations build up in the sheep, they become increasingly infertile.

Since plants cannot run away from predators, they have evolved an interesting array of defence mechanisms. Some smell bad, taste bad or produce poisonous substances. Others have thorns, spines or indigestible substances to discourage herbivores eating them. The chemicals produced by other plants mimic growth regulator hormones making the herbivore infertile and thus reduce its population. Since the herbivore's reproduction is limited by the number of fertile females, an effective plant strategy is to sabbotage females rather than males—these plants produce oestrogen mimics.

Figure 24.6 Hormone mimics produced by the fungus *Ergot*, growing on the pasture grass *Paspalum*, are known to cause spontaneous abortion in cattle.

The use of certain plants as a means of contraception or in inducing abortions has long been known. Throughout the ancient world a now extinct form of giant fennel (*Silphium*) was used for this purpose. In the fourth century BC wild carrot (now developed as the cottage garden plant Queen Anne's lace) was found to have abortive properties. Its seeds have since been found to contain a chemical that blocks progesterone, a mammalian hormone necessary for establishing and maintaining pregnancy. The ancient Greeks used pomegranate as a contraceptive. Research has established that this plant produces a plant oestrogen that acts like the chemicals found in modern oral contraceptives.

Although an Austrian endocrinologist (Ludwig Haberlandt) pinpointed the potential of progesterone as a contraceptive in 1920, the oral contraceptive did not become available until 1960. In 1942 Russell Marker, an American chemist, found large amounts of the steroid diosgenin in the inedible 'cabeza de negro' yam root growing in the mountains of Veracruz. This steroid can be converted into progesterone. He formed a chemical company in Mexico City whose initial interest was to develop cortisone to treat arthritis from the steroid. This work laid the foundation of the development of the synthetic progesterone, norethidrone, in 1951. This form of progesterone has a much higher biological activity than natural progesterone. The research was driven by the need to produce a new form of progesterone to treat menstrual disorders and infertility. Five years later, a competing American company began testing a nearly identical substance (norethynodrel) which they had synthesised in birth control pills. This pill was approved by the US Food and Drug Administration in 1960 for public use. In 1962 the use of norethidrone was also approved for this purpose. The contraceptive pill contains both synthetic oestrogen and progesterone, both of which control the release of FSH and LH (see Section 19.1.4). Both hormones are required for effective contraception.

Over the past 30 years oral contraceptives have been modified considerably. Many of the side effects that were experienced by the first 'pills' have been counteracted by changing the oestrogen to progesterone ratios and the actual amounts incorporated. New synthetic progesterone (e.g. desogestrel) and oestrogen (ethinyl oestradiol) were developed.

One of the drawbacks of the oral contraceptive is that it has to be taken daily to be effective. Missing taking the 'pill' on one day or even vomiting within hours of taking it can result in unwanted pregnancy. Research was therefore undertaken so that the hormones could be administered through the skin. A different synthetic progesterone was developed (Nestorone or 16-methylene-17a-acetoxy-nor-progesterone) that is very similar to natural progesterone. Although this is broken down in the digestive system, it remains active when absorbed through the skin (transdermal application). This hormone is used either alone, or in combination with oestrogen, as vaginal rings, patches, gels and implants. The vaginal ring, of which there are two different forms, is fitted over the cervix. One form combines both hormones and is similar to that of the contraceptive pill. Like subdermal implants, it slowly releases the low amounts of the hormones that prevent ovulation and is effective for a year. It needs to be removed one week in four to allow normal menstrual flow. Another vaginal ring contains only the progesterone element that can be used by lactating women to extend the contraceptive effectiveness of lactation.

Although female contraceptives have now been available for over 40 years, an effective male contraceptive has only recently been developed. In the normal sequence of events, the brain produces a gonadotropin-releasing hormone that stimulates the pituitary gland to produce gonadotropins. These act on the testes, resulting in the formation of both sperm and the hormone testosterone. Previous attempts to produce a male contraceptive by decreasing the production of gonadotropins resulted in side effects, such as enlargement of the prostate gland and decreased masculinity and sexual drive. Recent research has seen the development of a synthetic steroid that resembles testosterone. Combined with acetate, this synthetic hormone suppresses gonadotropin secretion and thus sperm production while the synthetic testosterone maintains maleness. The contraceptive is administered as either a transdermal patch or an implant under the skin.

Another method of male contraception has been successfully trialled in India for over a decade. This method does not depend upon hormones and so does not disrupt normal cycles. A solution of styrene maleic polymer dissolved in dimethyl sulphoxide is injected into the vas deferens. Although the chemicals coat the walls of the tube, they do not block them. Negatively and positively charged complexes are thought to form on the tube walls which rupture the sperm membranes as they pass. Small doses that were injected 10 years ago have remained effective spermatocides. Of even greater import, the chemicals can be washed out of the vas deferens using a correctly applied solution of sodium bicarbonate, restoring the fertility levels.

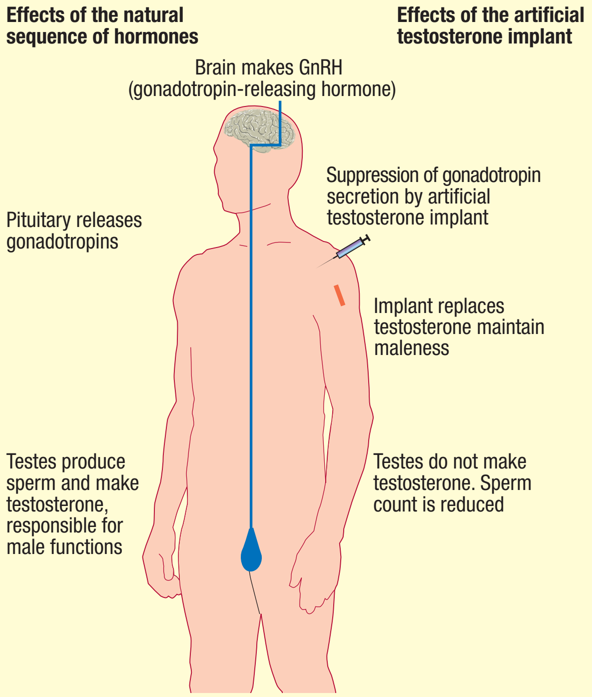


Figure 24.7 Comparision of the action of the synthetic steroid and testosterone in the male

SUMMARY

The first artificial hormone, DES, was developed to assist women experiencing difficulties during pregnancy during the late 1930s. It acted in a similar manner to oestrogen but was later found to have a number of deleterious effects in both male and female offspring, many of which did not show up until sexual maturity. At around the same time a number of plants were discovered to produce phyto-oestrogens, possibly as a defence mechanism against herbivores (by lowering their fertility there would be fewer animals to eat them).

The first plant steroid that could be developed into progesterone was isolated from a Mexican wild yam. Synthetic progesterone, to be used as an oral contraceptive, was released to the public in 1960. Since that time other varieties of progesterone, and different combinations of oestrogen and progesterone, as well as transdermal contraceptives, have been developed in an attempt to reduce the side effects of oral contraceptives. More recently subdermal implants and transdermal patches have been developed to prevent sperm production in men, or to inhibit the sperm once they have been produced.

Review questions

24.11 Referring to Chapter 19, explain how an oral contraceptive pill works by altering the body's natural hormone cycle.

24.12 From your knowledge of reproductive hormone activity, explain why DES would not have prevented miscarriage.

24.13 What were some of the difficulties experienced in the development of a male contraceptive pill?

24.2.2 Cell and tissue culture

Plants

Since plant cells are surrounded by a semi-rigid cell wall, most cells cannot readily divide. Specialised immature cells are maintained in areas of the plant that undergo active growth in tissues called meristems. The cells of meristematic tissues are **totipotent**, i.e they have the potential to grow into any other type of plant cell.

Modern techniques have been developed which allow plant cells to be grown in culture. Different techniques are used, depending on the way the culture is to be used. They may be grown as shoots, as suspensions of individual cells, as protoplasts which are plant cells without cell walls, as aggregates of cells called **callus** cultures, or as groups of particular tissues.

To grow a callus culture, meristematic cells of a plant are removed, sterilised and placed in a controlled environment. The nutrient culture medium is an agar base in which plant growth regulators have been mixed. The cells divide under the influence of the regulators to produce a callus of unspecialised cells. This callus tissue is capable of regenerating a new plant which is genetically similar to the original plant. When many plants are produced from a single callus culture, they form a clone. The first regeneration of a plant from callus culture was performed in 1959 on carrots.

Many commercial plants, such as eucalyptus, bottlebrushes (*Callistemon*), orchids and carnations, are reproduced asexually in this way. There are many advantages:

- Slow-growing plants can be produced in large numbers.
- Growth is independent of seasonal factors.
- Plants prone to virus infection (e.g. strawberries and potatoes) can be cloned in large numbers from virus-free plants.
- Sterile cultures can be readily transported from country to country.
- All plants developed are clones (genetically identical) to the donor plant and thus have known characteristics.

The callus tissue can also be treated with pectinases and cellulases to remove the cell walls. The **protoplasts** produced can be fused with the protoplasts of different species that are sexually incompatible, and thus cannot be crossbred by conventional means, to form hybrids. This protoplast fusion can be used to produce disease-resistant plants. The potato (*Solanum tuberosum*), for example, is susceptible to a water mould (*Phytophthora infestans*). The potato blight that results can be devastating—it was responsible, for example, for the destruction of potato crops in Ireland in the 1840s and the death of a million people who depended on this subsistence food. Tomatoes (*Lycopersicon esculentum*) belong to the same family as the potato and are resistant to *Phytophthora* infestation. Fusion of potato and tomato protoplasts can result in potato plants with the tomato mould-resistant genes. Treated with a suitable medium, the protoplasts will generate cell walls, multiply and differentiate into whole plants.

Figure 24.8 *Phytophthora* mycelia

The agricultural application of this micro-propogation technique in producing large numbers of high quality, identical plants is obvious. Another possibility is the production of chemicals. Different species of plants produce different chemical compounds which can be useful in pharmaceutical and other products. By culturing tissues that produce the particular chemical, extraction can be magnified. This technique is used to commercially produce shikonin, a dye used in the silk industry and to treat burns. Other products of plant tissue culture include:

- codeine (from the opium poppy), used as a pain killer
- atropine (from deadly nightshade), used to dilate the pupil in eye examinations and in the treatment of some heart conditions
- quinine (from the chinchona tree), for the treatment and prevention of malaria
- pyrethrin (from the chrysanthemum), for use as an insecticide
- menthol (from peppermint), used as food flavouring
- digitoxin (from the foxglove), used in the treatment of some cardiovascular conditions.

Animals

Many animal cells can also be grown in culture medium. The techniques used were established in the 1950s using mouse, monkey and chicken cells. The tissue to be cultured is treated with a proteolytic enzyme to separate the cells and then transferred to the sterile nutrient medium. Mitotic growth produces a sheet of one cell thickness over the medium—the **primary culture**. Secondary cultures, of limited life span, can then be grown from cells of the primary culture. The production of skin graft tissue for severe burns victims is one of the applications of this technology.

Viruses (e.g. those causing measles, poliomyelitis, German measles and rabies) can be grown on cultured tissues of monkey kidney cells, chicken embryos or human cells. After harvesting, the viruses are extracted from the culture medium by filtration, killed and packaged into vaccines.

Other pharmaceutical products (e.g. interferon, human growth factor and clotting factors in the treatment of haemophiliacs) are also produced from human tissue culture.

SUMMARY

Both plant and animal tissues have been grown on suitable culture media. The major purpose of plant tissue culture is to produce callus tissue that can, given growth regulator hormones, develop into a new plant. Large numbers of clones of species that are hard to grow, or of individual plants with exceptional qualities, can thereby be produced. It is also used to harvest chemicals produced by the plant for pharmaceutical applications.

Animal tissue culture is primarily used as a growth culture for viruses for the production of vaccines. It can also be used to produce skin tissue for grafting.

Review questions

24.14 What is a totipotent cell?

24.15 What is the difference between a callus cell and a protoplast?

24.16 Explain why protoplasts are essential for artificial hybridisation between related species of plants to produce a plant with particular characteristics (e.g. disease resistance).

24.17 List some of the plant chemical products that can be harvested from plant tissue culture.

24.18 Why are living cells necessary for the culture of viruses?

24.19 Describe how a viral vaccine can be produced using animal tissue culture.

24.2.3 Cloning

Cloning is the production of a large number of organisms that are genetically identical. The offspring of asexually reproducing organisms are all clones of the single parent. The only genetic differences that occur are as a result of mutations.

One of the applications of artificial cloning is in the production of **monoclonal antibodies**. These are antibodies to a specific antigen. They can be used to diagnose and treat the diseases caused by the antigen that produced them, or for diagnosis of non-disease conditions such as pregnancy. In pregnancy testing, the antibody is used to detect the hormone human chorionic gonadotropin (HCG) which is produced by a pregnant woman and present in her urine.

The production of a monoclonal antibody depends upon the identification and isolation of the specific antigen. This is then injected into a mouse or a rabbit. The animal's immune system is activated and b-cell lymphocytes start to produce the antibody to the invading antigen. The animal does not develop the disease, since the pathogen itself is not present, only its antigens. These lymphocytes are isolated from the animal's spleen and inserted into rapidly growing tumor cells. The fused cell is termed a hybridoma—a hybrid of the lymphocyte and tumor cell. When these are grown in a culture medium they produce large quantities of the single antibody, which can be extracted and purified.

Although artificial culture of sexually reproducing plants had been established using callus culture, and animal cells had been cloned, it was not until 1997 that the first mammal, Dolly the sheep,

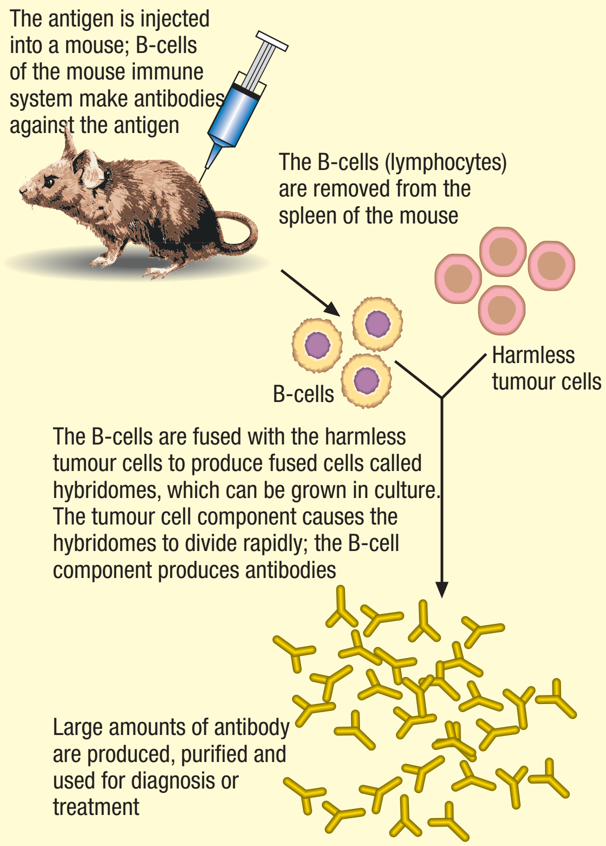


Figure 24.9 Production of a monoclonal antibody

was successfully cloned from an adult cell. Prior to that time, cloning had only been achieved on embryos of livestock. Embryos were developed *in vitro* and at about the 32-cell stage (2–3 days) of development were artificially split so that two embryos formed, in a process akin to natural identical twinning. Each of the cloned embryos could then be implanted into an adult female, where normal development took place.

Dolly, however, originated from an udder cell of an adult ewe. The process used is called **nuclear transfer** technique. Two types of cells are cultured in this process—recipient and donor cells. The recipient cell is an egg cell from which the chromosomes are removed. The donor cell can be any body (somatic) cell. This cell is, however, already specialised. Only some of its genes are active. In order for all of the genes to be active, the cell must be returned to its non-specialised, embryonic state. It was discovered that placing a specialised cell in a salt solution deprives it of the nutrients it requires and effectively causes the cell to forget its specialisation. The donor cell is then inserted into the recipient cell and fused using an electric jolt. The electric current also initiates cell division. Once the cell mass forms, it is implanted into the uterus of a surrogate mother, where is completes development. This cloning process is essentially simple but the success rate is low. It took 277 trials before Dolly was produced.

Originally it was thought that the recipient cell needed to be of the same species as the donor cell. It has been discovered, however, that this is not the case. Cow eggs have been successfully used as recipient cells for sheep, monkeys and pigs. Cow eggs can be easily harvested from a slaughtered cow and, being large, are readily manipulated. Once the donor cell has been inserted, the combined cell can be implanted into the uterus of a surrogate mother of the same species as the donor.

Each mammalian species has unique qualities. The eggs of some species may be more fragile and may not respond to micromanipulation to remove the nucleus and insert the donor cell. The process of stimulating cell division (such as use of an electric spark or infusing the cell with calcium to mimic the fertilisation signal of the sperm) may be different for different species. The exact nutrient medium on which the manipulated cell will grow may vary from species to species. In 2003 a team of Italian scientists succeeded in cloning a horse (a more difficult process than that for cattle and sheep) using adult somatic cell nuclear transfer. Furthermore the surrogate mother provided the donor cell for her cloned daughter. This implantation should have resulted in spontaneous abortion, since gestation normally depends upon the presence of foreign DNA in the embryo. Although the horse breeding and racing industry has placed bans on cloning, this success could lead to cloning using somatic cells of champion geldings (castrated male horses).

A second technique used in cloning is **blastomere** separation. This method was developed for the sole purpose of cloning human beings and involves a fertilised egg. The zygote divides to form identical cells called blastomeres within a covering called the pellucida. In blastomere separation, the pellucida is opened and the blastomeres are removed. Each cell is then covered in an artificial pellucida and develops into a new embryo. This process can be repeated many times to form multiple identical embryos, each of which can be implanted into a surrogate mother.

One of the concerns with cloning from adult donor cells is that the cloned animals appear to develop age-related diseases at a relatively young age and tend to die early. Dolly, for example, developed premature arthritis in late 2001, aged 4, and died by the time she was 7 years old. A parallel

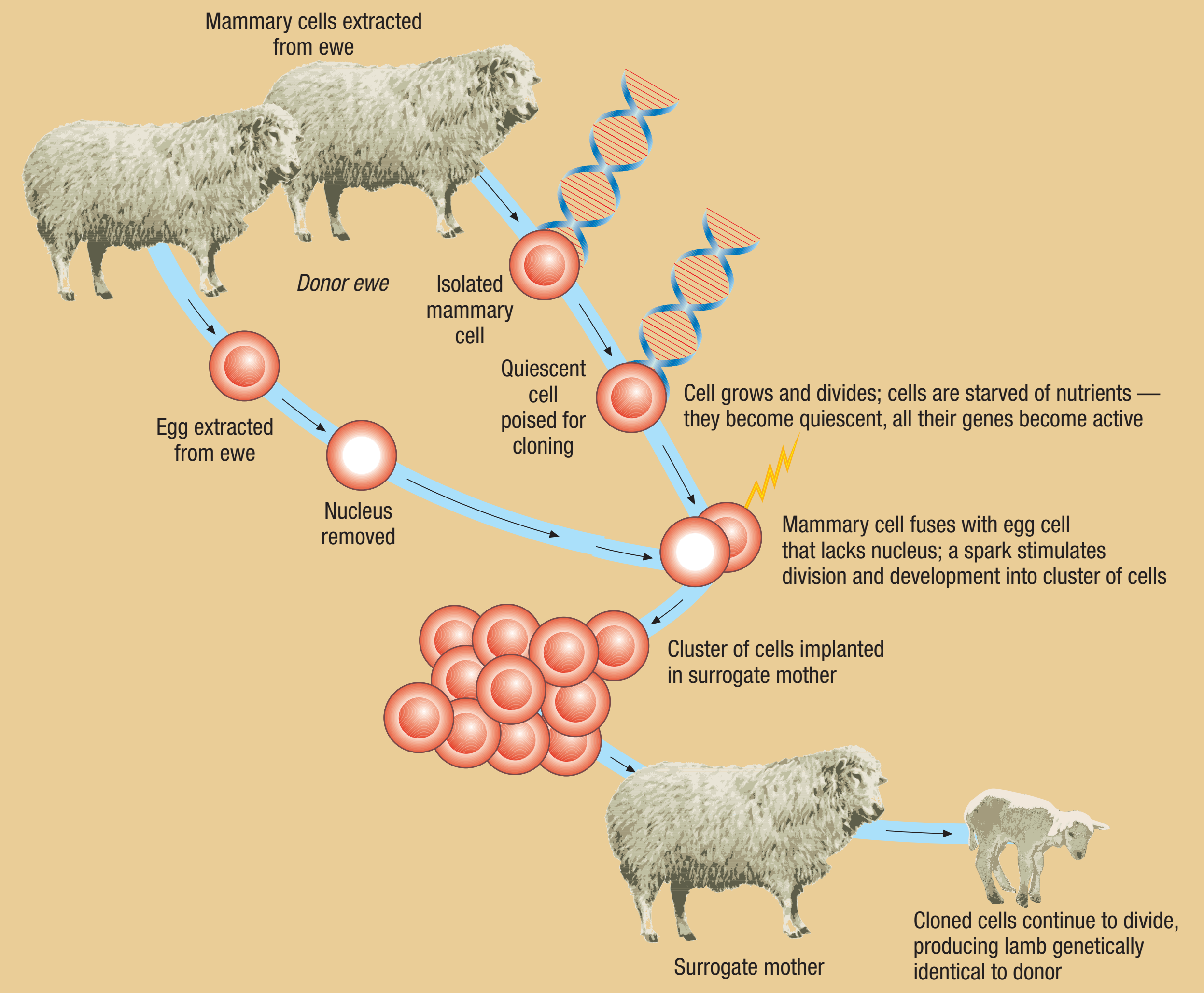


Figure 24.10 Cloning an animal—Dolly the sheep

study on mice by a Japanese group found that cloned mice were more likely to die at a young age, usually of diseases associated with a lowered immune response, than mice born from natural conception or in-vitro fertilisation. Possible reasons for this are:

- up to one-third of the oocyte cytoplasm is lost during the enucleation process
- the time taken to manipulate the donor and recipient cells may have an adverse effect on development
- the biological age of the differentiated donor cells may be transferred with their cytoplasm.

The advantages of producing farm animal clones can still outweigh a shortened life span if the illnesses the clones develop are able to be identified at an early stage and are treatable or if it does not occur until after the clone is too old to be productive. The findings do, however, provide a clear indication of the dangers to human cloning at this point of time.

An additional advantage of cloning is its potential to preserve genetic variability among livestock and endangered species. One of the problems of small populations of endangered species is that over time genetic variability decreases due to the small gene pool. Even slight changes to the environment could result in the loss of the entire population. The ability to clone individuals and introduce them into a number of populations of the species could increase the number of different types of alleles in any gene pool and thus aid survival. The ease with which this could be done would be greatly enhanced if it is found that bovine oocytes can be used as universal mammalian recipient cells.

Although the success rate of cloning has improved dramatically, the cost is still very high—US$20 000 per animal—and would currently be uneconomic for the general farmer to utilise in improving herd quality. The micromanipulator used to extract the oocycte nucleus and inject the donor cell or nucleus is extremely expensive. Independently a different, less expensive technique was developed by a Dane and an Australian. Under a microscope, the oocyte is cut into halves using a very thin blade so that one half contains the nucleus. The halves quickly seal themselves. The enucleated half is fused first with the adult donor cell and then another enucleated oocyte half (to complete the original volume of oocyte cytoplasm) using an electric current. The equipment is less expensive, the technique is relatively simple, the time taken to manipulate the oocyte is reduced and the newly 'fertilised' egg has its normal compliment of cytoplasm—all factors that should improve the chances of the clone's survival. In late 2002 a South African team tried the method under field conditions on cattle. They hope to eventually use the technique to clone endangered species using a closely related species as both an egg source and surrogate mother.

Although the potential for producing high-quality stock using an inferior surrogate mother for a cloned embryo is great, so too is the potential for misuse. At the present time, all governments have pledged not to research human cloning. With the technology available to achieve this, the question of honouring such a pledge must arise. Could it be that science-fiction movies such as *The Boys From Brazil* (depicting the successful cloning of cells from Hitler) no longer belong to the realms of fiction?

SUMMARY

Cloning is a natural process of asexually reproducing an organism that results in a large number of genetically identical offspring. Monoclonal antibody production is achieved by fusing active b-lymphocytes with tumor cells, cloning them and collecting and purifying the antibodies formed. Techniques have been developed to clone sexually reproducing animals. In nuclear transfer cloning, a somatic cell that has been treated so that it loses its specialisation is fused, using an electric current, with an enucleated egg cell. Cell division results in a blastula that can then be implanted into the uterus of a surrogate mother. Cloning using blastomere separation involves separating the new cells (blastomeres) formed from the division of a zygote and allowing each of the blastomeres to develop into a new embryo.

Clones produced from somatic donor cells tend to develop a variety of immune deficiency diseases and die at a younger age than normally conceived animals.

Review questions

24.20 What is a monoclonal antibody? Describe how monoclonal antibodies are produced and their applications.

24.21 Describe the cloning process using nuclear transfer.

24.22 How does the blastomere separation technique of cloning differ from that of nuclear transfer?

24.23 Production of large numbers of livestock with particular phenotypic expression of particular characteristics (such as higher productivity or disease resistance) is a significant reason for nuclear transfer cloning. Can this same result be achieved from cloning by blastomere separation? Explain your answer.

24.2.4 Stem cells

The somatic cell cloning of Dolly the sheep led to the idea that diseased human organs could possibly be repaired or replaced by taking some of the patient's cells, modifying them and then transplanting them back into the patient. It had been considered that once cells became differentiated the gene expression was irreversible. The mammary gland cell that was the donor cell for Dolly, however, was reprogrammed to an undifferentiated, unspecialised cell capable of dividing and forming the vast number of cell types that make up a complex organism.

Attention was therefore directed towards understanding the cell differentiation process using stem cells. A **stem cell** is a precursor cell that can potentially grow into a variety of different kinds of cells. The ability to develop along any particular set of cell-type pathways depends upon where the stem cells are found in the body. The number of different pathways open to a stem cell is referred to as its plasticity. Thus totipotent stem cells are highly plastic and can develop into any other type of cell, and can give rise to an entire new organism. The zygote is a totipotent stem cell. **Pluripotent stem cells** are less plastic but can still give rise to a large number of cell types, although not an entire organism. The inner cells of the embryonic blastula are pluripotent. They will eventually form the embryo proper but cannot form the placenta. A limited number of cell types can be derived from more differentiated **multipotent stem cells**. Bone marrow cells are a good example of multipotent stem cells. While maintaining their own numbers, these cells can produce new red and white blood cells. Mesenchymal stem cells give rise to a number

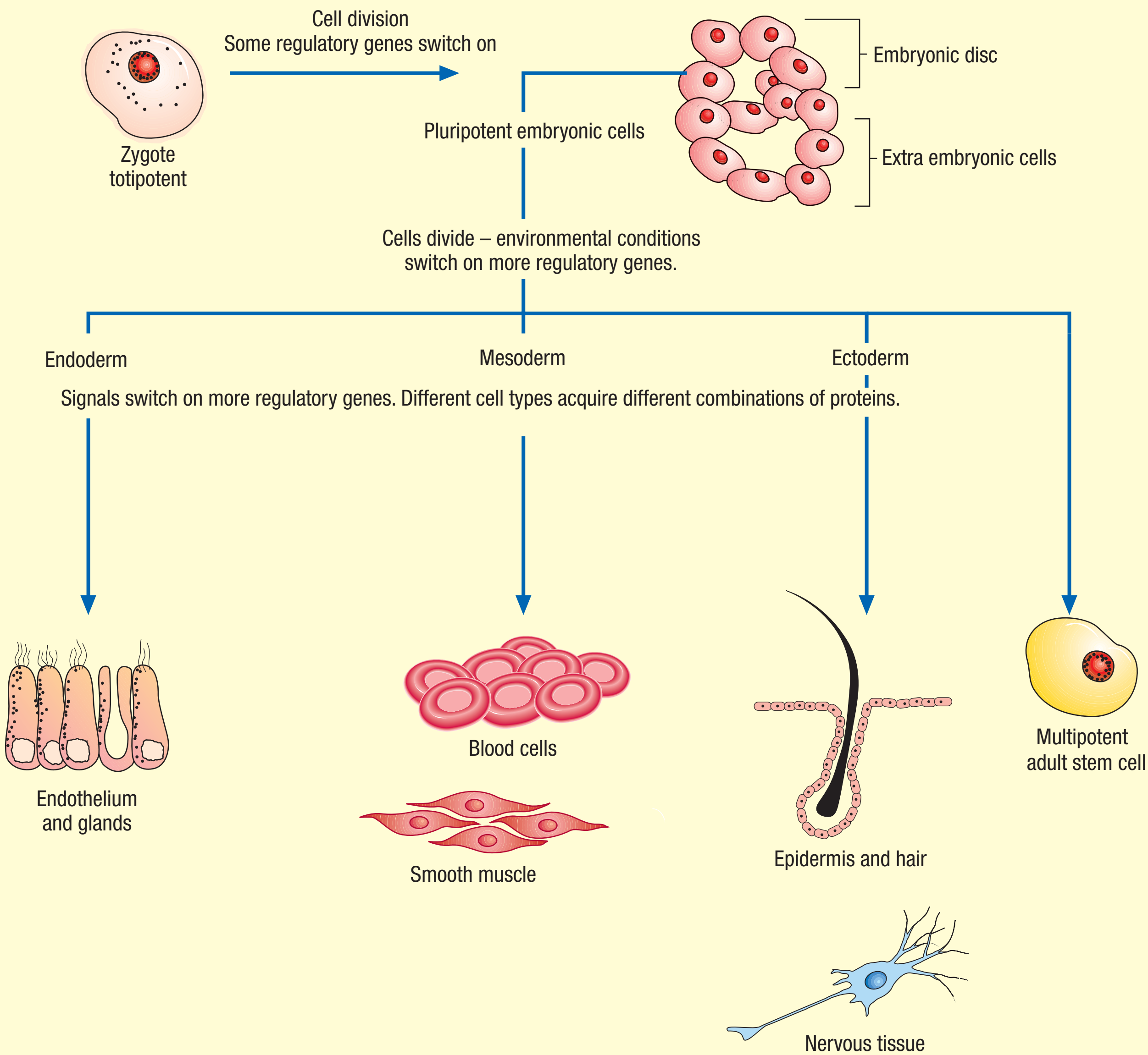


Figure 24.11 Changes in embryonic cells from totipotent to fully differentiated and mulitpotent cells

of different connective tissues such as bone, muscle and cartilage.

Sources for stem cells may be adult or embryonic. The original work on stem cells was performed on the pluripotent embryonic stem cells taken from the inner cells of a blastocyst. These cells were first isolated from human embryos and maintained in cell culture in 1998. It is hoped that by developing cultures of these cells, a greater understanding of the development and differentiation of cells will result. This then could lead to medical applications such as the formation of specific tissues and organs or a generic tissue repair cell (i.e. does not contain antigens) that could be used on a large number of different patients in, for example, bone marrow, cornea, skin and even nerve transplants.

Because most adult stem cells are multipotent, their ability to be used in tissue repair is more limited than those of embryonic stem cells. These can be developed by using a process similar to that used in cloning Dolly the sheep. In **therapeutic cloning** adult cells could be taken from a person's body to create cloned embryos. Embryonic stem cells extracted could then be turned into a wide range of tissues by placing them in different chemical environments, all of which are a perfect match for the patient.

Mouse studies have shown that adult stem cells from bone marrow (haemapoietic stem cells) can be turned into heart muscle cells when injected into a damaged mouse heart. Other transplants of haemapoietic stem cells have been successful in a range of mouse diseased tissues. With greater knowledge of methods to reprogram adult human stem cells back to their undifferentiated pluripotent state, the possibilities for repair of damaged tissues are great.

One application of adult stem cells, developed by a Brisbane husband and wife medical team, looks particularly promising. They have found that small sections of plastic piping inserted in the abdominal or pleural cavity of dogs becomes coated with haematopoietic stem cells that gradually form layers of connective and muscle cells—in effect an inside-out blood vessel. When these pieces of tissue are inverted by pulling them off the plastic tubing and inserted in a section of artery, they develop into new artery. The potential for growing pieces of artery for coronary bypass surgery or for kidney dialysis patients is very high, since the tissue can be generated within the patient and thus will not be rejected when transplanted into diseased tissue. Current bypass surgery uses a piece of vein (taken from the patient's leg). Since this does not have the muscularity of an artery, it has a limited life and the surgery has to be repeated over time.

An American team is working on neural stem cells in the hope of alleviating Parkinson's disease. Certain brain cells produce a chemical called dopamine that transmits nerve signals around the brain. In individuals with Parkinson's disease, these dopamine cells begin to degenerate. If 60 per cent or more of these cells die, the individual starts to show the characteristic tremors and slowed movement of the disease that is ultimately fatal. The researchers hope that by implanting neural stem cells into the affected part of the brain the dopamine-producing brain cells will be restored.

The development of treatments based on embryonic stem cells is limited by ethical issues related to the destruction of a human embryo to obtain the cells. Although the embryos used to date have been excess embryos from IVF programs which would have normally been destroyed, or therapeutically cloned embryos, it is thought that condoning this practice could lead to development of embryos purely for research or for producing cloned humans—a proposition that is distasteful to most people. Other researchers have therefore been searching for means of transforming already differentiated cells into other types of cells and

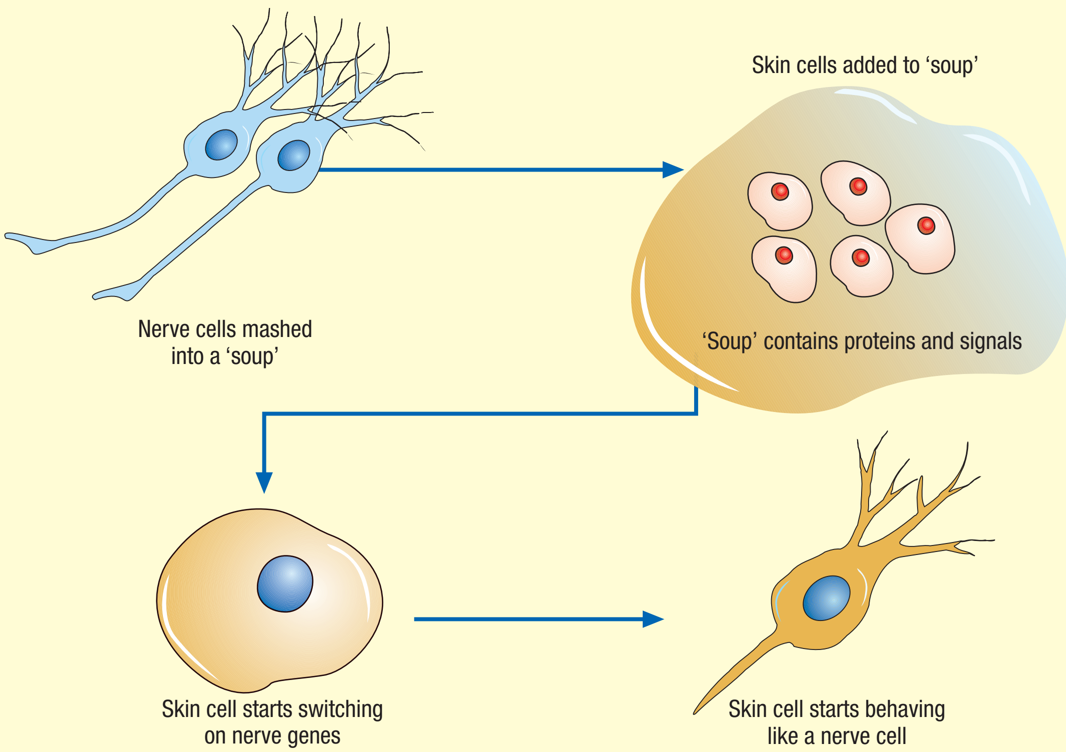


Figure 24.12 The transdifferentiation of a skin fibroblast cell into a nerve cell

bypassing stem cells altogether. This process is called **transdifferentiation**. If this process is successful, healthy cells from one type of tissue will be able to be transplanted into diseased tissue of the same person (and thus avoid an immune system rejection).

So far connective tissue cells (fibroblasts) from skin have been converted into either T-cells or nerve cells in artificial cultures. In the first experiment, T-cells from the immune system were mashed up to release their contents. The resulting soup was added to the fibroblasts for an hour, after which the fibroblasts were placed back into cell culture solution. Within a short period of time, the fibroblasts had at least partially deactivated one set of genes and activated T-cell formation genes. When the experiment was repeated using a soup of nerve cells, the fibroblasts not only changed their gene activity but also started to change shape, growing cytoplasmic extensions that resemble the axons and dendrites of neurons. In the culture medium these changes in the cells were sustained for months. In both cases, however, the switch was not complete in that all of the fibroblast genes were not switched off. The cells took on characteristics of new cell type while maintaining some of their original characteristics. Further research is required to determine if the environment within the body after transplant into the appropriate tissues would complete the switch of activated genes.

SUMMARY

Stem cells are cells that have the potential to differentiate in a number of different types of cells. By studying these cells scientists hope to more fully understand the processes by which cells differentiate and ultimately to produce different lines of cells that can be used in the treatment of diseased tissues. Sources of stem cells are from human embryos and from only partially differentiated somatic cells in the adult body.

Transdifferentiation is another technique being researched, where already differentiated cells are converted to another type of cell as a result of changing the chemical environment of the cells.

Review questions

24.24 Define a stem cell.

24.25 Compare and contrast totipotent, pluripotent and multipotent stem cells.

24.26 Explain why embryonic stem cells are potentially more useful than adult stem cells.

24.27 What is meant by therapeutic cloning?

24.28 Explain the process of transdifferentiation.

24.3 Gene technology

Biotechnology has undergone a massive explosion over the past 50 years. Mendel's pioneering work in explaining the inheritance of characteristics was further expanded in the early twentieth century. Although there was a basic understanding of patterns of inheritance, it was not until Watson and Crick were able to decipher the DNA X-ray diffraction patterns developed by Rosalind Franklin in 1953 that an understanding of the chemical processes of cell replication, development and the inheritance of characteristics began. Table 24.2 gives a brief history of the discoveries that frame our understanding of these processes.

Table 24.2 Landmarks in understanding and application of genetic processes

Year	Discovery
1866	Gregor Mendel proposed the basic laws of heredity. His findings were ridiculed and ignored by most scientists for 30 years.
1882	Embryologist Walter Flemming viewed dividing cells in salamander larvae and identified threads in the nuclei which were later identified as chromosomes.
1882	Francis Galton (Charles Darwin's cousin) advocated improving the human race by selective breeding and coined the word *eugenics*.
1910	Thomas Hunt Morgan, working with fruit flies, showed that some characteristics are sex-linked and that the factors (genes) for determining characteristics are located on chromosomes.

Table 24.2 (*Continued*)

Year	Discovery
1926	Hermann Müller discovered that X-rays can cause mutations in fruit flies.
1932	Aldous Huxley published his novel *Brave New World*, predicting the possibility of genetic engineering.
1944	Avery, MacLeod and McCarty, working with *Pneumococcus* bacteria, showed that DNA is the heredity material of most organisms.
1953	Watson and Crick announced the discovery of the double-helix structure of DNA.
1957	Crick and Gamov explained the sequence of protein synthesis—from DNA to mRNA to protein. The replication mechanism of DNA was demonstrated by Meselson and Stahl.
1958	Coenberg discovered and isolated DNA polymerase—the first enzyme used to make DNA in a test tube.
1961	Marshall Nirenberg built a strand of mRNA comprised of the base uracil, which led to the discovery that *UUU* is the codon for phenylalanine and the first step in cracking the genetic code. He succeeded in determining the complete code for the twenty amino acids in 5 years.
1964	Charles Yanofsky demonstrated that the sequences of nucleotides in DNA exactly correspond to the sequence of amino acids in proteins.
1967	Mary Weiss and Howard Green developed a technique for human gene mapping by growing human and mouse cells together in one culture—somatic cell hybridisation.
1969	A Harvard Medical School team isolated the first gene from a section of bacterial DNA. This gene plays a role in sugar metabolism.
1970	Researchers from the University of Wisconsin synthesised a gene from scratch. 'Reverse transcriptase', a restriction enzyme that cuts DNA molecules at specific sites, was isolated independently by Temin and Baltimore and shown as the means by which viral RNA integrates its message into the bacterial host's DNA.
1972	Berg produced the first recombinant DNA using a restriction enzyme to cut DNA and ligase to paste two DNA strands together to form a hybrid circular molecule.
1973	Cohen and Boyer inserted a gene from an African clawed toad into bacterial DNA. The gene worked in the bacterium, marking the beginning of genetic engineering.
1975	Scientists around the world sought guidelines for recombinant DNA research. Kohler and Milstein fused cells together to produce monoclinal antibodies.
1978	The gene for human insulin was cloned.
1980	The human gene for the protein interferon was successfully introduced into a bacterium. Martin Cline created the first transgenic animal—a mouse in which functional genes were transferred from another animal.
1982	The US Food and Drug Administration approved the production and sale of human insulin from genetically engineered bacteria.
1983	A genetic marker for Huntington's disease was located on chromosome 4, leading to screening tests. Mullins determined the polymerase chain reaction (PCR), a technique that enabled rapid reproduction of small segments of DNA.
1984	Jefferies developed the process of 'genetic fingerprinting' based on unique sequences of DNA to identify individuals.
1985	Genetic fingerprinting was used for the first time in a criminal investigation.

Table 24.2 (*Continued*)

Year	Discovery
1986	The first genetically engineered vaccine for humans (for hepatitis B) was approved.
1990	The Human Genome Project to map and sequence all human DNA was launched. The first gene therapy was performed on a four-year-old girl with ADA deficiency, an immune system disorder. Michael Critchton's novel *Jurassic Park*, exploring inherent dangers in bioengineering, was published.
1991	Mary-Claire King found evidence that a gene on chromosome 21 causes breast cancer and increases the risk of ovarian cancer.
1992	The US Army began collecting blood and tissue samples from all new recruits as a 'genetic dog tag' to better identify soldiers killed in combat. British scientists published a technique for in-vitro testing of embryos for genetic anomalies such as cystic fibrosis and haemophilia.
1993	A homosexual-related gene was discovered on the X chromosome. American researchers cloned human embryos and sustained them in culture for several days, an experiment that started social debate on the directions of bioengineering. French scientist Cohen produced a rough map of all twenty-three pairs of human chromosomes.
1994	Venter, based on his work of tracing human genes through mRNA sequences, developed a rapid means of gene sequencing.
1995	Three genetically altered pig hearts were transplanted into baboons and survived for some hours. Venter completely sequenced the genome of the bacterium *Haemophilus influenzae* that causes ear infections and meningitis. This genome comprised 1.8 million nucleotides.
1996	It was discovered that gene mutation due to oxidation (i.e. loss of an electron) could be transferred to non-coding regions (introns) via electrical conduction along the DNA molecule.
1997	Scottish researchers cloned a sheep (Dolly) from the cells of an adult ewe.
1998	The first animal genome was decoded. This was of a tiny roundworm (*Caenorhabditis elegans*) comprising 97 million nucleotides. Scientists at the University of Hawaii produced three generations of mouse clones. Matches between DNA from blood samples from President Clinton and semen found on Monica Lewinsky determined that there was a sexual relationship between them. DNA testing proved that US President Thomas Jefferson had at least one child with one of his slaves, Sally Hemmings. Embryonic stem cells were successfully grown. Japanese scientists cloned eight identical calves using cells taken from a single adult cow.
2000	Evidence was produced to support the idea that chemical groups attached to the histone proteins of the chromosome control the activity of individual genes and coordinate groups of genes. These groups on the histones can be changed by internal and external environmental factors. A working draft of 90 per cent of the Human Genome was published identifying 22 000 genes. Screening was made available for 300 genetic diseases.
2003	Completion of the Human Genome Project, with 99 per cent of gene-containing regions sequenced to 99.99 per cent accuracy, providing a valuable reference for future medical and human biology research comprising 3 billion nucleotide sequences. Complete mouse, rat and Japanese puffer fish genomes sequenced. Italian scientists cloned a horse in which the surrogate mother was the nuclear donor.

24.3.1 Genetic recombination

Genetic recombination (or genetic engineering) is a process in which genes (segments of DNA) are transferred between chromosomes, including those of different species. The new individual is thus genetically modified in a specific manner.

Although this process was known to occur between some viruses and their host bacteria, the exact method of how this occurred needed two significant discoveries—the exact nature of DNA and how it acts, and the presence of enzymes associated with DNA. Three types of DNA enzymes were isolated:

- **nucleic acid polymerase** is involved in the synthesis of nucleic acid molecules
- **DNA ligase** binds DNA molecules together
- **restriction nucleases** are responsible for breaking DNA molecules into fragments at particular base sequences (recognition sites).

Each of these types of enzyme plays an important role in cell division and crossing-over (see Section 20.4.2). Restriction nucleases are also important in protection of an organism against viral pathogens, cutting and inactivating the viral nucleic acid. The organism's own chromosomes can be protected by the addition of a methyl group to the recognition site, a process that occurs within the nucleus when a gene is inactive.

Restriction nucleases

The structure of DNA is the same regardless of the species from which it is obtained. The only differences between species are the amount of DNA present and the sequencing of nucleotides within each DNA strand. This structure was described in Chapters 12 and 21. In summary, a strand of DNA consists of two chains of complimentary nucleotides linked together by hydrogen bonds between the bases. Each nucleotide consists of a phosphate group, a sugar (deoxyribose) and a base (either adenine, thymine, guanine or cytosine). The five-carbon sugar forms the link between both the phosphate groups and the base of adjoining nucleotides. Each carbon in the sugar is allocated a particular number (1–5) to identify its location and thus type of bond formed in the nucleotide and between adjacent nucleotides. This is illustrated in Figure 24.13. Carbon 5' of the sugar always bonds with the phosphate of its nucleotide and carbon 3' bonds with the phosphate of the adjoining nucleotide, while carbon 1' bonds with the base.

Since the structure of DNA is the same in all species, the enzymes associated with the DNA of one species will work effectively with the DNA of any other species. Bacterial DNA enzymes, therefore, can be used in the manipulation of plant and animal species.

Since the first restriction nuclease was isolated from the *Haemophilus inflenzae* bacterium in 1968, more than 900 different types have been discovered from over 230 strains of bacteria. Each enzyme has been found to cut DNA molecules at a particular point within a specific sequence of six base pairs, i.e. each enzyme is site-specific. Each restriction nuclease is given a name that generally reflects its origin:

- The first letter (upper case) of the name comes from the genus. The next two letters (in lower case) come from the species of the bacterial cell from which it was isolated. If there is a fourth letter, it indicates the strain of that species.
- A Roman numeral following the name indicates the order in which the enzyme was isolated from a single strain of the bacterium.

Table 24.3 Some restriction nucleases and their sources

Enzyme	Organism from which derived	Target sequence (cut at *) 5' → 3'
Ava I	*Anabaena variablis*	C* C/T C G A/G G
Bam HI	*Bacillus amyloliquefaciens*	G* G A T C C
Bgl II	*Bacillus globigii*	A* G A T C T
Eco RI	*Escherichia coli* RY 13	G* A A T T C
Eco RII	*Escherichia coli* R245	* C C A/T G G
Hae III	*Haemophilus aegypticus*	G G* C C
Hha I	*Haemophilus haemolyticus*	G C G * C
Hind III	*Haemophilus inflenzae* Rd	A* A G C T T
Hpa I	*Haemophilus parainflenzae*	G T T* A A C
Kpn I	*Klebsiella pneumoniae*	G G T A C* C
Mbo I	*Moraxella bovis*	* G A T C
Pst I	*Providencia stuartii*	C T G C A* G
Sma I	*Serratia marcescens*	C C C* G G G
Sst I	*Streptomyces stanford*	G A G C T* C
Sal I	*Streptomyces albus* G	G* T C G A C
Taq I	*Thermophilus aquaticus*	T* C G A
Xma I	*Xanthamonas malvacearum*	C* C C G G G

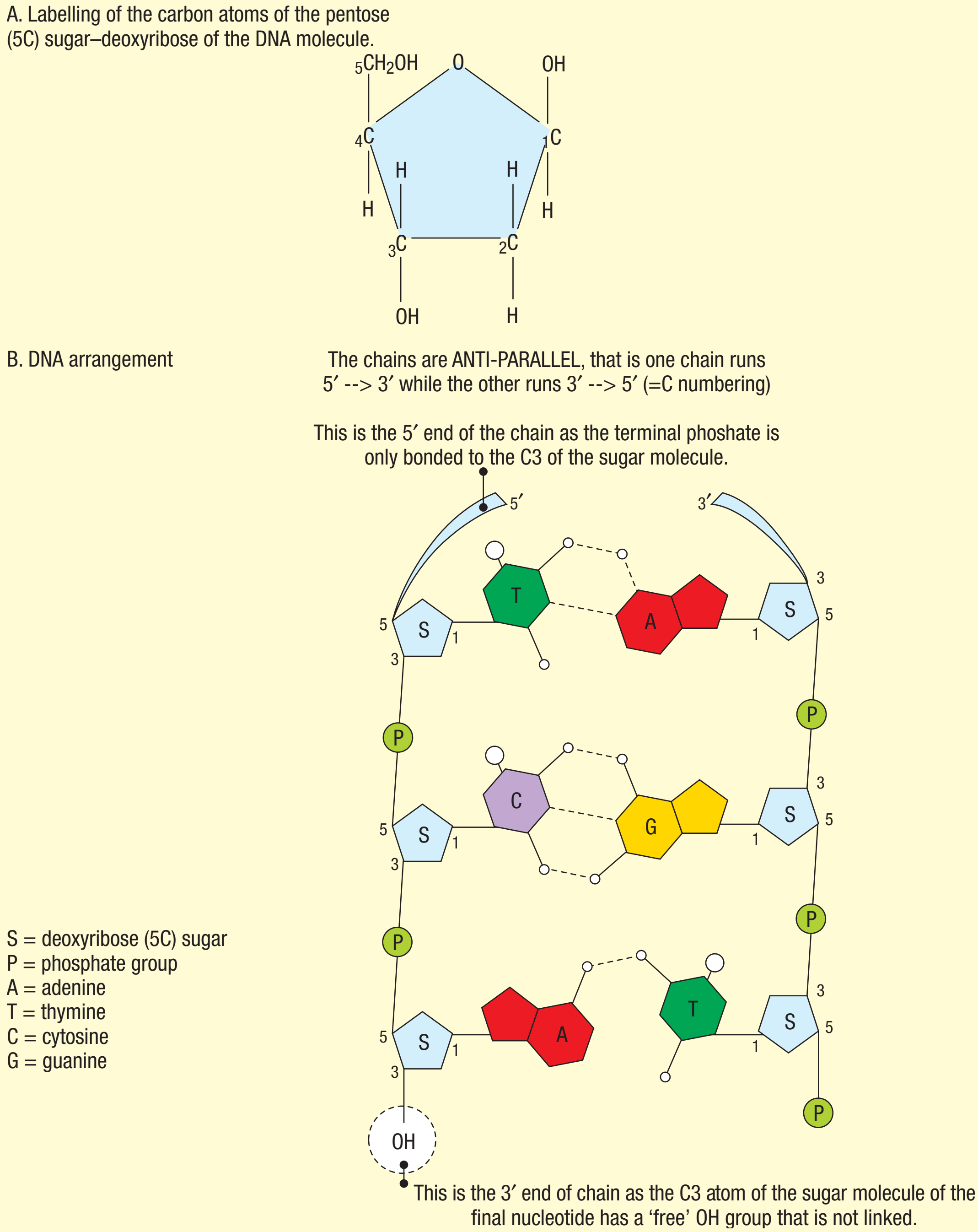


Figure 24.13 Relationship between the sugar carbons within and between nucleotides

Thus EcoRI comes from *Escherichia coli* RY13 strain, with a target sequence of 5'G*AATTC3'. EcoRII is derived from *E. coli* R245, with a target sequence 5'*CCATGG3'. The actual cleavage of the DNA chain occurs at the point indicated at the *. Restriction nucleases that break the nucleic acid chains somewhere in the interior of the molecule are called endonucleases, while those that break the chain at the ends of the molecule are called exonucleases.

A restriction endonuclease scans the length of a DNA molecule and, when it encounters its particular recognition site, bonds with the DNA causing it to cut between each of the two sugar-phosphate groups of the double helix. The DNA molecule breaks into fragments. Different endonucleases produce different sets of fragments, but one endonuclease will always cut a particular base sequence the same way, irrespective of the DNA molecule it is acting on. Because of their action, restriction nucleases are given the general name of **DNA scissors**.

Some nucleases, like Hind II, cut the DNA in the exact centre of the sequence. The recognition site for this enzyme is

Chain 1 5'GTT | AAC3'
Chain 2 3'CAA | TTG5'

Cleavage of both chains occurs between the third and fourth base pairs of the sequence and so the ends of both chains do not have any unexposed bases.

Other nucleases cut asymmetrically at positions not directly opposite each other. Thus the recognition site for EcoR I is

Chain 1 5'G | AATTC3'
Chain 2 3'CTTAA | G5'

Cleavage of the molecule always occurs between the G and the closest A base. This produces a cut in each chain, with the resulting fragments being held together by relatively weak hydrogen bonds between the complimentary bases. Separation results in fragments, each of which has a protruding end composed of unpaired bases. These fragment ends with their unpaired bases are called '**sticky ends**'. If they encounter other fragments with complimentary unpaired ends, they will stick together and the enzyme DNA ligase will then bond the appropriate sugar-phosphates of the fragments.

Producing recombinant DNA in bacteria

The earliest recombinant DNA experiments were performed on bacteria. In addition to the functional circular strand of DNA, bacteria have one or more additional small sections of DNA called plasmids. The genes on the plasmids give different strains of the same species of bacteria slightly different characteristics, such as the resistance to a particular antibiotic. Removal, manipulation and then reinsertion of a plasmid from the bacterial cell are relatively easily achieved with micromanipulation.

DNA from the donor cell can be readily isolated. In one method cells—for example, human cheek cells—are suspended in a solution of sodium lauryl sulfate (the active component of detergents). The lipids of the cell and nuclear membranes become emulsified, releasing the DNA into the solution. The DNA precipitates out when ethyl alcohol is then added to the mixture.

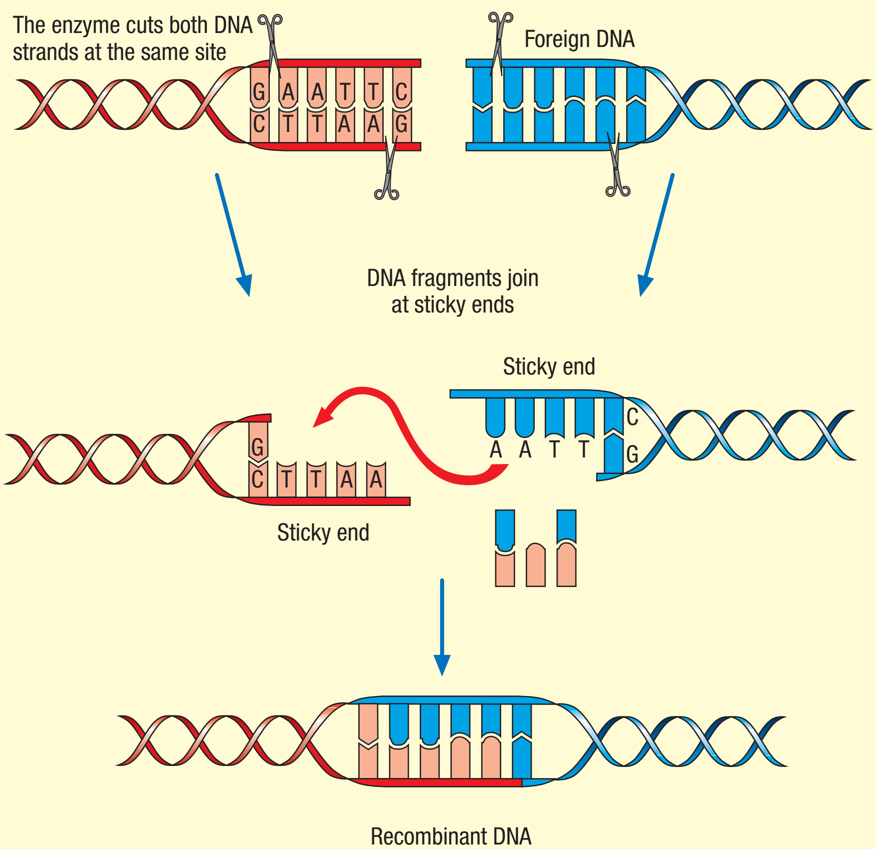


Figure 24.14 Restriction enzyme action of EcoR I

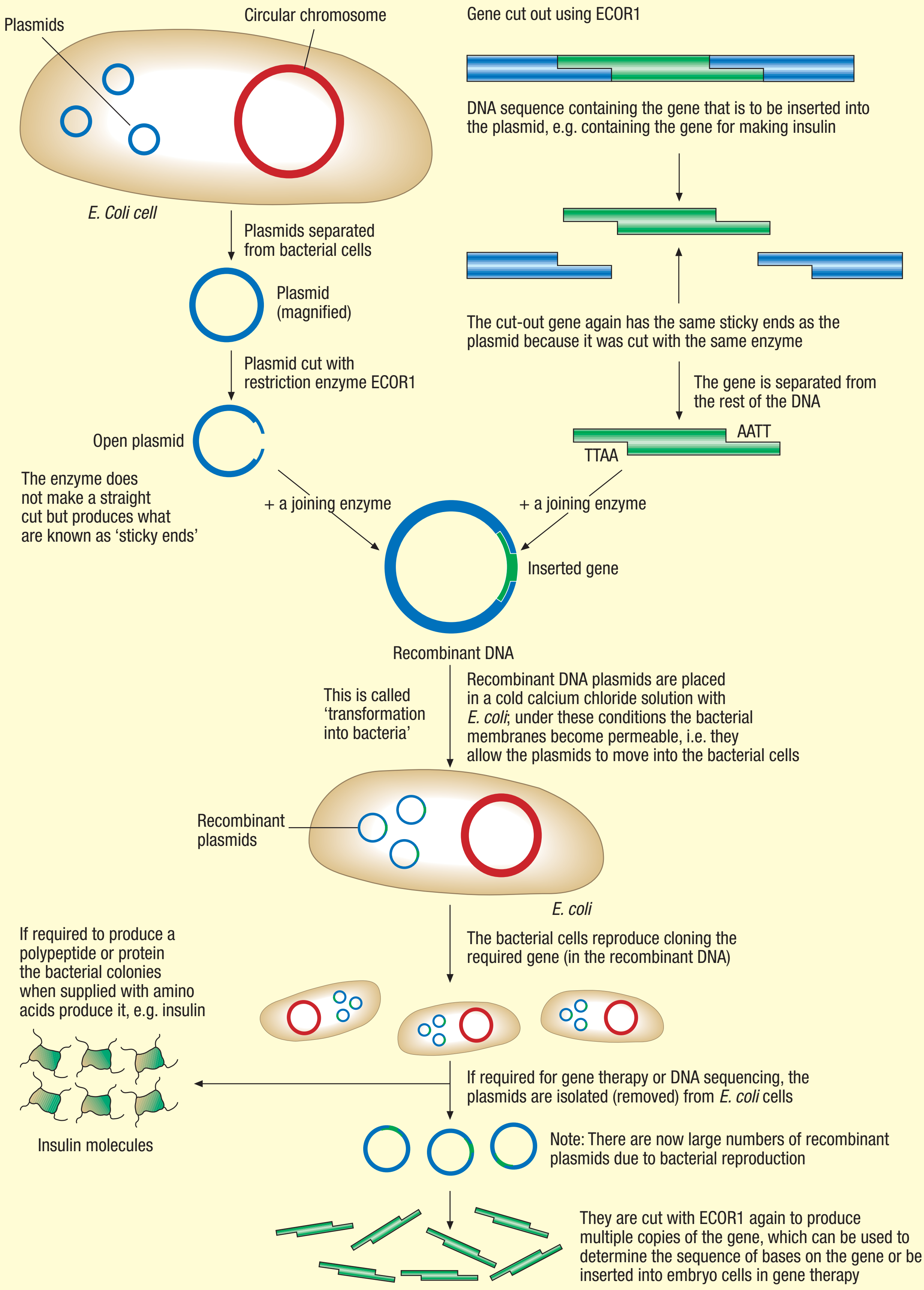


Figure 24.15 Recombinant DNA technology

Both the donor DNA and the plasmid DNA are then placed in the restriction nuclease so that it will cut both pieces of the molecule at the site of the specified gene. The donor gene is then added to the cut plasmid. Splicing occurs between the sticky ends of each DNA fragment. Treatment with ligase ensures complete bonding of the donor gene to the plasmid.

The genetically recombined plasmid is placed with the bacterial cell into a solution of calcium chloride. This makes the bacterial membrane more porous and the plasmid moves into the cell—the bacterium is transformed. Each time the bacterium divides, the plasmid is replicated and carried in the new bacterial cells. Under laboratory conditions high rates of reproduction can be achieved, producing large numbers of bacteria with the cloned gene.

The genes that have been recombined into the plasmid DNA can be used for a variety of purposes. The gene product may be required, such as human insulin. Because the human insulin gene would not be normally present in the bacterium, it is not automatically expressed when inserted into this organism. Regulator genes also spliced into the plasmid promote the expression of the desired gene when the bacteria are supplied with the appropriate amino acid building blocks for the product. In addition to human insulin, many substances are now produced in commercial quantities using recombinant DNA techniques. Examples include:

- vaccine antigens for diseases such as malaria and hepatitis
- interferon—used in cancer research and treatment of some viral conditions; previously extracted from infected human blood cells
- hirudin—anticoagulant used in plastic surgery; previously obtained by 'milking' the salivary glands of blood-sucking leeches.

Bacteria can also be used as the vectors for producing large numbers of a particular gene for other purposes such as gene therapy. Once adequate numbers of the bacteria have been produced, the plasmids are removed and the gene removed using the correct endonuclease.

The above description of recombinant DNA processes is idealistic and does not necessarily occur like this in reality. Some of the plasmids do not splice with the foreign gene. Some uncombined plasmids reinsert back into the bacterial cell and some recombined plasmids do not reinsert. To ensure that the bacteria to be cultured all contain the introduced gene, scientists use other properties of plasmid genes, such as antibiotic resistance, to identify the required cells.

The most commonly used bacterium for genetic engineering is *Escherichia coli*. The plasmids of this organism have two genes that are used for monitoring—one gene confers resistance to the antibiotic ampicillin (called ampR), while the other produces the lactose-digesting enzyme β-galactosidase (lacZ). The endonuclease EcoR1 cuts the plasmid in the centre of the lacZ gene, so that this gene cannot be expressed.

To separate the transformed bacteria from those without the recombined gene, the colonies are grown on a culture medium containing both ampicillin and a sugar X-gal which is broken down by lacZ. Only transformed bacteria will be able to grow because they contain the ampR gene. Bacteria with unrecombined plasmids will express the lacZ gene. The product of X-gal digestion is a blue colour. The colonies containing the recombined gene (and thus non-functional lacZ) will not be coloured blue. They can then be isolated and pure cultures of the recombinant bacteria grown.

To ensure that the correct gene has been inserted DNA probes are used. One chain of the DNA for the gene is made using a radioactive element (e.g. nitrogen). Some of the plasmids are removed and heat treated so that the DNA molecule unzips. If the probe attaches to a section of the plasmid, it can be assumed that recombination has occurred. This can be detected by exposing the DNA to photographic film. If the probe is complimentary to the gene and so attaches to the plasmid, the film will darken. This process is called **autoradiography**.

Genetic engineering has opened the door to techniques for producing microbes which can digest poisonous chemicals. One strain feeds on oil sludge and releases valuable reusable oil. One significant application of the process has been the better understanding of genes. Thus it has aided in determining the location of specific genes on the chromosome and their base sequences. Similarities and differences of a particular gene between different species can be ascertained as well as the different alleles within a species. This has helped in the understanding and possible treatment of hereditary diseases.

Transgenic organisms

The bacteria carrying the inserted genes are called **transgenic**, i.e. they contain DNA from another species. Plants and animals can also be transgenic. DNA of eukaryotes can be recombined using either plasmids or viruses as vectors. The regulation of genes in eukaryotes is more complex than in prokaryotes, and this places limitations on using bacteria for certain procedures. Caterpillars, for

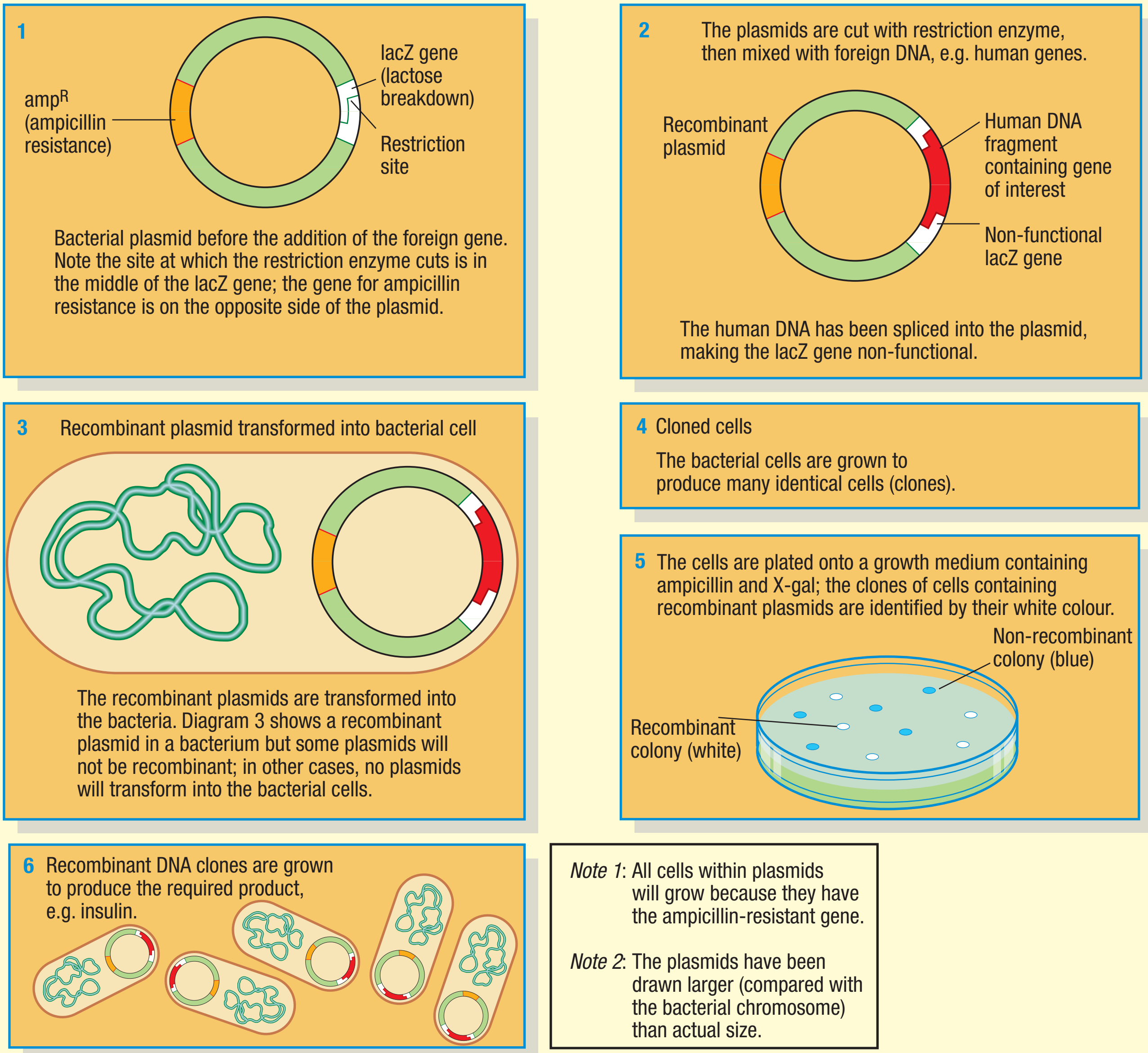


Figure 24.16 Identification of recombinant plasmids in bacteria

example, are now being used to produce some human products. Since caterpillars are prone to infection by certain viruses, the DNA segment is inserted into one of many such viruses which are then used to infect the caterpillar. In this way the required DNA is rapidly cloned within the caterpillar cells. Genetically engineered caterpillars are being used to produce the complex proteins needed for diagnostic tests for AIDS and hepatitis B.

Experimental work has been undertaken to eliminate the vector in genetic engineering. Instead, new genes are being microinjected directly into the fertlised egg cells of animals. So far this has been achieved in mice and farm animals, although the survival rate of the changed eggs is low. If the new genes are injected at an early stage, all the animal's cells will contain the added genes. If the foreign DNA is not taken up until after fertilisation and early cleavage, a mosaic of altered and normal cells results.

Transgenic sheep have been developed, carrying the gene for a human blood clotting factor which is missing in haemophiliacs. This factor is obtained from the ewe's milk when she is lactating. Australian scientists are working on introducing a gene from *E. coli* into sheep to synthesise cysteine, an amino acid which cannot be naturally produced by sheep and which promotes wool growth. A related Australian enterprise has been to genetically engineer alfalfa plants with increased cysteine levels so that sheep fed on this crop will have a higher intake of cysteine.

Although the control of rabbits by the myxamatosis virus was originally highly successful, many rabbits have developed a resistance to the virus and many of the viruses mutated to a less lethal strain. Thus after a period of time this biological control of the rabbit became ineffective and the populations again soared, creating ecological havoc and driving some native species to extinction. Australian scientists have again turned to this virus to control the rabbit population. They have isolated a gene that produces an antibody to proteins normally found in the thick layer surrounding an egg cell (the zona pellucida). This antibody damages the zona pellucida and so blocks fertilisation—it is an immunocontraceptive. A transgenic, non-lethal myxoma virus carrying the rabbit *ZPC* gene for this antibody was developed that is highly infectious but only causes a minor fever in the rabbit. In laboratory trials it has a success rate of over 70 per cent. If the same infertility rate occurred in the wild, the population densities would decrease dramatically and reduce the status of the rabbit in Australia to that of a relatively minor pest. This could save Australians millions of dollars each year in lost agricultural production and incalculable environmental damage.

Case study 24.1: Human insulin production by fish

A widely farmed fish of the tropics, *Tilapia*, has two different pancreases, one for digestive enzymes and one for insulin production. Scientists in Brussels, Belgium have successfully transplanted the human insulin gene into fertilised tilapia eggs. They are hoping that these transgenic fish will produce sperm and eggs with the human gene intact and so breed a stable line of fish producing human insulin.

Surgeons have already succeeded in transplanting islet cells of the pancreas, which produces insulin, between human donors and recipients. Encapsulated in a gel to prevent antibody formation, the islets are transplanted into the recipient's liver. The transplanted islets then produce insulin. There are two problems with this technique. It takes three human pancreases to supply enough islets for one transplant, and there are not enough donors to treat even the most serious diabetic cases that are not being controlled adequately by insulin injection. An even bigger problem, however, is that the gel prevents growth of blood vessels into the capsules and the cells eventually suffocate.

Tilapia live in warm, oxygen-deficient ponds. Their oxygen requirement is one-fifth that of humans and so their encapsulated cells should be able to survive in a human. The reseachers are hoping that they will be able to produce enough transgenic islet cells from pure-breeding fish to transplant into the livers of diabetics. The need for insulin injections would then be overcome.

Because of their tough cellulose walls, it is more difficult to insert foreign genes into plant cells than animal cells. Plant callus tissue can be treated to remove the wall and thus make plasmid insertion easier. Other methods involve:

- shooting tiny pellets of gold or tungsten coated with recombined DNA into cells using compressed helium gas
- making small perforations in the cell wall through which recombined DNA can enter by shaking cells in a solution of silicon carbide
- infection using a modified form of the bacterium *Agrobacterium tumefaciens*. This bacterium normally infects some dicotyledonous plants forming crown galls (tumours). By creating a form that does not produce the disease, vector Ti-plasmids can be incorporated into the plant.

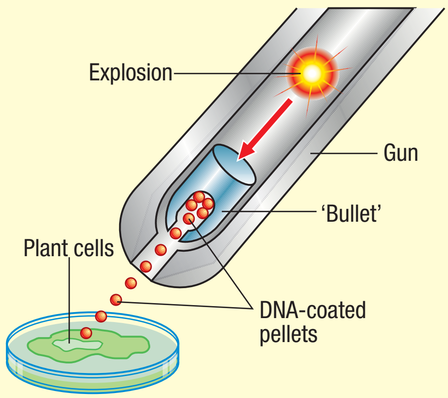


Figure 24.17 The DNA gun (not drawn to scale). DNA-coated pellets are shot under pressure through the wall and membranes and thus into the nucleus of the plant cells

Many transgenic plants are being trialled in Australia. The gene from the soil bacterium *Bacillus thurungiensis* that produces a toxin to kill budworm has been inserted into Bt cotton. Budworm normally attacks the plant buds, preventing the formation of the cotton boll. The transgenic cotton is thus able to control budworm infestation without growers having to resort to chemical pesticides. Canola plants are grown primarily for the oil that is extracted from their seeds. These plants are susceptible to fungal infestation. When transformed by certain genes from grapes and legumes, these

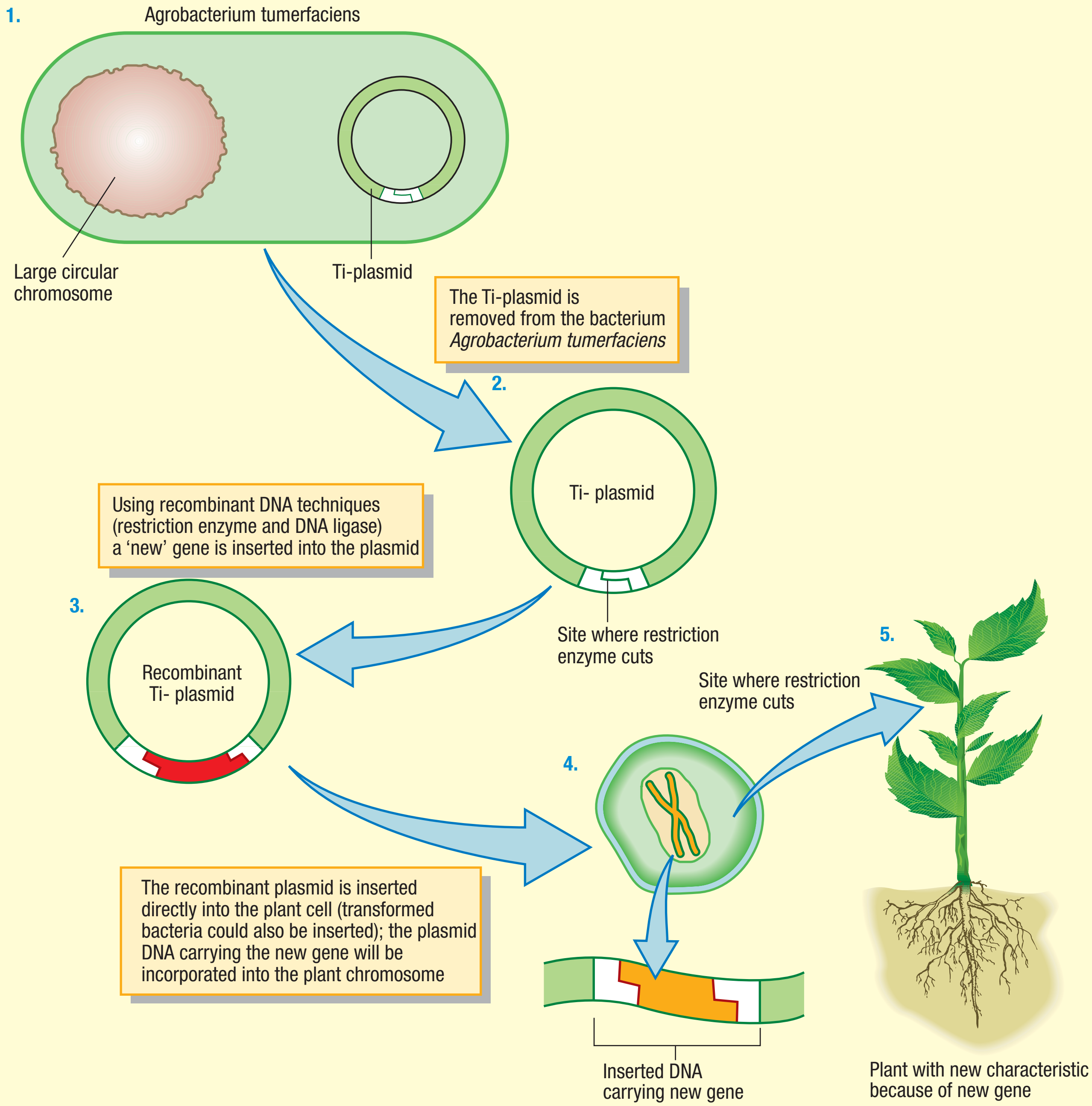


Figure 24.18 Development of a transgenic plant using the Ti-plasmid as a gene vector

plants are resistant to the fungal attack. Other plants are genetically modified to produce higher proteins or different types of proteins or useful chemical products.

Food plants so transformed in other parts of the world include cabbage, potatoes, tomatoes, carrots, alfalfa, citrus fruits and sunflower seed. Modifications to the coffee plant produce caffeine-free beans. While they are not directly available in Australia, some of their products are. Thus imported canned vegetables or soybean products such as tofu may well have originated from genetically modified plants.

The use of genetically modified (GM) food has produced mixed reactions from people around the world. While some of these concerns are unfounded, others are based on scientific reasoning. Questions that have been asked relate to the marker antibiotic-resistant gene that is often inserted along with the transgenic gene to monitor uptake by the host chromosome. Can this antibiotic-resistant gene be passed on to consumers? Much of the emotional response against GM food in Europe is probably related to the outbreak of 'mad cow disease' in the 1990s. Although not a result of genetic modification, this disease did highlight the fact that biological agents (in this case a specific protein that affects brain cells as described in Section 5.5) can be passed from animal-based foods to cattle to humans. Regulations in both Europe and Australia are in place requiring GM food to be so labelled—not as a warning but as advice. So far tests suggest that food modified to produce higher quality or different types of proteins (often in the form of enzymes) is safe to eat.

There are fears that the new proteins could cause a toxic or allergic response. Some people already display allergic responses to particular chemicals in certain food plants. They have been able to isolate the foods that contain these chemicals and thus avoid eating them. If other plants have been genetically engineered to produce these compounds which are not a normal constituent, these foods could inadvertently trigger a severe allergic response in sensitive people. Simply labelling the food as GM may not be an adequate safeguard. The digestive system breaks down complex molecules into their smaller components so that they can be absorbed through cell membranes and thus be assimilated into the body. Testing has shown that this is the case for the modified proteins and so would not have an adverse effect on non-sensitive consumers. What is not so clear, however, is whether non-biological chemicals in herbicides (such as the glyphosphate of Roundup), which can be used in GM herbicide-resistant crops such as soybeans, become incorporated into the crop plant. The long-term effect of these plants on the health of consumers has not been ascertained.

Other ethical concerns are related to the source of the transgene. Is it right for vegans to eat plants that have been modified with animal genes? How would religious strictures apply to Muslims or Jews who eat sheep with a pig transgene or a Hindu eating chicken with an inserted cow gene?

Contamination of natural crops by GM counterparts is of greater concern. Small farmers in Mexico grow a large number of different strains (selective bred over 6500 years). They also keep some of each season's crop to grow in the next planting. In order to prevent contamination, Mexico imposed a ban on growing GM maize in 1998. In spite of this, transgenic Bt maize was found growing among some crops. It was imported from the United States as food and was either deliberately or accidentally planted. Bt maize contains a gene for a bacterial toxin that kills some pests. Because of this attribute it could be competitively superior among the contaminated crops and this could lead to loss of genetic diversity.

While this contamination does not affect the quality of the food source, contamination of food crops by 'pharmed' crops could be dangerous. These are GM crops specifically modified to produce particular substances such as vaccines, human therapeutic proteins and industrial chemicals. In late 2002, for example, it was disclosed that fields of soybeans were contaminated by GM corn in two different locations, probably by seed left over from a previous growing season. Since the pharmaceutical companies will not disclose the exact nature of the transgenic genes to avoid competition with other companies, this type of contamination is very serious. In these cases, the contaminated soybean crop was detected in time and destroyed at an estimated financial loss of nearly US$3 million. Growing 'pharmed' crops anywhere near food crops is also a potential hazard due to the possibility of cross-pollination if both crops were of the same food.

There are ways in which contamination could be prevented. The best method would be to only allow genetic modification for pharmaceutical purposes in non-food plants. Other proposals include that 'pharmed' crops be separated in time (to prevent cross-pollination since fertile periods will not coincide) and space (an adequate distance apart) from food crops. This distance, however, is highly speculative. In Australia, for example, it was found that pollen from GM oilseed rape had contaminated fields up to 3 km away. More stringent safeguards also need to be placed on the separation of harvested products. There is one instance in America where a strain of 'pharmed' corn ended up on grocery shelves as taco shells and other products. The transgenic gene that it carried was for an insecticidal protein that had the potential to trigger allergies in some people.

Some plants are being modified so that they can grow effectively in very marginal conditions. If there is gene leakage from these to wild plants, they could become extremely noxious weeds that could well lead to the extinction of other indigenous plants. The potential for negative environmental impact of gene leakage from such transgenic plants is very great. The same can be said for transgenic animals. There is a real fear that fish such as salmon and trout genetically modified for faster growth rates that are currently farmed in contained areas could escape and contaminate, or out-compete, wild fish. However, since organisms in the wild are subject to natural selection, most of the transgenic gene flow is unlikely to confer any real advantage on the wild counterparts. It may even make them less able to compete with their transgenic-free counterparts since, for example, more of the plant's energy may be converted into producing larger seeds or fruit, leaving inadequate energy and nutrients for other growth functions.

In 1998 the American seed company Delta & Pine Land deliberately designed a gene that sterilised a GM crop's seeds so farmers could not retain seed for later crops. The outrage that was generated (critics of the technology pointed out that half of the world's farmers were too poor to buy new seed every growing season) resulted in the 'Terminator' gene being withdrawn from the GM seeds. A later development conceived at another biotech company, dubbed the 'Exterminator' gene, however, may hold the answer to preventing gene leakage.

Certain bacteriophages (viruses that infect bacteria) have a gene that produces a recombinase enzyme called Cre that cuts out DNA segments that lie between two copies of a marker sequence that has been called *loxP*. The idea is to insert, alongside the gene for the trait being engineered, the gene for Cre and flank the entire piece with *loxP* markers. In addition a promoter gene could be inserted that would activate Cre at exactly the time or place required. Thus the gene could be activated just prior to pollen formation or early in the development of fruit. The transgenic gene would therefore be eliminated. This would prevent not only gene leakage but would ensure that the gene was not in the food actually eaten even though its effects would be expressed. This technique has proven to be successful in laboratory trials in plant tissues but less effective in seeds. Whether or not, in the unpredictable environmental conditions of crop planting, it will work has yet to be determined.

While this development could overcome some fears of the safety of GM food and of environmental damage through decreased genetic diversity, it still does not address one of the most powerful objections to this technology, the increasing dependence of farmers on large seed companies. Several questions need to be asked:

- Is the nutrition quality of GM food that much more improved to warrant its use?
- Is the increased production adequately offset by the increased cost of buying GM seeds?
- Is it more environmentally responsible to grow transgenic disease- or insect-resistant food than to use chemical sprays?
- To what extent should government regulate the use of transgenes or be involved in case assessments of the risks?
- What types of risk-assessment research should be instigated?

The chance of gene leakage from transgenic livestock is far less likely than that for crops since the reproductive opportunities for farm animals can be more easily controlled. In addition, few countries have wild counterparts of the domesticated species and there is far less likelihood for hybridisation between farm stock and closely related wild animals. Transgenic animals, however, can be used in biological control. In these situations regulation of risk assessment is very high (and appears to be greater than for transgenic food and 'pharm' crops). For example, when Australian scientists announced in 2002 that they had discovered a gene that ensures that all progeny of European carp are males, they also stated that at least seven more years of laboratory investigation would be needed before field trials could be carried out. The European carp is an invasive pest in Australia that has decimated most indigenous fish in the Murray–Darling river system and now makes up 90 per cent of the fish biomass in those areas. It would not take long for this species to be eradicated if the majority of the fish were males. Although the gene is a modified version of a carp-specific enzyme, thorough testing must be performed on every other fish species to ascertain that the gene does not jump between species or does not confer other survival advantages over normal carp in case they were inadvertently introduced to other parts of the world.

SUMMARY

Genetic recombination has now progressed past the process of selective breeding of individuals with the most desirable characteristics to being able to deliberately transfer genes from one organism to another so that the host organism can perform new functions. Transgenic organisms are those in which a gene from another species has been inserted. The process involves removing the desired gene and inserting it into the DNA of the host organism.

In the genetic recombination of bacteria restriction nucleases are applied that act as 'scissors' to open both host plasmid and donor DNA at specific recognition sites. The enzymes most used produce asymmetrical breaking of the DNA strand so that each chain has several unpaired nucleotides that act as 'sticky ends' to attract the complimentary unpaired nucleotides of the inserted gene. Another enzyme, a ligase, is then applied to 'glue' the DNA together. Methods used to monitor the success of the gene transfer include bacterial resistance to certain antibiotics and ability to metabolise a marked sugar.

Recombinant DNA technology of microorganisms has been used to produce a variety of proteins for therapeutic use or as a cloning organism to rapidly produce a large number of a particular gene for gene therapy. Other bacteria have been engineered to rectify environmental hazards such as oil spills.

The production of transgenic plants and animals is usually achieved using a bacterial or viral vector to transport the desired gene into the target cells. In animal cells these are inserted using microinjection. Those plant cells that cannot be invaded by the vector can be modified using a pulse of electricity or by shooting a pellet coated with the desired DNA through the cell wall. The production of GM food and pharmaceutical crops has resulted in strong public debate. Concerns centre on possible side effects of the transgene and its products, and gene leakage into natural crops and wild species.

Review questions

24.29 Distinguish between nuclear polymerases, restriction enzymes and ligase.

24.30 Describe the role of 'sticky ends' in recombinant DNA technology. How are they produced?

24.31 Read the following passage and fill in the most appropriate word or words in the blank spaces.

The isolation of specific genes during a genetic engineering process involves forming eukaryotic DNA fragments. These fragments are formed using … (a) … enzymes which make staggered cuts in the DNA within specific base sequences. This leaves single-stranded 'sticky ends' at each end. The same enzyme is used to open up a circular loop of bacterial DNA which acts as a … (b) … for the eukaryotic DNA. The complementary sticky ends of the bacterial DNA are joined to the DNA fragment using another enzyme called … (c) … DNA fragments can also be made from … (d) … templates. Reverse transcriptase is used to produce a single strand of DNA and the enzyme DNA polymerase catalyses the formation of a double helix. Finally new DNA is introduced into host … (e) … cells. These can then be cloned on an industrial scale and large amounts of protein harvested. An example of a protein currently manufactured using this technique is … (f) …

24.32 Why do promoter genes often have to be inserted with a functional human gene into the transformed plasmid of a bacterium in order to form the gene product?

24.33 What is a transgenic organism?

24.34 Explain why it is more difficult to produce transgenic plants than animals.

24.35 Describe at least two techniques used to insert foreign genes into plant cells.

24.36 List some of the concerns about genetically modified food. For each state, with reasons, whether or not the concern is scientifically valid.

24.3.2 Polymerase chain reaction

The potential for treatment of human genetic disease using either replacement normal alleles from a human source or other sources, or by producing chemicals that are lacking due to a genetic defect, is enormous. It is, however, limited by our knowledge of the location of particular genes on the chromosomes and their roles in biochemical cycles. Some human genes were identified and located on chromosomes using the crossing-over ratios that create natural allele recombinations during meiosis. Snipping pieces of DNA randomly and transforming bacteria allowed particular genes to be studied out of the human body. But it was a slow and laborious process.

The idea of the **polymerase chain reaction (PCR)** for rapidly making multiple copies of segments of DNA was first conceived in 1983 and was a well-established procedure by 1993. The reaction exploits the natural function of nuclear enzymes called polymerases that copy genetic material. In the process:

- the target genetic material is denatured—the strand of DNA is separated by heating to 90–96°C to produce single chains of nucleotide sequences. This process is not necessary if copies of the single-stranded RNA are required.
- primers are added. These are short, single strands of nucleotides and must be duplicates of the sequences on either side of the piece of nucleic acid to be replicated. The primers bind to their complimentary bases along the single strand of nucleic acid.
- polymerase and nucleotides are then added. A new copy of the nucleic acid is made from the starting sequences formed by the primers. For DNA there are now two helixes, each composed of one of the original strands plus a newly

assembled complimentary chain.

Each of these steps requires a different temperature. An automated cycle of rapid heating and cooling can take between 1 and 3 minutes depending on the length of nucleic acid to be copied. Repeating the process for 45 minutes can result in millions of copies of a specific piece of nucleic acid. Most enzymes, which are proteins, are unstable at high temperatures. The polymerase (*Taq*) used in this process is obtained from the bacterium *Thermus aquaticus*, an organism that lives in hot springs at temperatures lethal to other organisms. This enzyme is stable at high temperatures and thus ideal for the fluctuating temperatures of automated PCR.

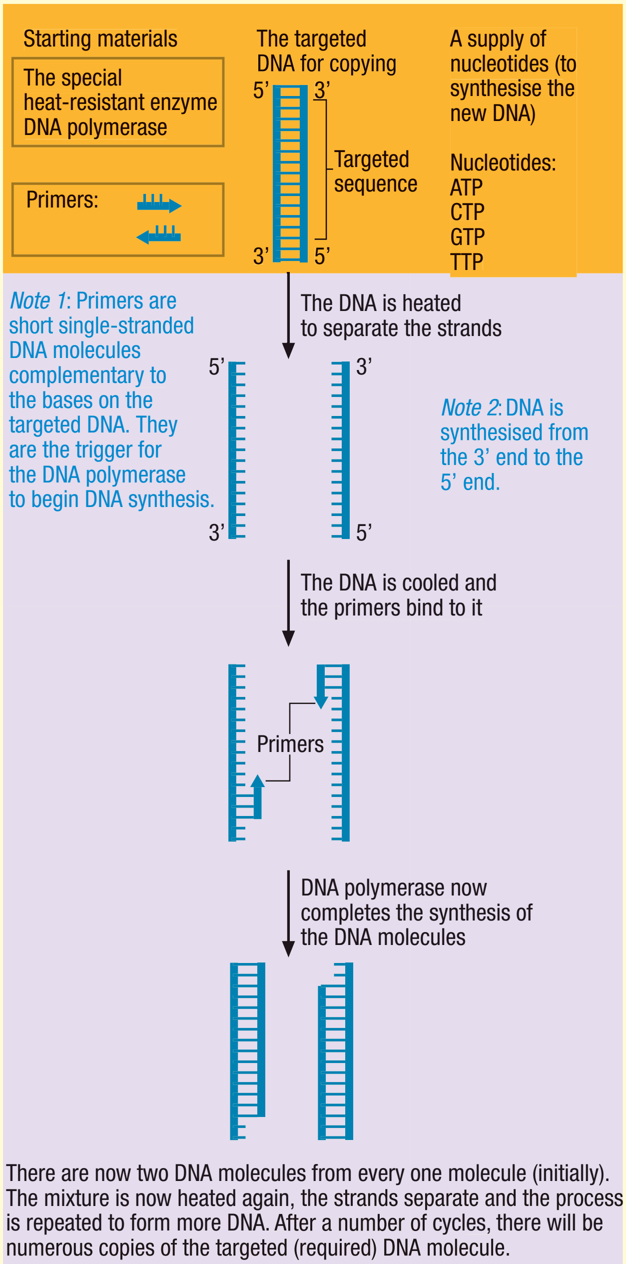


Figure 24.19 The polymerase chain reaction (PCR)

PCR has a variety of applications. It is a significant tool in the detection of infectious disease organisms and of variations and mutations in genes. Using primers of known DNA sequences, particular types of DNA can be detected. Because a small fragment of DNA can be amplified rapidly, only a very small amount of the DNA is required. Thus detection of the HIV virus is more rapid after infection because PCR is looking directly for the virus's DNA rather than the standard test that looks for indirect evidence through antibody formation. It has been used for the detection of otitis media (a childhood middle ear infection), Lyme disease (a painful joint inflammation caused by bacteria transmitted in tick bites), the presence of the bacterium *Helicobacter pylori* that causes stomach ulcers, and three sexually transmitted disease organisms (herpes, papilloma viruses and chlamydia) on a single swab.

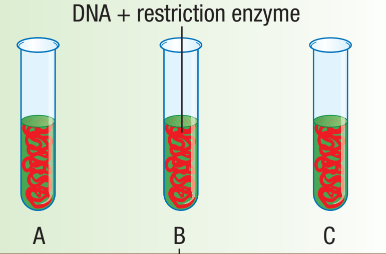
As PCR can distinguish between very small variations in DNA, this process can be used for **genetic screening** to diagnose inherited disorders and carriers of those disorders and can help in tracking the presence or absence of DNA anomalies characteristic of particular cancers.

The method can also be used in solving many evolutionary questions since it has been shown that DNA from ancient sources, such as mummified remains and fossils, thousands of years old can be amplified successfully. Studies of DNA extracts from termites imprisoned in amber 40 million years ago, for example, reveal that they appear to differ little from contemporary termites.

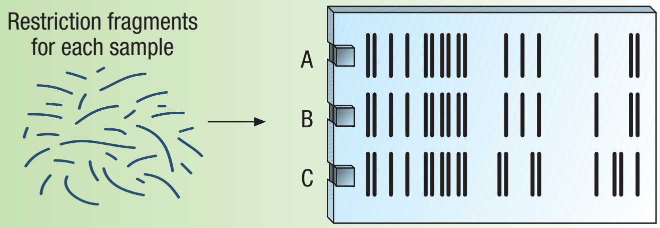
PCR is an indispensable adjunct to forensic DNA typing that is commonly called **genetic fingerprinting**. In any human genome there are regions of extremely variable DNA called hypervariable regions, which are repeated many times. The underlying base sequences in these segments are of fixed composition and very short (10–15 bases). Each individual varies in these regions by the number of times each sequence is repeated at one place. This pattern is unique for each individual with the exception of identical twins, who have identical DNA. Using radioactive base probes, scientists can identify these sequences.

DNA typing has been used successfully in forensic work. A number of crimes have been solved using this technique as has the innocence been proved of previously convicted individuals. In this process only a very small fragment (a single sperm cell, a hair, skin cells caught under the victim's fingernails, etc.) can be collected from the crime scene. The DNA is extracted and amplified using

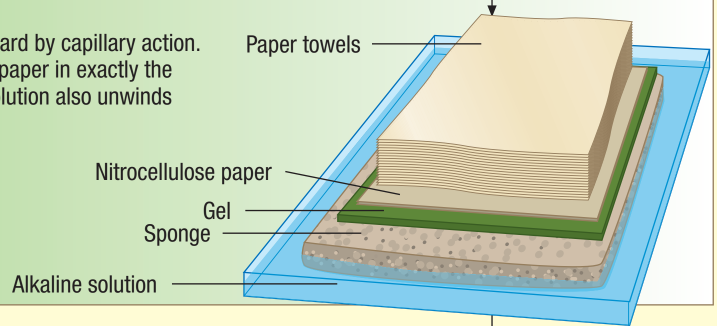
1. The preparation of restriction fragments — three DNA samples from different sources, labelled A, B and C — are treated with restriction enzyme. DNA fragments are produced.



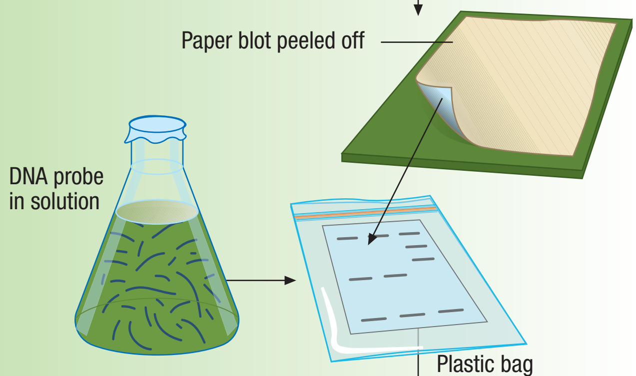
2. Gel electrophonesis — the mixtures of restriction fragments from the three samples are separated; each sample forms a pattern of bonds.



3. Southern blotting — the alkaline solution is pulled upward by capillary action. The DNA fragments are transferred from the gel to the paper in exactly the same positions as they were on the gel. The alkaline solution also unwinds (denatures) the DNA into single strands.



4. DNA hybridisation — the nitrocellulose paper is transferred to a plastic bag and a solution of selected radioactive probes is added. The probes will bind to some of the fragments by complimentary base pairing.



5. Autoradiography — after rinsing off unattached probes, the paper is overlaid with a sheet of photographic film. The radioactivity in the bound probes exposes the film and the probes with their complementary DNA fragments from the samples appear as dark bands.

The patterns can then be compared. In this case, samples A and B are identical but C is different.

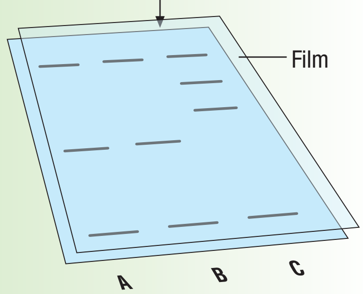


Figure 24.20 The steps in DNA fingerprinting

PCR. The analysis of the DNA involves five steps:

- The DNA is cut into fragments using restriction endonucleases.
- The fragments are separated by **gel electrophoresis**. An electric current is passed through a gel on which the fragments have been placed. Different fragments move through the gel at different rates—smaller fragments travel further. Each fragment separates into a specific pattern of bands. These bands can be seen if the DNA is treated with a dye that shows up under UV light.
- The gel is covered with an alkaline solution and then nitrocellulose paper. Capillary action causes the bands to be transferred to the nitrocellulose in the same positions that they occurred on the gel. This process is called **Southern blotting** (after the scientist who developed the technique).
- The nitrocellulose is immersed in a solution of radioactive probes of complimentary bases to known variable regions. These probes will attach to appropriate segments of the DNA in a process called **DNA hybridisation**.
- After washing off the excess probes, a sheet of photographic film is placed over the nitrocellulose. The radioactive probes expose the film (autoradiography) and form dark bands.
- The DNA from different sources can then be compared.

Figure 24.21 A DNA fingerprint—this fingerprint shows that the blood (D) on the defendant's clothes is that of the victim (V) and not the defendant.

Thus DNA found at a crime scene can be compared with a DNA sample from a suspect. In a similar way paternity of a child can be established by comparing DNA from the child, the mother and possible father(s) since the child will have hypervariable regions with both maternal and paternal bands.

The blotting technique is time-consuming and requires relatively large amounts of DNA, much of which may be degraded. PCR is now used to rapidly produce many copies of small samples of intact DNA. Each different locus on the DNA is colour-coded with a fluorescent dye. The labelled DNA is then placed in a 'Genescan' machine that identifies the loci and automatically compares them with loci of known profiles.

SUMMARY

The polymerase chain reaction (PCR) is a process in which small fragments of DNA can be made to produce multiple copies in a short period of time. In each cycle the DNA is treated to unzip the helix, then placed in a solution of nucleotides which will link to the complimentary nucleotides of the exposed chains and the enzyme polymerase to bring about the bonding of the new nucleotides into a chain. Each step requires a different temperature.

The process has many applications—understanding the human genome, detecting infectious organisms, genetic screening, tracing evolutionary pathways and individual typing.

Review questions

24.37 Briefly list the main features of the polymerase chain reaction.

24.38 Explain why the PCR has increased the rate at which gene location and function can be determined.

24.39 List applications of PCR.

24.40 Explain the term 'genetic fingerprinting'.

24.41 Define the following terms:
(a) hypervariable region
(b) gel electrophoresis
(c) Southern blotting
(d) autoradiography
(e) DNA hybridisation.

24.3.3 The Human Genome Project

In order for genetic engineering to be effective, the recombinant DNA must contain known genes. Since the manipulation of disease-causing alleles in humans is now a possibility, the need to identify and locate these genes on their chromosomes has become a priority. The complete 'map' of a species' genes is called its **genome**.

Gene mapping of linked genes can provide information about the relative position of particular genes on a chromosome. These maps can be achieved by studies of recombinant alleles (see Section 20.4.3). In eukaryote cells the nucleotide sequences of specific genes have been identified using reverse transcription. Some cells synthesise specific proteins: for example, the thyroid produces the enzymes required in the metabolic pathway for thyroxin production. Isolation of the mRNA for each of these enzymes then allows the molecular biologist to synthesise the complementary DNA. This is single-strand DNA. By 'labelling' this cDNA with radioactive nucleotide markers, the scientist can determine the area of the chromosome in which the gene is located.

Chromosomes can be stained to identify heterochromatin and euchromatin (which contains the functional genes). Segments of euchromatin can be cut out of the chromosome and subjected to electrophoresis. In this process the sample is placed on one end of a thin sheet of gelatinous material (called a gel), then an electric current is passed through the gel. The DNA separates out into bands along the gel, the position of each band depending on the electrical properties and size of the fragment. Smaller fragments move further away from the base than do larger ones. The separated DNA on the gel can then be cut into strips and each section separately analysed for nucleotide sequence.

Specific genes can then be inserted into bacterial plasmids. Rapid reproduction, both within the plasmid and of the whole bacterium, produces many clones of this gene. Similarly the protein product of the gene can be analysed. More rapid, automated cloning of DNA is achieved using PCR.

Most of the DNA in prokaryote cells codes for proteins, whereas only about 10 per cent of eukaryote DNA has this function. It is believed that as little as 1 per cent of human DNA constitutes genes. The rest of the genome may be involved in regulatory processes or hyper-variable regions. It may be that all of the functions of DNA have not as yet been identified. This has made the identification of genes for specific characteristics more complex.

In 1985 the Human Genome Project (HGP) was conceived in the USA. The project began in 1989 and was scheduled to last for 15 years, with total funding of $3 billion. Its aim was to map and analyse the nucleotide sequences of each of the 100 000 human genes. In 1998 a milestone was passed, with the total mapping of one human chromosome. The project also aimed to examine the social, ethical and legal implications of the research. Similar programs have been established in other countries, such as Italy, the United Kingdom, France, Japan and Canada. Genomic libraries, where thousands of clones prepared from plants and animals are stored, have now been established.

The HGP is a multi-institutional project. One group, for example, studied Mormon families (which are generally large) over three generations, and focused on gene mapping using recombinants. Another group mapped gene locations with gene markers, and another used recombinant DNA techniques. Yet other groups directed their efforts towards determining the nucleotide sequencing of specific genes which have been located.

By 2000 a working draft of 90 per cent of the human genome was published, identifying 22 000 genes, and screening was made available for 300 genetic diseases. These genetic diseases include the cystic fibrosis gene, ADA, retinitis pigmentosa, SCID, Duchenne muscular dystrophy, neurofibromatosis and retinoblastoma. In May 2003 the human genome project was completed with 99 per cent of gene-containing regions sequenced to 99.99 per cent accuracy. These sequences provide a valuable reference for future medical and human biology research comprising 3 billion nucleotide sequences.

This research aimed to determine the possible allelic forms found in humans in general, as well as individual genome data. The possible determination of personal genomes raises many issues, particularly that of confidentiality. Some of the issues being examined as part of the project include the following:

- Should employers be permitted to discriminate on the basis of predisposition for later onset of a disabling disease?
- Should this information be available to insurance companies? Should non-disclosure of a known possible effect be grounds for invalidation of an insurance policy?
- Who should have access to personal genome data?
- Is it beneficial to patients if a disease is diagnosed for which there is presently no known cure?
- Which genetic disorders should receive funding priorities to find effective treatments?

- Do individuals who have a family history of a genetic disease have an obligation to undergo genetic testing?
- Can courts order reluctant family members to undergo genetic testing?
- To what extent should public policy recognise intellectual property rights such as patents, copyrights and trade secrets of researchers?
- Should scientists withhold results of their work from the rest of the scientific community in order to sell their research to private companies for personal gain?
- Does an organisation, funded by public monies, have the right to patent research techniques or copyright their findings?

It is vital that questions such as these are addressed, in order to safeguard the results of this important research against misuse by individuals, groups or governments.

SUMMARY

The Human Genome Project was an American joint research effort to identify and locate all human genes and their alleles. This would not only provide a greater understanding of the human condition but, through identifying the sites of disease-causing genes, could lead to alleviation of these diseases. The techniques developed during this process could also be utilised in a cost-effective way to determine individual genomes.

Review questions

24.42 What were the aims of the Human Genome Project?

24.43 List some of the techniques used to determine the human genome.

24.44 Describe how cDNA is formed.

24.45 What information is found in a genomic DNA sequence of a eukaryote but not in a cDNA sequence?

24.3.4 Applications of the human genome

Gene therapy

Prenatal diagnosis using DNA is still in its early stages, but scientists are already working on the ultimate genetic goal, **gene therapy**, which could render unnecessary the use of abortion. This process involves inserting the new gene into the target cells, getting the transplanted gene to replace the function of the harmful one and ensuring that the new gene does not harm the patient. If, however, the transplanted gene splices into the cell's DNA at some locations, it could bring about another harmful mutation. The ultimate cure would mean correcting all sperm and eggs as well, so that the defective gene is not passed on to future generations. So far research has been directed mainly at diseases of the immune system, such as adenosine deaminase deficiency (ADA, or the 'boy in the bubble' syndrome). Diseases such as this involve white blood cells which grow and develop in the bone marrow. These cells are easily transplanted.

Case study 24.2: Cystic fibrosis

Cystic fibrosis is an autosomal recessive genetic disorder that mainly affects people of European ancestry. The exocrine glands are unable to function normally, instead producing thick, sticky secretions that clog the tubules within the internal organs. Clogged bile ducts lead to cirrhosis of the liver; pancreatic ducts can rupture and release digestive enzymes into the body cavity, resulting in the formation of fibrous tissues. Incomplete digestion and absorption in the alimentary canal occurs. The lungs become congested and this results in both impaired breathing and increased susceptibility to bacterial infection. Fertility of both males and females is reduced. Since individuals with this condition cannot reabsorb salt, their sweat is extremely salty.

Funded by the Human Genome Project, two scientists isolated and determined the nucleotide sequence of the gene responsible for cystic fibrosis (CF) in 1989. The recessive allele responsible for this disease was found to cause the deletion of one amino acid, phenylalanine, in the protein involved in transporting ions across cell membranes. By 1990, researchers had developed a technique to experimentally copy the normal allele to CF and insert it into an affected cell. The normal allele corrected the defective cells.

Two avenues for correcting this defect are available. **Somatic cell gene therapy** is a technique whereby the normal allele is inserted into cells that are affected by the disease, such as lung cells. Since these cells are fully differentiated, they will eventually die. The treatment needs to be repeated periodically to target the replacement cells. An aerosol inhaler has been developed, in which the gene is packaged in microscopic fatty globules called liposomes. When sprayed into the nostrils, this has been shown to restore the missing allele to lung epithelia in approximately 50 per cent of CF sufferers for a period of time. Unfortunately it has been found that over time the affected individual develops an immune response to this type of treatment.

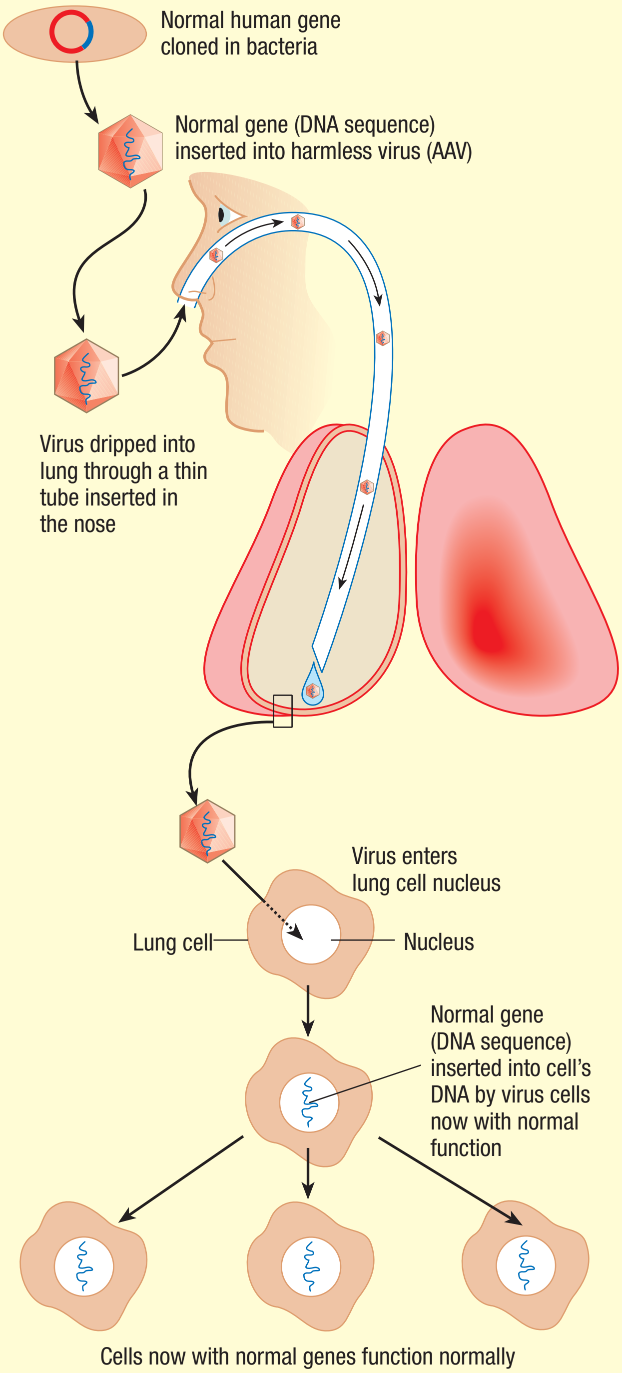


Figure 24.22 Somatic cell gene therapy treatment of cystic fibrosis

The second type of treatment involves replacing the defective allele in the fertilised egg. Thus parents known to be carrying the disease allele would be counselled to have a 'test-tube' fertilisation to allow gene therapy. The resulting individual would have the disease allele totally eliminated from the body and replaced with the normal alleles for the gene(s).

This technique, called **germ-line therapy**, is the subject of considerable controversy. It raises the ethical question of the right to alter the genes of future generations. It might alleviate the high financial and emotional costs to individuals, groups and governments associated with care of individuals with such diseases; but germ-line therapy is open to enormous misuse as our knowledge of the human genome increases. Because of the potential for abuse of this type of therapy, its use has been prohibited in many countries.

With the advent of stem cell research, a third type of treatment for genetic diseases like cystic fibrosis may become available in the future. Stem cells could be produced in which the disease alleles are replaced with normal alleles. If these cells are transplanted into the lung tissue, they could then fully differentiate into normal endothelial tissue, including exocrine glands. Since they are not differentiated at implantation, the treated stem cells should maintain themselves and replace the endothelium as in the normal individual.

There are several possible methods for inserting desired genes into cells in both somatic cell and germ-line gene therapy—that is homologous recombination. All have inherent difficulties. Even using cutting and splicing techniques on the correct chromosome location (a very expensive process producing relatively few donor cells), the donor gene may fail to insert, it may randomly insert somewhere else in the genome or it may insert in the correct location. As with bacterial recombination, a marker gene for resistance to an antibiotic could be inserted with the donor gene and the cells screened before culture. The difficulty with this when used in human gene therapy is that the marker gene itself could bring about changes in the human body that in themselves could produce adverse results.

One of the other difficulties with gene therapy is that most genetic diseases occur as a result of gene interactions. Few—including cystic fibrosis, muscular dystrophy, haemophilia and X-SCID—are the result of a single gene defect. In the past five years considerable work has been done by a French team on the gene therapy of X-SCID. This is an immune deficiency caused by a mutation of a gene on the X chromosome (γc) that prevents both T-cells and killer cells from developing. Since the sufferer has no defence against infection, the child normally dies within the first year of life if bone marrow transplants are not regularly undertaken. The team were able to remove bone marrow stem cells from the patient, inject them with a retrovirus (harmless MLV) carrying the normal γc gene so that the correct white blood cells would be formed, and then reinsert the stem cells into the infant's bone marrow.

Retroviruses do not have DNA as their genetic material but the single-stranded RNA. When a retrovirus invades a host cell it undergoes reverse transcription. The RNA is used as a template for the production of a single chain of DNA which in turn becomes the template for a strand of DNA completing the double helix. The RNA is degraded and the DNA inserts into a host cell chromosome. This then causes the cell to make new viral particles. The viral DNA becomes a permanent part of the host cell and replicates with the chromosome in each cell generation. A number of retroviruses are known to be cancer-causing viruses, either because they carry genes involved in triggering cancerous growth in cells or because they activate the host's own cancer-producing genes (**oncogenes**). It has been found that more than one human oncogene must be activated to transform a cell into a fully cancerous state. The selection of a non-cancer-forming retrovirus for gene transfer into human cells therefore is of great significance.

By May 2002 the French team, using this technique, had treated eleven children. After treatment they all were living normal lives. Then in August of that year one of the boys who had been treated 2 years previously caught chicken pox. This activated T-cell formation as a part of the immune response. After a month, however, T–cells were still being produced in enormous numbers. The child had developed leukemia. A second child also developed leukemia by the end of 2002. Examination of their white blood cell genome determined that the retrovirus had inserted near a gene called *Lmo2*, which is a 'master switch' for early blood formation and the growth of blood vessels. Because of the nature of X-SCID, these children are treated at a very young age. Thus the stem cells that are removed are highly active. It is highly likely that the *Lmo2* gene is being expressed in a fairly high proportion of stem cells. The DNA at this section of its chromosome (number 11) would be unwound, making the insertion of the retrovirus in its close vicinity more likely than elsewhere. In some way it is thought that the inserted viral DNA causes the site to remain permanently unwound during a later activation of *Lmo2* due to an infection, or that the viral switch attached to the normal gc gene also activates the *Lmo2* gene. It keeps on producing T-cells that result in leukemia.

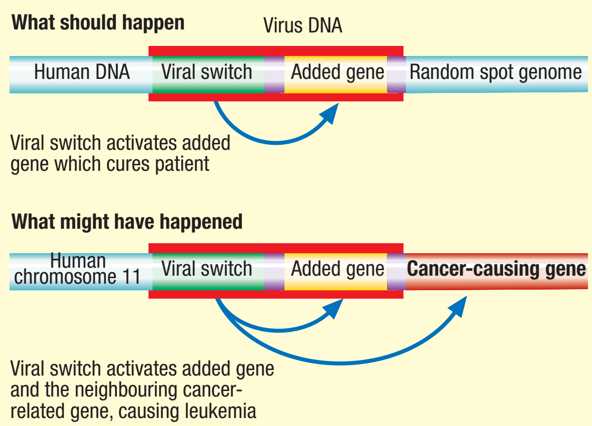


Figure 24.23 Possible insertion sites of retroviral DNA during gene therapy for X-SCID

Further research has determined that only about 1 in 100 000 of the treated children's white blood cells had the inserted gene near the *Lmo2* gene. However, since about a million bone marrow stem cells are modified by the retrovirus, there is a high probability that at least a few will have this positional insertion. Each stem cell, when replaced in the bone marrow, will divide to produce both more stem cells and the differentiated blood cells. Thus even one stem cell with this type of gene insertion has the potential for development of leukemia in the patient.

Although both children are responding to chemotherapy to treat their leukemia, there is concern that the treatment will kill both the cancerous cells and the other modified cells. If that is the case, the children will redevelop X-SCID symptoms.

These findings create a dilemma. Without gene therapy X-SCID infants will die at a very young age unless they are maintained in a completely sterile environment or unless they can find a matched donor for bone marrow transplant. With gene therapy in its present state of development, there is a chance that the child will later develop leukemia. Further research is required to ensure that the retrovirus does not insert near any of the 300 known human oncogenes or to treat the retrovirus genome so that it only activates the added gene.

IVF is now a well-established process. Although most countries do not allow it, it is possible to select the gender of the offspring by only fertilising the eggs with either the X or Y chromosome carrying sperm. It could be possible in the near future for a complete genome of each parent to be carried out. Not only could disease-causing genes be replaced by their normal counterpart, but genes for other desirable attributes could be selected. The age of the 'designer baby' could be upon us. The ethical implications of this possibility are enormous and decisions now need to be made concerning the kinds of genetic manipulation that will be allowed in human embryos. Although research scientists claim no interest in non-therapeutic gene transfers, because it is a possibility it is likely that someone will attempt the process in the future. If this is the case, it has been suggested that society could be even further split than today's economic division into 'gene-rich' and 'gene-poor'. Because of the cost of any IVF and gene therapy program, difficult decisions will need to be made concerning the eligibility of individuals to access the process.

Development of pharmacological treatments

Perhaps the greatest potential of the Human Genome Project is in producing missing chemicals for a person with a genetic disease. Each gene codes for a particular protein. Most of these proteins are enzymes that are significant in a particular reaction of a metabolic pathway. If a gene does not produce the correct enzyme, the complete pathway is disrupted. The precursor chemical for the next step is not present. Either the lack of the final product or the accumulation of a previous product causes malfunction of the body; that is, the individual displays a disease.

By understanding both the metabolic pathway and the exact enzyme (and thus gene) that is missing in the sequence of reactions, treatment can be provided. While our knowledge of gene locations has progressed enormously, their potential for explaining life at the molecular level is still unrealised. This is because of a slower rate of discovering how the genes function. Just as the development of automated PCR aided in the identification of genes, a similar high-throughput method for assessing the function of a gene is required to utilise our knowledge of its role in any particular metabolic pathway.

DNA microarray hybridisation analysis is one technique that has been developed to assist in the determination of gene function. This method is based on two facts—that labelled nucleic acid molecules in solution hybridise with high specificity to complimentary sequences on a solid substrate and that a gene is usually transcribed only when and where its function is required (thus, determining the locations and conditions under which a gene is expressed allows inferences about its functions).

Known DNA nucleotide sequences are physically placed at specific, known locations on a minigrid engraved on a microscope slide (sometimes called a DNA chip). This is usually achieved using a robotic arrayer with capillary printing tips so that the locations are very finite and specific.

For simplicity, the process will be described using both aerobically respiring and anaerobically respiring yeast cells to determine which genes are activated and which are repressed when the two cell populations are compared.

Two cultures of the same yeast are grown—one under aerobic conditions and one under anaerobic conditions. When sufficient cells have been produced they and their solutions are centrifuged resulting in pellets of cells at the base of the centrifuge tube. The liquid is discarded and the mRNA is extracted from the cells using an extraction buffer solution. This solution containing mRNA is then transferred to a fresh tube to which nucleotides with bound fluorescent dyes are added. cDNA is thus formed using the mRNA as a template in the process known as reverse transcription. cDNA is a single chain of the DNA molecule. Different coloured dyes are used for the two conditions under which the yeasts were grown. Once the cDNA has been formed, the mRNA is degraded. The two sets of coloured cDNA are then mixed and spread over the prepared DNA microarray, then incubated. The cDNA will pair with its complementary DNA fragment on the grid. Unbound cDNA is washed off and the grid is then examined under appropriately coloured laser beams to detect the bound cDNA. The fluorescent image is then transferred directly to a computer for analysis. In this way it can be determined that yeast gene 127 is expressed in aerobic conditions but not gene 5854, which is expressed only in anaerobic conditions. Gene 2619, however, is expressed in both conditions. Knowledge of the enzymes coded by the specific gene then allows a greater understanding of the role of the gene in the respiration pathways.

The use of microarrays to compare DNA from a recently infected person (e.g. from HIV) with several patients who have shown successful responses to different treatments could help in the determination of the most appropriate treatment for that individual based on genetic profiles.

Pharmaceutical companies using bacterial recombinant DNA production have been able to produce a number of drugs specific to human conditions. By focusing on particular target cells and understanding their chemistry they have been able to develop other drugs. Thus by targeting the serotonin receptors in the brain, the drug Prozac was developed for the treatment of depression. In a similar manner, Zantac targets histamine receptors in the stomach and so alleviates acid indigestion. By understanding the action of disease-causing genes, chemicals can be developed that target specific sites.

Colon cancer, for example, has been well studied. At least three genes are responsible for the development of this condition. One gene (*ras*) that promotes cell division for some reason remains activated. It acts by producing a protein that stimulates cell growth. The gene that controls the expression of the 'accelerator' gene somehow becomes inactivated and a third gene produces an enzyme (farnesyl transferase) that activates the *ras* protein. A treatment that targets this enzyme and so deactivates it or prevents the expression of its gene could therefore inhibit colonic cancer development.

The new pharmaceuticals therefore are focusing on the development methods by which to block the expression of particular genes ('anti-sense' technology), or to supply the hormones, proteins or other chemicals that would be produced by the normal gene. One anti-sense drug that is showing some promise (Vitravene) is used to prevent blindness in AIDS patients infected with cytomegalovirus.

This technique is a more rapid method of comparing DNA from different individuals than gel electrophoresis.

SUMMARY

The knowledge of the human genome has opened the door to possible treatment of genetic diseases. This could be achieved through gene therapy, a process that inserts normal genes into affected tissues (somatic cell therapy) or replaces a disease-producing gene with a normal one in a fertilised egg (germ-line therapy) using IVF technology. Retroviruses carrying normal genes have been used as a vector to insert the normal gene into bone marrow stem cells of young children suffering from an extreme immune deficiency disease (X-SCID).

DNA microarray analysis is a technique which enables identification of expressed genes (and thus the conditions under which they are expressed). mRNA is collected from cells, converted to cDNA by reverse transcription and compared with known DNA sequences. Analysis of the activated gene sequences can then be used to determine the gene product which can lead to an understanding of the role of the gene in metabolic pathways. This in turn can lead to the development of drugs for the treatment of the disease or to block the expression of the gene promoting the disease. DNA microarray analysis is also a significant aid in screening procedures.

Review questions

24.46 What techniques are available for genetic transformation in humans or human cells?

24.47 Explain why retroviruses are significant in transferring a therapeutic gene into body cells.

24.48 What is a DNA microarray?

24.49 On what known facts are genetic profiles of individuals determined using DNA microarray analysis?

24.50 Does a DNA microarray analysis provide an individual's complete genome? Explain your answer.

24.51 How could DNA microarray analysis help determine the best treatment for an individual who has contracted a disease?

EXTENDING YOUR IDEAS

1. UB The Jack Russell terrier is a small dog that has only recently been recognised as a pure breeding variety and thus granted pedigree status. Research the origins of this breed, the desired characteristics and the processes undertaken to achieve pedigree status.

2. EBI In 2003 a proposal for fish farming in Moreton Bay near Brisbane was proposed. This proposal was strongly opposed by environmental groups. Research arguments for and against this project. Evaluate the data and write an article that supports one side based on your analysis.

3. UB Date palms are dioecious in that there are separate male and female plants. Most female plants are now produced from callus tissue culture in order to produce consistent, high-quality fruit. The growers plant any available male plants and do not go to the expense of producing them from culturing. Explain their lack of concern regarding the quality of the male palms.

4. IB Propose reasons why cloned animals tend to die at a younger than normal age. For one of these reasons, suggest an experimental method that could test its validity.

5. EBI Mammalian cloning studies have found that the recipient oocyte does not have to be the same species as the donor cell in nuclear transfer techniques. This suggests that the functional genes of the mitochondrial DNA are similar in mammalian cells. Since cow oocytes are large and easily extracted, they have been used to clone several different types of mammals and could well be used for human cloning.
   (a) Discuss the ethical issues involved in using cow oocytes in human cloning.
   (b) How would you feel if you found out from mDNA studies that your great-grandmother was a cow?

6. A sheep farmer, wishing to increase the efficiency of fat lamb production, decided to develop a flock of ewes, all of whom only produced twins. Each season he culled all ewes and their offspring that had single births. A similar flock could have been produced by cloning techniques. Suggest which of the two methods (selective breeding or cloning) is most effective. Justify your answer.

UB

7. An American team has successfully cloned calves from the kidney cells of a 48-hour-old slaughtered carcass, after it had undergone tests for meat quality. Explain why this development would have potential benefit to both producers and consumers.

UB

8. Genetic modification of soybeans has made them resistant to the herbicides such as Roundup to which the normal soybean plants are susceptible. This process is shown in Figure 24.24.

EBI

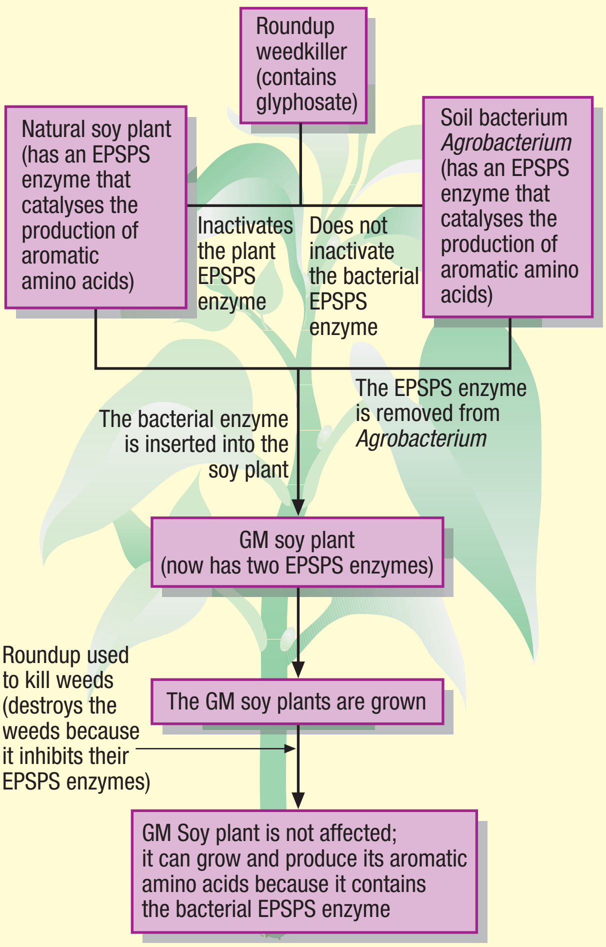


Figure 24.24 The production of Roundup-ready soy plants

Thus it is an advantage to the farmer to grow the genetically modified variety, since he can eradicate all competing weeds within the crop by a simple application of herbicide, thereby ensuring a higher production rate. Most herbicides undergo biological magnification through food chains.

Present a well-reasoned discussion of the possible implications for human health of using this variety of genetically modified soybeans.

9. In Section 24.3.4, the treatment of X-SCID using gene therapy and the inherent problems of this procedure were described. Present a well-reasoned argument that either supports or opposes the continued use of this treatment.

EBI

10. Although experimental work can be performed on laboratory animals, the true test for human gene therapy is to trial it on patients. Two different views have been presented by bioethicists concerning the use of gene therapy:

EBI

1. *If the balance between potential risks and benefits are on the side of the latter, it is ethically justifiable to use the treatment.*
2. *Although the potential benefits may outweigh the risks, to go ahead with trials not completely understanding the cause of the risk could turn this risk into disaster. The trials should therefore be banned until the cause of the risks can be eliminated.*

Critically evaluate each view.

11. The Golden Rule of ethicists was developed by Immanuel Kant from Christian dogma: *Do unto others as you would have them do unto you: treat each person as an individual rather than a means to some end.*

EBI

Discuss the following situations with this imperative in mind:

(a) cloning humans

(b) the use of homologous human engineering to change the personal attributes of a human embryo (physical appearance, IQ, sexuality, disease resistance etc.)

(c) the use of gene therapy.

12. In the following genetic profiles 1 and 2, each letter represents a gene. The upper and lower case letters represent the different alleles of the gene. A slash (/) indicates the end of a chromosome. This data therefore represents genes found on three chromosomes.

EBI

Profile 1

Paternal genes: I S C P M B h / I v b c
c / Mi P P v S

Maternal genes: I S c p M B H / I V b c
c / MI P P v S

Profile 2

Paternal genes: I S c p M B h / I V B c
c / MI p p V s

Maternal genes: I S c P m B h / I V B c
c / ml P p V s

The potential traits exhibited by particular genotypes for these alleles are given in the following table.

Symbol	Potential trait
S	Spatial perception (2 genes, each with 2 alleles) 3–4 S = excellent, 1–2 S = good, 0 S = fair)
I	Interpersonal skills (3 genes, each with 2 alleles) 4–6 I = excellent, 2–3 I = good, 0–1 I = fair
M	Maths ability (2 genes, each with 2 alleles) 3–4 M = high, 1–2 M = average, 0 M = fair
V	Verbal skills (2 genes, each with 2 alleles) 3–4 V = excellent, 1–2 V = good, 0 V = fair
C	Creativity (3 genes, each with 2 alleles) 4–6 C = fair, 2–3 C = average, 0–1 C = high
B	Body build (2 genes, each with 2 alleles) 3–4 B = light, 1–2 B = average, 0 B = heavy
P	Predisposition to heart disease (3 genes, each with 2 alleles) 4–6 P = low, 2–3 P = moderate, 0–1 P = high
H	Gene for unknown trait (1 gene with 2 alleles) H/H = +, H/h = +, h/h = –

(a) Determine the genotypes and potential phenotypes for each of the two individuals.

(b) Use the potential phenotypes to suggest both a suitable and an unsuitable career for each individual. Possible careers could be artist, athlete, carpenter, pilot, fire-fighter, scientist or teacher; but your answer is not restricted to this list. Give reasons for each suggestion based on the profile.

(c) Discuss the rationale behind using the term 'potential phenotypes' for these genes.

(d) In the future, corporations may be tempted to base their recruitment only on genetic profiles. Discuss the validity of such a policy.

13. EBI Salmon farming in the Northern Hemisphere is a lucrative business. Fry are hatched in tanks and then reared in netted ponds. It takes about 3 years for them to reach sexual maturity and marketable size. Some of these fish escape into the wild, where they compete for resources with the wild fish. Wild salmon hatch in freshwater streams and develop in the ocean. At maturity they return to their hatching stream to reproduce.Thus separate breeding populations make the salmon genetically diverse. Local adaptations are lost, however, as wild salmon are replaced by escaped fish, or breed with them.

Advances in biotechnology have resulted in transgenic salmon which can grow at least five times as fast as normal farmed fish. They reach sexual maturity at 2 years of age. These fish have been genetically engineered from eggs which have been injected with a salmon growth hormone gene combined with a promoter sequence from another fish, the oceanic pout. Relatively few eggs were engineered, then these were cloned to produce a great number before allowing them to develop normally.

Salmon growth hormone is produced only in a few cells in normal fish and is inhibited during winter. The pout promoter induces all cells to secrete the hormone throughout the year. This results in massive and rapid growth up to sexual maturity, when they reach a stable size. The implications for the industry are great.

There are fears, however, of the environmental damage which could be incurred if the 'super salmon' escape into the wild.

From your knowledge of reproduction, genetics and ecology and the information given above, discuss the possible environmental impact of escaped transgenic salmon.

14. UB A scientist wanted to cut a bacterial plasmid into five pieces, each of a particular base length (kilobase—kb). She had five restriction nucleases available (RA, RB, RC, RD and RE). The following diagram shows how a plasmid 4.7 kb in length can be cut by these five restriction enzymes.

Which **three** enzymes would she use to obtain the five pieces of DNA of 1.5 kb, 1.2 kb, 0.9 kb, 0.6 kb and 0.5 kb long? Explain your answer.

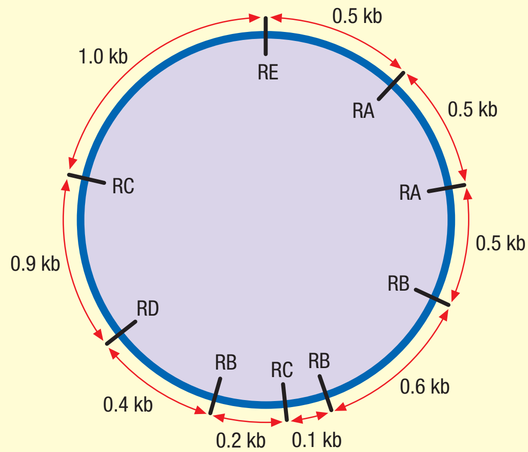


Figure 24.25

15. EBI Although the economic advantages of genetic engineering may be compelling (particularly to drug companies using these techniques), wholesale research and development should be approached with caution and with considerable

knowledge—not just by the individuals involved, but by the public in general. Some questions which need careful consideration include the following:

- How safe are genetically engineered microorganisms, plants and animals?
- Will genetically engineered organisms create ecological disruption?
- Who decides what is or is not safe research?
- Do the experimental animals have rights?
- When is it ethical to start trials on humans?
- If people are to make educated choices, how is information to be effectively disseminated to them?
- Who 'owns' living things?

Write an essay which examines at least three of these questions and suggest ways of achieving a positive result for each.

Glossary

Abdomen region of vertebrate body in which are found organs of digestion, excretion and reproduction; in arthropods the posterior group of segments.

Abiogenesis formation of a living organism from non-living matter.

Abiotic non-living.

Abscisic acid (ABA) plant hormone which inhibits stem and root growth and stimulates leaf and fruit fall.

Abscission formation of a special cell layer in the leaf or fruit stalk which results in leaf and/or fruit fall.

Absorption uptake of matter.

Absorption spectrum graph of the relative absorption of different wavelengths by a pigment.

Abundance number (of a species) in a specific area at any time.

Abyssal zone deepwater zone (depth greater than 1000 m).

Acclimatisation series of long-term physiological changes in response to an environmental condition.

Acellular describing a structure or organism not divided into separate cells.

Acetylcholine (ACh) chemical released from nerve endings when nerve impulses arrive there, which stimulates the adjacent neuron or effector organ.

Acid chemical which in solution forms more hydrogen ions than hydroxide ions, with a pH of less than 7.

Acid rain acids formed in the earth's atmosphere as a result of reactions involving sulfur dioxide or nitrogen oxides.

Acini cells in the pancreas which produce digestive enzymes.

Acoelomate having no body cavity.

Acrosome membrane-bound sac of hydrolytic enzymes found at tip of the animal sperm head.

Action potential a localised change of the electric potential between the inside and outside of a nerve fibre during the passage of an impulse.

Action spectrum graph of the effectiveness of different wavelengths to bring about a particular reaction.

Activation energy the energy needed to start a chemical reaction.

Active site portion of an enzyme in contact with the substrate; at this point it will have a specific shape which corresponds to the shape of at least a portion of the substrate molecule.

Active transport movement of materials in and out of a cell, usually against a concentration or ionic gradient, requiring cellular energy.

Adaptation feature of an organism which enhances its ability to survive and reproduce in a particular environment.

Adaptive radiation evolution, from a more primitive type of organism, of several divergent forms adapted to distinct modes of life.

Adenosine triphosphate (ATP) organic chemical able to store and release large amounts of energy.

Adhesion force of attraction between molecules of different substances.

Adolescence the period of time following puberty during which the human body completes its growth and development.

Adulthood the period of time in the human life cycle following adolescence when growth and development are complete.

Adventitious root root which develops from the stem, branches or leaves; usually fine and numerous.

Aerobic respiration respiration in the presence of oxygen; conversion of glucose to carbon dioxide and water in cells with oxygen present, resulting in a large release of energy; respiration which occurs in the mitochondria in the presence of oxygen; results in a net gain of 36ATP.

Afferent leading towards, e.g. arteries leading to vertebrate gills, sensory nerve fibres.

Afferent arterioles arterioles leading into a structure, e.g. the glomerulus of the kidney.

Agglutination sticking together of incompatible cells, e.g. bacteria or red blood cells.

Aggregation a group of animals which do not necessarily interact socially.

Agonistic behaviour displays of threat and submission.

AIDS acquired immune deficiency syndrome, brought on by infection by the human immune deficiency virus (HIV), and resulting in susceptibility to other pathogens.

Albinism failure to develop skin pigments; in mammals due to a recessive allele.

Algae plant-like photosynthetic protists.

Alkaptonuria human disease in which the individual has inherited an inability to make the enzyme which metabolises the chemical alkapton: alkapton is released in the urine, turning it a dark red–black colour.

Allanto-chorion fusion of a portion of the extra-embryonic allantois and chorion membranes; forms a respiratory surface in embryonic birds and reptiles, and the placenta in eutherian mammals.

Allantois extra-embryonic membrane, forming cavity for excretory wastes in birds and reptiles.

Allele one of two or more forms of a gene located in the same position on homologous chromosomes.

Allergen a chemical produced by an organism that causes an allergic reaction in another organism.

Allometric growth differential growth of various organs or body parts.

Allopatric species species which are unable to interbreed with similar species, due to different geographical ranges.

All-or-nothing response neuron membranes will respond completely to a stimulus, regardless of its strength if it is above a threshold intensity but will not respond if it is below the threshold intensity.

Alternation of generations life cycle in which a haploid individual alternates with a diploid individual; alternation between a sexually reproducing individual and an asexually reproducing individual.

Altitudinal zonation bands of vegetation communities showing adaptations to particular environmental conditions associated with altitude.

Alveolar duct end divisions of the bronchioles in the lungs.

Alveolus thin-walled endings of the alveolar ducts in the lungs, through which gas exchange occurs.

Alzheimer's disease a progressive loss of short-term memory, often associated with senility, and resulting from a variety of factors.

Ambivalent behaviour a response in which an animal alternates between two different behaviour patterns, each equally motivated.

Amensalism inhibition of one species by an other in a relationship between them.

Amino acid building block of protein consisting of an amino group (NH_2), a carboxyl (acid) group (COOH), a variable (R) group and a hydrogen attached to a carbon.

Ammonotelic describing an animal which excretes ammonia.

Amniocentesis withdrawal of amniotic fluid from a pregnant woman by a needle inserted through abdominal and uterine walls.

Amnion extra-embryonic membrane forming a fluid-filled protective cavity around the embryo of amniotes.

Amniotes reptiles, birds or mammals, essentially terrestrial vertebrates whose embryos produce an allantois and amnion.

Amniotic fluid fluid secreted by cells of the amnion into the amniotic cavity, in which the developing embryo is immersed.

Amphibian vertebrate animal which reproduces in water but may spend the adult phase of its life cycle on land.

Amylase enzyme which stimulates the conversion of polysaccharides to dissacharides.

Anabolism chemical reactions in which large molecules are built up, usually with a net input of energy.

Anaerobic respiration respiration in the absence of oxygen which results in a net gain of 2ATP and lactic acid (in animals), or ethyl alcohol and carbon dioxide (in plants and fungi).

Anal sphincter ring of muscle which controls voiding of faeces.

Analogous structures structures with a similar function but no structural relationship.

Anaphase stage in cell division which results in the separation of chromatids.

Anaphylaxis a severe shock reaction to an allergen that is potentially fatal due to lowered blood pressure.

Anatomy internal structure of an organism.

Anchoring junction a junction between cells which holds them together.

Androecium male structure of the flower, composed of stamen, each consisting of a filament and anther.

Angiosperm a seed plant, the reproductive structure of which is the flower.

Animal behaviour overt responses made by an animal to stimuli.

Animalia taxonomic group of multicellular, heterotrophic organisms, capable of locomotion at some stage in the life cycle.

Anion negatively charged ion resulting from an atom or radical gaining electron(s).

Annual ring band of xylem produced each year by a growing tree.

Annulus ring of tissue left on the stem of a mushroom or toadstool where the rim of the cap was attached to it.

Anoxic oxygen-deplete.

Antenna sensory, jointed appendage of the head of many arthropods.

Anterior the front end (head) of bilaterally symmetrical animals.

Anther part of stamen of flower producing pollen grains (male gametophytes).

Antheridium male reproductive system in plants.

Anthropomorphism attribution of human emotions to a behavioural response in an animal.

Antibiotic chemical which prevents reproduction in bacteria.

Antibody protein formed by the immune system in response to the presence of foreign matter in the body.

Anticodon triplet of nitrogen bases found on tRNA.

Antidiuretic hormone (ADH) hormone produced by the posterior lobe of the pituitary gland; increases absorption of water by the collecting ducts of the kidney.

Antigen identification protein on cell surfaces.

Anus posterior opening of the digestive system through which undigested material is voided.

Aorta major arterial blood vessel in vertebrates.

Aortic body nodule of tissue in the aorta containing chemoreceptors sensitive to pH and oxygen levels of the blood.

Apical meristem growing point at the tips of the roots and stems in vascular plants.

Appendage extension of the body of segmented animals used in locomotion, feeding or reproduction.

Appendix blind ending to the caecum, extension of the alimentary canal at junction of small and large intestines; vestigial in humans.

Aquaculture farming of aquatic organisms.

Aqueous refers to water, e.g. solution of a solute in water.

Arboreal organism living in trees.

Archaea domain containing prokaryotic bacteria (methanogens, thalophites and extreme hapophites) found in extreme environmental conditions.

Archegonium female reproductive system in plants.

Arterial pressure pressure of blood experienced in artery as a result of ventricular systole.

Arteriole branch of an artery which breaks up into capillaries.

Artery thick-walled vessel which leaves the heart or the aorta and ends in an arteriole.

Artificial active immunity immunity achieved through injection of sterile pathogens or their toxins.

Artificial passive immunity immunity achieved through injection of antibodies to a particular pathogen.

Artificial selection the breeding of organisms by humans based upon desired characteristics.

Asci (singular ascus) sac-like structures in which spores are produced by meiosis in fungi in the division Ascomycota.

Asexual reproduction production of one or more offspring, which are genetically identical to the parent, without the involvement of gametes.

Asphyxiation death resulting from lack of oxygen.

Assimilation incorporation of simple organic molecules, or products of digestion, into complex constituents of the organism.

Association neuron (intermediate neuron) nerve cell within the CNS which relays information between sensory input and motor output.

Associative learning (conditioning) learning in which a particular response becomes associated with a stimulus as a result of reinforcement (reward or punishment).

Atom basic unit of elements.

ATP (adenosine triphosphate) organic chemical able to store and release large amounts of energy.

Atrioventricular node muscular region in the connective tissue between right atrium and ventricle which transmits a wave of muscle contractions to the ventricle.

Atrioventricular valve tissue found between the atrium and ventricle of the heart to control direction of blood flow.

Atrium (auricle) thin-walled compartment of heart which receives blood from veins.

Auricle (pinna) external ear flap that channels sound into the ear of mammals.

Autoclave machine used to kill pathogens on surgical equipment etc.

Auto-immune disease disease which results from inability of organisms to recognise 'self' from 'non-self'.

Autonomic nervous system system controlling the actions of the inner (visceral) body tube, not under conscious control. Two types of motor nerves are present: sympathetic (secrete noradrenalin) and parasympathetic (secrete ACh), which are mainly antagonistic in their action.

Autoradiography process of obtaining a photographic picture of the position of radioactive substances in tissues or organic compounds.

Autosome non-sex chromosome.

Autotroph self-feeder; organism which can convert simple inorganic molecules into complex organic molecules; organism that synthesises carbohydrates from carbon dioxide and water using a non-living energy source.

Autotrophic nutrition nutrition derived from either photosynthesis or chemosynthesis.

Auxin name given to a group of plant growth hormones which promote cell enlargement and division when present in specific concentrations in various parts of the plant.

Axon extension of the nerve cell body through which impulses are passed.

Bacilli rod-shaped bacteria.

Bacteria prokaryotic organisms believed to be the first life forms.

Bacteriophage virus that infects a bacterium.

Balanced diet correct ratio of nutrients required by a particular organism.

Bark corky tissue of dead cells, present on the outer surface of older stems, branches and roots of woody plants.

Baroreceptor receptors sensitive to changes in stretching/pressure in a tissue.

Barr body inactivated X chromosome in the cells of female vertebrates.

Base chemical which, in solution, forms more hydroxide ions than hydrogen ions; has a pH greater than 7.

Basidium club-shaped, spore-producing structure in fungi in the division Basidiomycota.

Basophil vertebrate white blood cell involved in inflammation reactions.

Behavioural neotony retention of juvenile behaviour in the adult form.

Belt transect an elongated area through a particular habitat in which specific community parameters are measured and recorded; e.g. a metre-wide strip.

Benthos bottom-dwelling, aquatic organisms.

Bicuspid valve atrioventricular valve found between left atrium and ventricle, composed of two flaps.

Bilateral symmetry body pattern in which only one longitudinal cut will produce two sides that are mirror images.

Bile solution of waste materials produced by the liver and stored in the gall bladder.

Bile duct duct leading from the gall bladder to the duodenum.

Binary fission asexual reproduction where two daughter cells are produced from a single-celled organism.

Binomial nomenclature method of naming species of organisms in two parts: the generic and specific names, e.g. *Eucalyptus crebra*.

Biochemical evolution theory that the first organic molecules on earth could have been spontaneously generated and that, from these, cells and then organisms were formed.

Biochemistry study of the chemicals of organisms.

Biodegradable able to be broken down by organisms.

Biodiversity the range of living organisms.

Biogenesis formation of new organisms by the reproductive activities of (an)other organism(s).

Biogeochemical cycle circulation of chemical elements in the biosphere.

Biogeographical region area having distinctive plants and animals, e.g. Australia.

Biological control use of natural enemies (predators, parasites and pathogens) to control the status of a pest.

Biological evolution the change in organisms over time as a result of natural selection.

Biological magnification concentration of substances within the tissues of organisms as they pass along a food chain.

Biological oxygen demand (BOD) decrease in the availability of oxygen for aquatic, aerobic organisms.

Biology the study of life and living organisms.

Biomass amount of organic matter in a system.

Biome area with a specific set of climatic conditions which controls the distribution of organisms and the adaptations they display, e.g. desert.

Biosphere that part of the earth which supports life.

Biotechnology the use of biological knowledge for the development of industrial processes and the production of useful organisms and their products.

Biotic describes living components in the environment.

Biotic potential number of offspring capable of being produced by individuals of a species.

Bipedal describes support and locomotion of the animal body achieved by the hind limbs.

Bladder storage organ for urine in vertebrate animals.

Blade portion of the leaf which is attached to the stem by a petiole.

Blastocyst stage in mammalian embryonic development resulting from division of the zygote; a thin-walled hollow sphere, one end of which is thickened and becomes the embryo.

Blastomere cell formed from the fertilised egg during cleavage.

Blastula hollow ball of cells resulting from cleavage of zygote.

Blood transporting medium of the body; in mammals composed of plasma, platelets and red and white blood cells.

B-lymphocytes lymphocytes which do not pass through the thymus gland and which produce antibodies and memory cells in response to the presence of foreign matter in the body.

Bohr effect the shifting of the oxygen dissociation curve downwards and to the right in the presence of carbon dioxide or hydrogen ions.

Bolus round, softened and moistened food mass formed in the buccal cavity.

Botany study of plants.

Bowman's capsule area of mammalian kidney nephron in which ultra-filtration of the blood occurs.

Brachiating describes locomotion using forearms to swing from tree branch to branch; typical of the primates.

Brachycardia decreased heart rate.

Brain enlarged, anterior part of the central nervous system which coordinates sensory input and responses.

Broad-spectrum antibiotic an antibiotic that acts on a large variety of pathogenic bacteria.

Bronchiole small air-conducting tube of the tetrapod lung connecting the bronchus with the alveolar duct.

Bronchus major subdivision of the trachea.

Brownian motion movement of solid particles within a fluid.

Brush border finger-like projections (microvilli) from the cell membrane.

Buccal cavity cavity bounded by the oral opening anteriorly and pharynx posteriorly.

Bud compact, undeveloped shoot of vascular plants.

Budding asexual reproduction resulting from division of particular cells in an individual, forming a new organism which is released from the 'parent'; method of artificial propagation of plants in which a bud is inserted into the bark of a stock plant.

Bulb organ of vegetative reproduction in some plants; modified shoot consisting of a shortened stem surrounded by fleshy leaves, e.g. onion.

Bulbus arteriosus muscular region of the fish heart which leads into the aorta and evens out blood pressure.

Buttress root triangular, upwardly projecting ridges of lateral roots which support trees in shallow and/or unstable soils and through which gas exchange occurs.

C3 plant a plant in which the first stable product of photosynthesis is a 3-carbon compound, phosphoglyceric acid.

C4 plant a plant in which the first stable product of photosynthesis is a 4-carbon compound such as malate.

Caecum sac-like structure found at junction of ileum and colon; site of microbial cellulose digestion in some herbivores.

Callus cells produced at a cut surface of a plant; widely used in in-vitro culture.

Calvin cycle cyclic reactions of the light-independent phase of photosynthesis.

Calyx outer whorl of flower composed of green leaf-like structures called sepals.

CAM plant an arid-zone plant in which carbon dioxide entering the stomata during the night is converted to organic acids, and which releases carbon dioxide for photosynthesis during the day when the stomata are closed.

Cambium a layer of actively dividing cells between the xylem and phloem of vascular plants.

Camouflage adaptations which 'hide' the organism in its environment; any means of blending with the environment.

Canine mammalian tooth adapted in carnivores for piercing and holding prey; may form tusk.

Canopy leafy portion of a tree.

Capillary fine vessel with walls only one cell thick, permeating tissues; pressure in these vessels causes plasma to pass out into the tissue fluid.

Capsule dry, dehiscent fruit of some flowering plants; in liverworts and mosses, the 'organ' in which spores are formed; gelatinous coating of some bacteria; connective tissue covering of an organ in animals which provides mechanical support.

Capture–recapture method of estimating population density of animals. Animals are captured, marked and released. The proportion of marked to unmarked animals in subsequent trapping provides an estimate of population size.

Carapace shield of exoskeleton covering several segments of some arthropods, e.g. crabs; dorsal part of the 'shell' of turtles consisting of exoskeletal plates fused with the vertebral column.

Carbamino group formed by the attachment of carbon dioxide to amino acids of the haemoglobin molecule.

Carbohydrase general term given to enzymes which catalyse carbohydrate metabolism.

Carbohydrate molecules of carbon hydrated with water; monomer having the general formula of $(CH_2O)_n$ i.e. ratio of C : H : O = 1 : 2 : 1. Polymers have the general formula $(C_6H_{10}O_5)_nH_20$ (there is less hydrogen and oxygen due to formation of glycosidic bonds).

Carboxyhaemoglobin union of carbon dioxide with haemoglobin in red blood cells.

Carcinogen producer of cancer.

Cardiac cycle succession of muscular contractions and movements of the valves during the heartbeat.

Cardiac muscle special kind of muscle arranged in a meshwork of striated muscle fibres which undergo automatic rhythmic contractions and result in heartbeat.

Cardiac sphincter ring of muscle controlling the movement of food into the stomach.

Carnassial tooth (premolar or front molar) in carnivores adapted for shearing action to crack bones.

Carnivore meat-eating organism.

Carotene yellow plant pigment.

Carotid body nodule of tissue in the carotid artery (junction of internal and external carotids) containing chemoreceptors sensitive to pH and oxygen levels of the blood.

Carpel flask-shaped female reproductive part of flower, consisting of stigma, style and ovary.

Carrier an individual (female in humans) who is heterozygous for a sex-linked gene; an individual who is infected by a pathogen but does not display the symptoms.

Carrier molecule molecule which transports another molecule across the cell membrane.

Carrying capacity the total population able to be supported by a particular environment.

Casparian strip a thickening of waxy, waterproof suberin found in the endodermal cells of the root of angiosperms and which directs the flow of water and dissolved ions into the root xylem.

Caste system a social system in which individuals performing certain functions in the group invariably differ in structure.

Catabolism chemical reactions in which large molecules are broken down into smaller ones, usually accompanied by the release of energy.

Catalyst a chemical that causes or accelerates a chemical change but is not altered by the reaction.

Cation positively charged ion, resulting from the loss of electron(s) from an atom or radical.

Cell basic unit of living things.

Cell body the mass of cytoplasm with contained nucleus, from which arise the branches of a nerve cell.

Cell cycle the continuous cycle of growth and division in cells.

Cell division division of both the nucleus and cytoplasm of the cell into two different cells.

Cell membrane phospholipid bilayer, in which proteins are embedded, surrounding cell contents

Cell plate thickening of the cytoplasm which occurs across the spindle of dividing plant cells.

Cell sap watery solution contained within the large vacuole of plant cells.

Cell theory theory that all organisms are made up of cells and their products, and that growth and reproduction are fundamentally due to division of cells.

Cell wall a rigid structure surrounding the cells of some organisms. In plants this is composed of cellulose; in eubacteria of murein (peptidoglycan); in fungi of chitin.

Cellulose a long-chain polysaccharide. In the cell walls of plants these chains are aligned parallel to each other and held together with pectin.

Cement a bonding chemical which holds other molecules together; a bone-like structure covering the roots of mammalian teeth.

Central nervous system (CNS) a mass of nervous tissue, comprising the brain and spinal cord in vertebrates, which coordinates the activities of animals.

Centriole paired tubular structure found in animals and algae; involved in formation of cilia and flagella and in cell division.

Centromere point of attachment of two chromatids.

Cephalic describes the head region.

Cephalothorax fusion of the segments of the head and thorax in some arthropods.

Cerebellum outgrowth of the dorsal surface of the vertebrate hindbrain concerned with the coordination of complex muscular movements.

Cerebral ganglion a concentration of nerve cell bodies in the head region of some invertebrate animals; the forerunner of the brain.

Cerebrospinal fluid fluid which fills the cavity inside the vertebrate brain and spinal cord.

Cerebrum front end of the vertebrate brain composed of a pair of hemispheres, involved in general coordination activities.

Cervix muscular opening between vagina and uterus in female mammals.

Chaetae chitinous bristles found in Annelida.

Character displacement the evolutionary divergence of characteristics displayed by two or more species with the same niche in a particular habitat.

Chemical bond energy potential energy stored within a molecule.

Chemical digestion hydrolysis of complex organic molecules to smaller units which are small enough to pass through cell membranes; mediated by enzymes specific to each chemical.

Chemical formula (molecular formula) represents number and kinds of each atom in a molecule.

Chemical transmitter substance a chemical that passes from one area to another (e.g. axonic end of one neuron to dendritic end of the adjoining neuron) to bring about a change.

Chemoreceptor a receptor which detects and differentiates substances according to their chemical structure.

Chemosynthesis the formation of complex organic molecules from simple inorganic molecules, using chemical energy derived from oxidation of inorganic molecules.

Chemotropism growth in response to a chemical stimulus.

Chiasma (plural chiasmata) connection between chromatids of homologous chromosomes during meiosis, where interchange occurs during crossing-over.

Chloride shift maintenance of the correct electrical balance within a red blood cell, by exchange of chloride ions with bicarbonate ions across the membrane, during the transport of carbon dioxide away from respiring tissues.

Chlorophyll green plant pigment.

Chloroplast plastid found in green plants, containing chlorophyll on membranous grana, and enzymes in liquid stroma; photosynthetic organelle.

Cholecystokinin hormone produced in the intestinal wall which stimulates the gall bladder to secrete bile.

Cholesterol a steroid found in animals; an important constituent of cell membranes and precursor molecule for other steroids.

Chordae tendinae tendons, attached to muscles in the ventricular wall of the heart, which regulate the cuspid valves.

Chorion outer extra-embryonic membrane formed in amniotes; contributes to the formation of the mammalian placenta.

Chorionic villus projection of the chorion into the maternal uterine wall.

Chorionic villus sampling removal of a small section of the chorionic villi of a pregnant woman for genetic disease analysis.

Chromatid replicated chromosome, still attached to the original at the centromere

Chromatin the aggregate mass of dispersed genetic material, formed of protein and DNA, found in eukaryotic cells in the interphase stage.

Chromoplast plastid found in plants, containing red, yellow or orange pigments.

Chromosomal defect an alteration to a chromosome so that incorrect or incomplete genetic information is transmitted.

Chromosome thread-shaped bodies consisting of nucleic acid (usually DNA) and, except in bacteria, protein.

Chromosome map representation of gene positions on the chromosome

Chyme liquefied food mass formed in stomach.

Chymostrypsin a protein-digesting enzyme.

Chymotrypsinogen precursor to chymotrypsin, a protein-digesting enzyme secreted by the pancreas.

Cilia (singular cilium) hair-like projections of the cell membrane.

Circulatory system the system of blood vessels.

Cisternae membrane-bound flattened sacs of the Golgi apparatus and endoplasmic reticulum.

Class division of classification system which represents a subdivision of a phylum (or division in plants or fungi).

Classification grouping of organisms in terms of similarities in morphology, anatomy and biochemistry.

Cleavage repeated division of the zygote into daughter cells.

Climax community a more or less stable plant community.

Clinal variation differences in a characteristic of adjoining populations of a species across a range of environments.

Cline a graded series of changes to a specific characteristic of a species resulting from different environmental selection pressures within the range of the common gene pool.

Clitellum glandular segment in earthworms (class Oligochaeta) which secretes the cocoon.

Clitoris female homologue of penis in mammals.

Clone a lineage of genetically identical individuals.

Closed blood system a transport system in which blood is enclosed in vessels.

Coccus (plural cocci) spherical bacterium.

Cochlea fluid-filled spiral structure of the inner ear of mammals.

Code sequence of nucleotides in DNA which specifies the amino acid sequence in a protein.

Codominance genetic inheritance of two or more traits of a characteristic, each of which is expressed in the phenotype.

Codon triplet of nucleotides on mRNA specifying an amino acid.

Coelom body cavity enclosed on both sides by mesoderm.

Coenzymes non-protein, organic molecules loosely bound to enzymes which act as carriers for transporting chemical groups, atoms or electrons from one molecule to another.

Coevolution the mutual evolution of two different species interacting with each other and reciprocally influencing each other's adaptations.

Cofactor non-protein components of an enzyme necessary for efficient functioning.

Cohesion force of attraction between molecules of the same type.

Coitus (copulation) joining of male and female reproductive organs during mating.

Coleoptile protective sheath surrounding the developing shoot in 'grass' seedlings.

Collecting duct duct into which waste materials from each nephron in the kidney drain.

Collision zone area of impact between two adjoining continental plates.

Colloid (colloidal suspension) a heterogenous suspension of groups of molecules in a liquid.

Colon first part of large intestine in which microbial digestion of cellulose occurs, with production of vitamin K; water and vitamin K are absorbed.

Colostrum milk produced by mammals during the first few days after birth, particularly rich in proteins, including antibodies.

Colour blindness inability of individuals to distinguish the colours red and green.

Commensalism relationship between two organisms in which one organism benefits and the other is not affected.

Community all the species which occupy a particular place at any particular time.

Companion cell plant cell associated with a sieve-tube element in phloem of angiosperms, believed to provide energy for translocation.

Compensation period the time taken, after the onset of daylight, for the rate of photosynthesis to equal that of respiration in plants.

Compensation point the point at which the rate of photosynthesis equals the rate of respiration.

Competition rivalry between individuals, of the same or different species, for specific resource(s).

Competitive behaviour actions in which individuals compete for some resource.

Competitive exclusion principle states that two populations cannot simultaneously occupy the same ecological niche in the same area.

Competitive inhibition a substance that competes with normal molecules for the active site of an enzyme.

Complementary DNA single-stranded DNA formed by reverse transcription from mRNA.

Complete anaerobe an organism which is independent of oxygen for respiration.

Complete metamorphosis developmental pattern from a larval phase which neither looks like the adult nor occupies the same niche.

Compound a molecule formed from the chemical bonding of two or more different elements in fixed proportions.

Concentration the amount of solute dissolved in a solvent.

Concentration gradient a difference in the concentration of a solution at two different points; e.g. across a barrier such as the cell membrane.

Condensation (dehydration synthesis) the formation of a chemical bond between two monomers with the removal of a water molecule.

Conditioned reflex response by an animal to a stimulus which it has come to associate with one which would normally elicit the response.

Conditioning (associative learning) learning in which a particular response becomes associated with a stimulus as a result of reinforcement (reward or punishment).

Conduction the passage of a physiological disturbance through a cell or tissue as a result of stimulation at one point, such as a nerve impulse.

Conduction velocity the speed at which conduction takes place.

Cone reproductive structure of gymnosperms composed of modified leaves called sporophylls; light-sensitive nerve cell in the retina of the vertebrate eye.

Congenital anomaly a disorder of the body, produced during pregnancy, which is not of genetic origin.

Conidiophore specialised hypha for bearing conidium in fungi in the division Ascomycota.

Conidium asexual spore formed at the tip of a conidiophore.

Conjugation fusion of nuclei of two cells, e.g. bacteria; process of sexual reproduction in ciliates; union of gametes.

Conservation the controlled maintenance of an environment or resource.

Consumer organism which eats another living organism (or part of an organism) for nutrition.

Contagious a disease that can be transmitted directly from one individual to another of the same species.

Contamination upset of the normal state by foreign matter.

Continental drift theory theory that the continents are not fixed in position but drift about the surface of the earth.

Continuous variation variety of phenotypes as a result of more than one gene contributing to a characteristic.

Control (group) a standard in an experiment which acts as a reference for the experimental group, in which only one variable is different.

Control centre group of ganglia in the brain responsible for the actions of a particular organ or system in maintaining homeostasis.

Convergent evolution the independent development of similarities between species as a result of their having similar ecological roles and selection pressures.

Convoluted tubule coiled, tubular section of the nephron in the vertebrate kidney.

Cooperation association between (or within) species which benefits both but is not essential for survival of either.

Cooperative behaviour regulated activities of individuals of a group.

Coordination working together.

Coralloid roots coral-like upward growths of roots of certain plants (she-oaks, cycads) following root hair infection by the bacterium *Frankia* or cyanobacteria.

Cork protective tissue of dead, impermeable cells which replaces the epidermis in older roots and stems of woody plants.

Cork cambium a cylinder of meristematic tissue in plants which, during secondary growth, produces cork towards the exterior and epidermis towards the interior.

Corm organ of asexual reproduction, formed from a modified swollen underground stem, e.g. gladiolus.

Cornea transparent epithelium and connective tissue at the front surface of the vertebrate eye.

Corolla coloured, usually conspicuous, part of the flower consisting of petals.

Coronary vessel artery, vein or capillary supplying the heart muscles.

Corpus luteum tissue, formed after release of secondary oocyte in female mammalian ovary, which produces the hormone progesterone.

Cortex outer part of a structure, e.g. the vertebrate kidney in which are found Bowman's capsule, glomerulus and convoluted tubules of nephron.

Cosmozoan theory of evolution theory that life could have arisen in various parts of the universe; favours the idea that life on earth is of extra-terrestrial origin.

Cotyledon leaf-like structure, forming part of the embryo of angiosperm seeds, which may store food for the developing embryo.

Counter-current movement of two media (usually fluids) parallel to each other but in opposite directions.

Covalent bond bond formed when two or more molecules share their electrons in the formation of a molecular compound.

Cowper's gland male accessory sex gland, the secretion of which cleanses the urethra of urine.

Cranial nerves nerves that enter or leave the brain.

Cranium skull enclosing the brain of vertebrates.

Crenation cell collapse as a result of osmosis of water out of the cell.

Cristae folded inner membrane of mitochondria.

Critical period limited time during which imprinting can occur.

Crossing-over breaking and rejoining, with exchange of material, between adjacent chromatids of homologous chromosomes during meiosis I.

Cross-pollination transfer of pollen from a stamen of one flower to a stigma of another, between flowers on two different plants of the same species.

Crown upper exposed part of the mammalian tooth.

Crustaceous flattened, encrusting form; usually refers to a lichen.

Cryptic colouration colouration of animals which conceals by resembling the surroundings.

Culturally patterned activities learned behaviour acceptable to the culture in which the individual lives.

Culture growth and development of an organism or part of an organism on an artificial medium.

Cusp projection on the surface of premolar and molar teeth; rounded in omnivores, ridged in herbivores.

Cuticle superficial, non-cellular layer covering a plant or animal.

Cutin complex mixture of chemicals derived from fatty acids, of which the plant cuticle is composed.

Cutting artificially detached part of a plant used as a means of vegetative propagation.

Cyanobacteria bacteria containing blue-green pigments; do not undergo sexual reproduction.

Cyclic phosphoryation the formation of ATP only in the light-dependent reactions of photosynthesis, where activated electrons cycle between photosystem I and the coenzyme chain.

Cycling pool small compartment of the biogeochemical cycle with active exchange of matter between organisms and the environment.

Cyst cell or group of cells enclosed in a protective coating.

Cytokinin group of plant hormones which have a stimulatory effect on cell division.

Cytology study of cells.

Cytoplasm cell contents not including the nucleus.

Cytoplasmic streaming the flow of cytoplasm around the cell.

Cytoskeleton a network of microtubules and microfilaments which permeate the cytoplasm, providing support and transport within the cell.

Darwinism theory of evolution by natural selection.

Data quantitative or qualitative information.

Daughter cells cells resulting from the division of a single cell.

Day-neutral plants plants which are not dependent upon specific periods of light or dark to flower.

De-amination removal of amino group (NH2) from an amino acid.

Death cessation of life processes in an organism.

Debris scattered fragments.

Deciduous describes a plant, usually found in temperate regions, which loses leaves over winter when soil water is unavailable or the temperature is too low for chemical reactions to proceed.

Decomposer organism which utilises dead organisms or waste matter for its nutrient requirements, breaking down the complex organic molecules and releasing simple molecules back into the environment for reuse by producers.

Defecation egestion of undigested food matter.

Deficiency disease disease resulting from lack of a particular nutrient.

Degenerative evolution loss of structure and/or function.

Dehiscent fruit fruit which open when dried to release seeds, e.g. pea.

Dehydration synthesis (condensation) the formation of a chemical bond between two monomers with the removal of a water molecule.

Deletion an aberration in chromosome structure in which there is a loss of part of the chromosome or a nucleotide in a gene code.

Denaturation structural change produced in soluble (globular) proteins by heat or chemicals, decreasing their solubility and ability to take place in chemical reactions.

Dendrite branching cytoplasmic projections of a nerve cell which receive and transmit impulses.

Denitrifying bacteria bacteria which convert nitrate to nitrite, or atmospheric nitrogen or nitrite to ammonia.

Density-dependent describes any factor influencing population regulation that has a greater impact as the density increases.

Density-independent describes any factor influencing population regulation which has the same impact regardless of population density.

Dentine bone-like substance without cells; the main constituent of mammalian teeth.

Dentition shape and number of teeth for a particular mammalian species.

Deoxyribonucleic acid (DNA) a double-chained, helical nucleic acid capable of replicating and determining the inheritance of a cell's proteins.

Deplasmolysis restoration of turgor pressure in plant cells.

Depolarised an electrical state in an excitable cell (e.g. a nerve cell) whereby the inside of the cell is made more negative relative to the outside than was the case in the resting cell.

Desert an ecosystem characterised by low rainfall and stunted plant growth.

Desertification formation of desert conditions, usually resulting from overgrazing of susceptible areas.

Detritivore an organism which utilises detritus as a source of nutrition.

Detritus debris and dead remains of organisms in an ecosystem.

Development series of changes that an organism undergoes in reaching its final form.

Developmental homeostasis phenotypic uniformity in a species despite genetic differences between populations.

Developmental neotony retention of juvenile structure in adult form.

Diabetes mellitus a condition in which glucose metabolism cannot be controlled due to the absence of the hormone insulin.

Diagnostic feature any feature used to separate groups in the classification of organisms.

Diastema gap between incisors and premolars, found in herbivorous mammals, that allows manipulation of grass by the tongue.

Diastole stage in the heart cycle in which the muscles are relaxed, allowing the chambers to fill with blood.

Diastolic pressure blood pressure in the major arteries during diastole.

Dichotomous key identification key with only two alternatives at each stage.

Dicotyledonae class of angiosperms distinguished by two cotyledons in the embryo, net-venation of the leaves and other structural features.

Differentially permeable (semipermeable) describes a barrier, such as the cell membrane, which allows the diffusion of some molecules but not others.

Differentiation process of change in cells, tissues and organs during development, resulting in division of labour within cells or organisms.

Diffusion movement of solute molecules through a differentially permeable membrane, along a concentration gradient from an area of their high concentration to an area of their low concentration.

Digestion breakdown of large, insoluble molecules into small, soluble molecules capable of passing through the cell membrane; can be intracellular, extracellular, physical or chemical.

Dihybrid ratio predicted ratio of offspring obtained from a cross between individuals simultaneously heterozygous for two characteristics.

Dioecious describes an organism in which sperm and ova are produced by different individuals.

Dipeptide molecule formed by the bonding of two amino acids.

Diploblastic describes an animal having two cell layers: endoderm and ectoderm.

Diploid cellular condition in which there are two of each type of chromosome present in the nucleus.

Disaccharide molecule composed of two chemically bound monosaccharides, e.g. sucrose.

Disclimax community final community formed after succession as a result of degrading environmental factors.

Disease a condition in which an organism or part of an organism does not function correctly.

Dispersal movement away from an area.

Displacement activity an inappropriate behaviour pattern performed by an animal when two conflicting drives are equally motivated.

Disruptive selection selection for the extreme traits of a particular characteristic in a gene pool with the elimination of the intermediate form, leading to two distinct forms of the species.

Distal situated away from, e.g. a limb is distal to the body.

Distal convoluted tubule part of the nephron which joins the loop of Henle to the collecting duct; responsible for reabsorption of sodium, potassium, phosphate and calcium ions under the control of hormones.

Distribution regions in which a species is found.

Divergent evolution evolution that leads to descendants becoming different in form from their common ancestor.

Divergent zone area in which divergent evolution occurs.

Division major classification group of the plants, fungi and plant-like protists.

Dizygotic (non-identical/fraternal) twins twins resulting from the fertilisation of two separate eggs.

DNA (deoxyribonucleic acid) a double-chained, helical nucleic acid capable of replicating and determining the inheritance of a cell's proteins.

DNA hybridisation attachment of DNA probes to specific segments of a section of DNA under investigation.

DNA ligase a linking enzyme essential for DNA replication.

DNA microarray hybridisation analysis a technique used to determine gene function.

DNA polymerase enzymes that catalyse the replication and repair of DNA.

DNA probe a chemically synthesised, radioactively labelled segment of nucleic acid used to find a gene of interest by hydrogen bonding to a complementary sequence.

DNA scissors common term used for restriction nucleases, the enzymes that split DNA at particular sites.

Domain broadest taxonomic group.

Dominant allele an allele for a gene which overrides the effects of the recessive allele in the heterozygus condition.

Dominant species the most common species in a community.

Dominant trait the particular trait of a characteristic which is expressed in the phenotype of a heterozygous individual.

Dorsal describes the top (or back) half of a bilaterally symmetric animal.

Double circulation a circulatory system with separate pulmonary and systemic circulations; blood passes through the heart twice during one complete circulation of the body.

Down syndrome a variety of structural and functional changes to the body associated with the nondisjunction of one pair of chromosomes (chromosome 21) during gamete formation.

Drip tip pointed, drooping shape of the tip of the leaf; an adaptation of plants to high rainfall/humidity habitats, increasing transpiration flow.

Drive internal state of an animal which motivates a sequence of behaviours.

Duodenum first part of small intestine into which bile duct and pancreatic duct enter; main site of digestion.

Duplication an aberration in chromosome structure resulting in the replication of a section of the chromosome.

Dynamic equilibrium the situation which exists when the amount of a particular substance entering a cell is exactly the same as the amount leaving it.

Ecdysis moulting (shedding) of exoskeleton in arthropods and regrowth of new exoskeleton.

Ecological pyramid model of the relationships between different organisms in a food chain.

Ecology study of the relationships between organisms and their environment.

Ecosystem a community of organisms and their environment.

Ectoderm outer primary germ layer of an animal.

Ectoparasite a parasite that lives on the outer surface of its host.

Ectotherm an animal capable of physiologically regulating body temperature.

Edaphic factor abiotic factor connected with the soil.

Effector organ or cell by which an animal acts, e.g. muscles, glands.

Efferent leading away from.

Efferent arterioles aterioles leaving a structure, e.g. the glomerulus of the kidney.

Egestion removal of undigested food (faeces) from alimentary canal.

Egg (ovum) female gamete.

Ejaculation release of semen from penis.

El Nino an unusually warm current originating in the central Pacific which occurs periodically and which brings about global changes in weather patterns.

Electron transport chain a series of coenzymes along which high-energy electrons pass, releasing energy to form ATP at each step in the chain; final stage of aerobic respiration in which most ATP molecules are formed.

Element matter which contains only one type of atom.

Embryo early developing stage of an organism formed as a result of division of a zygote.

Embryo sac female gametophyte in angiosperms; produces the ovum.

Embryology growth and development of zygote until birth.

Embryonic disc that part of the mammalian blastocyst from which the embryo will form.

Emergent species tree which rises above the main canopy.

Emulsification break-up of large lipid particles into small droplets.

Enamel hard covering of the exposed part (crown) of the tooth.

End plate a thickened and folded part of a muscle fibre membrane which receives nerve impulses.

Endemic confined to a particular region.

Endergonic describes a chemical reaction requiring input of energy.

Endocrine gland ductless gland in animals which secretes hormones into bloodstream.

Endocytosis movement of material into the cell.

Endoderm primary inner germ layer.

Endometrium glandular epithelium lining the inner surface of the uterus.

Endoparasite a parasite that lives within its host.

Endoplasmic reticulum (ER) membranous structure with connections with both nuclear and cell membranes, involved in production, storage and transport of materials within the cell. Lipids and steroids are produced in *smooth ER*; proteins are synthesised on ribosomes of *rough ER*.

Endoscope magnifying instrument which can be inserted into a body opening or small incision to view internal structures.

Endoscopy use of endoscope.

Endoskeleton skeleton lying inside the body, e.g. the bony skeleton of vertebrates.

Endosperm triploid (3n) tissue formed by union of two polar nuclei and male nucleus during fertilisation in angiosperms; forms food reserve of seed.

Endospore thick-walled, resistant spores formed within a cell.

Endotherm animal with a relatively constant body temperature maintained by internal regulation of heat production.

Endotoxin toxin which remains within the organism that produces it, and which is released only when the cells are ‘broken’.

Energy ability to do work or cause a change.

Energy pyramid model of the energy relationships in an ecosystem.

Enterokinase intestinal juice enzyme which activates trypsinogen and chymotrypsinogen.

Environment the conditions (biotic and abiotic) in which an organism lives.

Environmental limiting factor any factor which limits the growth of a population.

Environmental resistance sum total of all environmental limiting factors.

Enzyme an organic catalyst, produced by living cells, that changes the rate of chemical reactions in living organisms.

Eosinophil white blood cell involved in the allergic reaction.

Ephemeral describes desert-adapted plants which undergo their complete life cycle in a very short period of time when water is available.

Epidermis outermost layer of cells in plants and animals.

Epididymis sperm storage area in male mammals.

Epigeal germination seed germination that results from elongation of the top of the radicle.

Epiglottis flap of tissue guarding the entrance to the glottis.

Epiphyte plant attached to, but not growing parasitically on, another plant for light and support.

Equator central part of the spindle along which the chromosomes are attached in one plane during metaphase of nuclear division.

Erythrocyte red blood cell.

Essential amino acid an amino acid that must be ingested by a particular heterotroph that is unable to be synthesised by that organism.

Essential nutrient nutrient which must be absorbed since it cannot be synthesised by the organism.

Ester bond bond formed by condensation between a fatty acid (removal of OH) and glycerol (removal of H).

Ethene (ethylene) plant hormone which stimulates fruit ripening and promotes abscission.

Ethology study of animal behaviour under natural conditions.

Eubacteria domain containing prokaryotic ‘normal’ bacteria and cyanobacteria of the kingdom Monera.

Euchromatin chromosomal material which contains the genes.

Eukarya domain containing kingdoms Fungi, Protista, Plantae and Animalia.

Eukaryote organisms whose cells contain membrane-bound organelles.

Eutrophication build-up of nutrients in water; may result in oxygen depletion.

Evolution change in organisms over time due to natural selection, resulting in changes in the gene pool of a population.

Excretion removal of metabolic wastes from the body.

Exergonic describes a chemical reaction in which energy is released.

Exocytosis movement of materials out of the cell.

Exon individual coding sequence of a eukaryotic gene that is transcribed into mRNA.

Exoskeleton external hard body covering of some animals.

Exotic describes organisms not naturally occurring in a particular region.

Exotoxin toxin released by the living organism.

Experimental test an experiment in which a single variable is compared with that of a control group.

Experimental variable (variable factor) the single factor under investigation in a controlled experiment.

Expiration movement of air out of the lungs in tetrapods.

External auditory canal canal leading from the external environment to the middle ear.

External development the development of the zygote outside the maternal body.

External fertilisation fertilisation of the ovum by sperm outside the body.

Extracellular outside the cell.

Extracellular digestion digestion which occurs outside the cells.

Extra-embryonic membranes membranes formed by tissues derived from the dividing zygote, as protective and ‘metabolic’ surfaces.

Extraneous variable some factor in an experiment which was unaccounted for and thus was not controlled.

Facilitated diffusion passive movement of molecules through cell membrane loosely bound to carrier molecules.

Fact information which has been verified by observation or experimentation.

Facultative anaerobe organism that is able to survive without oxygen by respiring anaerobically.

Facultative halophyte a plant able to withstand, but not fully adapted to, salt water conditions.

Facultative parasite an organism that is able to parasitise another but not dependent upon it.

Faeces compacted, undigested food mass which is voided from an animal.

Fallopian tube (oviduct) passageway for ovum from ovary to uterus in female mammal; site of fertilisation.

False fruit fruit which has developed from the receptacle of the flower, e.g. strawberry.

Family subdivision of an order in the complete classification of an organism.

Family tree (pedigree) concept map showing the inheritance of a particular characteristic through several generations.

Fauna a general term for animal life.

Feather component of outer covering of birds, composed of the protein keratin.

Feral an exotic animal which has escaped from domestication.

Fertilisation union of male and female gamete to form a zygote.

Fertilisation membrane membrane formed around the mammalian egg, stimulated by the penetration of a sperm; prevents entry of more than one sperm nucleus.

Fertilisers chemicals, either artificial or organic in nature, applied to improve soil nutrients for plant growth.

Fetal haemoglobin haemoglobin found in the red blood cells of the mammalian fetus that has a higher affinity for oxygen than does adult hameoglobin — this ensures uptake of oxygen through the placenta from maternal blood.

Fetoscopy technique used to directly view a developing fetus within the uterus.

Fetus late stage in embryonic development of mammals.

Fibrous roots a tuft of adventitious roots arising from the stem base, bearing smaller lateral roots.

Filament stalk which supports the anther in flowers.

Filter feeder animal which sieves out small organic matter from its surroundings as nutrients.

First law of thermodynamics energy cannot be created or destroyed but can be changed from one form to another.

Fission form of asexual reproduction in animals (utilising mitosis); may be binary (two offspring formed from unicellular animal) or multiple (a rapid series of mitotic divisions to form many offspring).

Fission track dating method of determining the age of rocks using the marks made by particles emitted from radioactive elements.

Flagellum (plural flagella) whip-like extension of cell, used in locomotion by some Protozoa.

Flora a general term for plant life.

Florigen general term proposed for hormone(s) associated with flowering.

Flower reproductive structure of angiosperms, composed of four whorls of modified leaves.

Fluid mosaic model explanation of the structure and function of the cell membrane.

Foliage leaves of plant or tree.

Foliose spreading, leaf-like in form.

Follicle cellular structure containing developing oocytes in female mammal.

Follicle stimulating hormone (FSH) hormone released from the anterior pituitary gland; responsible for the development of gametes.

Food chain simple linear arrangement of organisms showing the flow of matter and energy from one organism to another through feeding relationships.

Food web all the possible feeding relations in an ecosystem.

Foot base; termination of the leg.

Fossil preserved remains or evidence (e.g. footprints) of an organism.

Fovea shallow pit in the retina of some vertebrates, which is the place of greatest acuity of vision.

Fragile X syndrome sex-linked disease resulting from repeated duplication of three nucleotides of one gene that may result in mental retardation, behavioural and emotional problems and specific physical features.

Fragmentation a process of asexual reproduction in animals where a piece of the organism can grow into a new individual.

Frond fern leaf.

Fructicose describes an upright, branching form of lichen.

Fructivore fruit-eating organism.

Fruit expanded ovary of angiosperms formed after fertilisation.

Fruiting body specialised, spore-producing structure of a fungus.

FSH (follicle stimulating hormone) hormone released from the anterior pituitary gland; responsible for the development of gametes.

Fungicide a chemical used to prevent fungal growth.

Fungus (plural fungi) heterotrophic, eukaryotic organism, the cell walls of which are composed of chitin.

Fur short, fine hair of some animals.

Galactosemia human genetic disease caused by a recessive allele; results in degeneration of the nervous system, and eventually death.

Gall bladder small bladder in many vertebrates arising from the bile duct near or in the liver, in which bile is stored.

Gametangium gamete-producing 'organ' in plants and fungi.

Gamete haploid (n) reproductive cell.

Gametocyte male or female individuals in the life cycle of the malaria-causing *Plasmodium*.

Gametophyte generation multicellular haploid phase in life cycles of algae and plants.

Ganglion area of concentration of nerve cell bodies.

Gap junction intercellular junction between animal cells which allows materials to path through.

Gas exchange movement of oxygen into cells and removal of carbon dioxide from them; may take place directly from the environment or via a transport medium and specialised respiratory surface.

Gastric juice fluid secreted from gastric pits in the stomach wall.

Gastrin hormone released from the pyloric end of the stomach which maintains the release of gastric juice while food remains in the stomach.

Gastrovascular cavity internal cavity of Cnidaria in which digestion occurs and through which absorption of nutrients and gas exchange takes place.

Gastrulation complex movement of cells in the early animal embryo to form a three-layered structure from the single-layered blastula.

Gel eletrophoresis separation of different sized molecules (e.g. nucleotide sequences) on a gel through which an electric current is passed.

Gemma cup organ of vegetative reproduction in liverworts.

Gene segment of DNA which controls a specific characteristic.

Gene amplification selective synthesis of DNA, resulting in multiple copies of a single gene.

Gene complex two or more genes interact to determine the phenotypic expression of a characteristic.

Gene flow movement of alleles between populations, as a result of mating, immigration and emigration.

Gene linkage location of genes on the same chromosome.

Gene pool the total aggregate of genes in a population at any one time.

Gene probe a piece of radioactively-labeled DNA used to detect a gene.

Gene therapy replacement of defective with normal genes in target cells.

Gene tracking determination of the position of a gene on a chromosome using a distinguishing linked gene.

Generative nucleus male reproductive nucleus within a pollen grain.

Genetic code sequence of nucleotides in a DNA molecule, coding for a particular protein.

Genetic counselling advice based on the probability of a couple's child inheriting a disease known to occur with the family group.

Genetic defect an error in the gene code that could result in a defect in body form or function.

Genetic disease inherited disease.

Genetic drift change in the gene pool in a small population due to chance.

Genetic engineering techniques making use of recombinant DNA to produce transgenic (transformed) organisms.

Genetic equilibrium hypothetical state of a population where the frequencies of genes in a gene pool remain stable over time.

Genetic fingerprinting method of identifying individuals from specific, unique sequences of nucleotides in the DNA molecule.

Genetic marker a distinguishing gene (e.g. for a blood group) which is linked with another gene in determining its position on the chromosome.

Genetic recombination transfer of genes between chromosomes of the same or different species.

Genetic screening diagnosis of inherited disorders through identification of the presence of specific alleles.

Genetics study of the transmission of traits from parents to offspring.

Genome totality of genes found in an individual.

Genotype the genetic makeup of an individual.

Genus classification category between family and species; first part of the scientific name of an organism.

Geographical isolates a population which has become separated from the main gene pool by an extrinsic barrier.

Geotropism growth in response to gravity.

Germ line therapy replacement of a defective allele in a fertilised egg.

Germination sprouting of seed.

Gestation length of time between conception and birth.

Gibberellin a plant hormone promoting stem elongation and seed germination.

Gill spoke-like structure in the cap of a mushroom on which are located the basidia; respiratory surface of many aquatic animals.

Gill filament respiratory surface of fish; thin-walled, highly vascular structures arising from the gill arches.

Glomerulus capillary knot found in Bowman's capsule through which ultrafiltration of blood (plasma minus protein) into the nephron of the mammalian kidney occurs.

Glottis opening arising in the pharynx which leads to the trachea.

Glucagon hormone released by the pancreas which stimulates the conversion of glycogen to glucose.

Glycolysis first stage in cellular respiration; occurs in cytoplasm and results in the formation of 2 ATP molecules and 2 pyruvic acid molecules.

Glycosidic bond bond formed by condensation between two monosaccharides.

Golgi apparatus membranous stack of cisternae involved in packaging and secretion of cell products.

Gonads gamete-producing organs of animals.

Graafian follicle fluid-filled spherical vesicle in the mammalian ovary containing a secondary oocyte.

Grafting method of artificial propagation of plants, in which a shoot is inserted into the top of a stock plant and union between the tissues is induced.

Granum (plural grana) stacked portions of membranes found at sites of light-dependent reactions of photosynthesis.

Grassland plant community, usually devoid of trees or shrubs, found in areas of low rainfall or low retention of soil water.

Greenhouse effect retention, through absorption, of heat by carbon dioxide and other particles in the earth's atmosphere.

Grey matter parts of the central nervous system, associated with coordinating activities, where the fibres are not myelinated.

Gross primary production the total amount of organic matter in an ecosystem produced as a result of photosynthesis.

Group behaviour coordinated activities of the members of a group.

Growth increase in the amount of matter (dry mass) in an organism.

Guano sedimentary rock, rich in phosphates, formed from the build-up of sea birds' excreta.

Guard cells specialised, sausage-shaped, paired epidermal cells surrounding stomata.

Guttation ability of some plant leaves to secrete excess water from special glands at the end of the veins.

Gymnosperm a seed plant, the reproductive structure of which is a cone.

Gynoecium female reproductive structure of flower, consisting of carpels.

Habitat a specific locality, with a particular set of abiotic conditions, inhabited by an appropriately adapted community of organisms.

Habitat fragmentation division of a habitat into smaller, isolated portions as a result of human activities in the intervening spaces.

Habituation learning to permanently ignore certain unimportant stimuli.

Haemocoel large sinus which replaces the true coelom in arthropods and some molluscs, and in which blood surrounds the organs of the body.

Haemoglobin pigment molecule found in the red blood cells; contains four iron-containing haem groups, each of which can bond with one oxygen molecule; has a high affinity for oxygen.

Haemoglobinic acid weak acid formed when hydrogen attaches to haemoglobin.

Haemolysis rupture of red blood cells as a result of osmotic flow of water into the cells.

Haemophilia human genetic disease caused by a sex-linked recessive allele; causes defective blood clotting.

Half-life the time for half the mass of a substance to break down into another substance.

Halophyte a plant adapted to saline conditions.

Haploid (n) cellular condition in which the nucleus contains only one of each type of chromosome.

Hardy–Weinberg law maintains that the sexual shuffling of genes alone cannot alter the overall genetic make-up of a population.

Haustoria short hyphae specialised for penetrating the host in some parasitic fungi and plants.

Heartwood central mass of xylem in trunks of trees with no living tissue; no longer functioning in water transport but instead in support and storage of excretory products.

Heat capacity amount of heat required to raise the temperature of 1 kg of a substance by 1 °C.

Heat shock proteins proteins which become associated with DNA and prevent inappropriate separation of the strands when cells become overheated.

Heath low-growing shrubland.

Heparin chemical produced by basophil white blood cells that prevents blood clotting.

Hepatic portal vein vein which transports absorbed food molecules directly from the small intestine to the liver.

Herb low-growing plant with soft shoot system and no persistent above-ground parts.

Herbicide chemical substance used to eradicate particular plant species.

Herbivore plant-eating organism.

Hermaphrodite describes an organism with both male and female reproductive parts present.

Heterochromatin non-transcribed eukaryotic chromatin.

Heterogeneous mixed unevenly.

Heterothallic describes a condition in which the body of an alga or fungus has two chemical forms.

Heterotroph literally, other-feeder; an organism which derives its external source of energy from other living organisms

Heterotrophic nutrition nutrition based on the intake of organic matter derived from other living organisms.

Heterozygous each allele for the characteristic exhibiting a different expression.

Hierarchy graded organisation; in groups of animals the hierarchy may be based on dominant–submissive behaviours; in classification it is from general (kingdom) down to very specific (species) characteristics.

Histamine chemical released during an allergic reaction causing dilation of blood vessels and thus swelling of the affected part.

Histogenesis tissue formation during development of organisms.

Histology study of tissues.

Holandric gene gene found on vertebrate Y chromosome.

Holdfast base of large brown algae; attaches to the substrate.

Home range any area traversed by an animal in its normal activities.

Homeostasis maintenance of a constant internal environment, mediated by feedback systems.

Homogeneous evenly mixed.

Homologous chromosomes (homologs) chromosomes of the same type; usually a pair.

Homologous structures structures with different functions but a similar structure and development.

Homozygous describes a condition in which both alleles for the gene are the same.

Horizonal zonation distribution of organisms in zones along a horizontal gradient of environmental conditions.

Hormone chemical produced by endocrine gland; part of control and coordination system; capable of bringing about a specific response to a particular stimulus.

Humidity measure of the amount of water vapour in the air.

Hybrid heterozygote for a characteristic; plant or animal resulting from a cross between parents which are genetically unalike.

Hybrid belt adjoining area between two populations in which hybrids may be found.

Hybrid vigour improved characteristics found in the hybrid than either parent.

Hydrogen bond weak bond formed between two molecules, resulting from uneven distribution of charge on each molecule.

Hydroid a type of cnidarian composed of colonial polyps.

Hydrolysis enzymatic breakdown of polymers involving the addition of a water molecule when the bond between monomers is broken.

Hydrophilic describes substances that dissolve readily in water.

Hydrophobic describes substances that are insoluble in water.

Hydrophyte plant adapted to aquatic conditions.

Hydrostatic skeleton body support derived from the pressure of fluid exerted in the cells or coelom.

Hydrotropism growth in response to water.

Hygroscopic movement mechanical movement brought about in plant cells by dehydration.

Hypertonic having a higher concentration than that of the surroundings.

Hypervariable regions sequences of DNA which are repeated many times and which are unique to the individual.

Hyphae (singular hypha) fungal filaments.

Hypogeal germination germination of a seed which results from elongation of the base of the plumule.

Hypothesis a statement which attempts to answer questions raised by observations and can be tested by experimentation.

Hypotonic having a lower concentration than that of the surroundings.

Igneous rock rock formed as molten magma cools and solidifies.

Ileum posterior part of small intestine in which most absorption occurs.

Immunity ability of an organism to resist infection.

Implantation embedding of mammalian blastula into uterine wall.

Imprinting a simple, very rapid and irreversible form of learning which occurs during a short critical period of an animal's life.

Inbreeding a process in artificial selection where consistency of a particular characteristic is maintained by mating close relatives of the organism.

Incisor front mammalian teeth, typically chisel-shaped for cutting food.

Incomplete dominance a situation where there is no dominant or recessive allele for a gene; instead, both expressions blend in the heterozygous condition.

Incomplete metamorphosis development from nymph form to adult form where the nymph that hatches from the egg bears a general resemblance to the adult but must pass through a series of growth and development stages to reach maturity.

Incubation period the time taken for an egg to hatch; the time between infection by a pathogen and the first symptoms of the disease.

Incus one of three bones in the middle ear that vibrate during the transmission of sound.

Induced fit hypothesis idea that the active site of an enzyme, after initially attracting a specific substrate, can change in order to suit the substrate's shape and in doing so affects the shape of the substrate and thus lowers its activation energy requirements.

Inducer cell substrate which stimulates the production of a protein.

Infectious a disease that can be passed from one individual to another either directly or indirectly.

Inferior below.

Inflammatory reaction response by part of the body to trauma or disease resulting in swelling, heat, pain and redness.

Inflorescence flowering shoot.

Ingestion transfer of food into the buccal cavity.

Innate behaviour pattern which is genetically controlled and not subject to change due to experience.

Inorganic relating to chemical compounds that do not contain carbon (except carbonates and cyanides).

Insecticide chemical used to decrease the numbers of insect pests.

Insectivore insect-eating organism.

Insight the ability of an animal to respond correctly the first time to a situation different from any previously encountered.

Insoluble suspension a mixture in which there is negligible Brownian motion and the particles separate into layers.

Inspiration intake of air into the lungs of tetrapods.

Insulin hormone produced by the pancreas which stimulates the conversion of glucose to the storage chemical glycogen.

Integral protein protein found within the structure of the cell membrane.

Integrated pest control pest control which monitors the status of the pest organism and uses a variety of strategies to reduce the numbers of the pest.

Intercellular between cells.

Intercellular fluid fluid found between cells.

Interferon a chemical messenger of the immune system, produced by virus-infected cells and capable of helping other cells resist the virus.

Intermediate dominance a pattern of inheritance in which neither allele for a characteristic completely masks the effects of the other; results in a blending of traits for the characteristic.

Intermediate filament a component of the cytoskeleton that includes all filaments intermediate in size between microfilaments and microtubules.

Intermediate neuron (association neuron) nerve cell within the CNS which relays information between sensory input and motor output.

Internal development development of the zygote within the parent body.

Internal fertilisation fertilisation which occurs within the body of the organism.

Interpersonal behaviour actions between individuals.

Interphase stage in the cell cycle in which the cell grows and stores energy.

Interspecific between different species.

Intestinal juice watery, alkaline secretion from glands in the walls of the small intestine containing enzymes.

Intracellular within the cell.

Intracellular digestion digestion within the cell; occurs in a special vacuole to prevent digestion of the cytoplasm.

Intraspecific within a species; between individuals of the same species.

Intrinsic isolating mechanisms genetic differences, operating within a species, which maintain a distinctive gene pool and prevent breeding with other species.

Intromittent organ male organ used for the transfer of sperm to the genital opening of the female during internal fertilisation, e.g. the mammalian penis.

Intron intervening sequences of non-coding regions in eukaryotic genes.

Inversion an aberration in chromosome structure occurring during meiosis, in which a chromosome fragment is reattached in reverse orientation to the original.

In-vitro fertilisation fertilisation of ova in laboratory containers followed by artificial implantation of the early embryo in the mother's uterus.

Involuntary reflex learnt reflex in which the animal does not take an active part in finding the new stimulus.

Ion a charged particle formed when an atom, or group of atoms, gains or loses electrons.

Ionic bond bond formed by the force of attraction between two ions of opposite charge.

Ionic compound compound formed by the bonding of oppositely charged ions.

Iris coloured structure controlling the amount of light admitted to the vertebrate eye.

Irritability basic property of protoplasm: detection and response to changes in the environment.

Islets of Langerhans groups of exocrine cells in the pancreas that produce and secrete the hormones insulin and glucagon.

Isomer compounds with the same molecular formula but different spatial arrangements of atoms, and thus different properties.

Isometric growth change in size not associated with change in shape or external form.

Isotonic having the same concentration as that of the surroundings.

Isotope distinct form of a substance consisting of atoms with the same atomic number but different atomic mass.

Karyotype pictures of the chromosomes of a cell arranged in relation to size, shape and number.

Kidney excretory organ of vertebrates.

Kinesis movements not oriented with respect to the direction of the source.

Kinetic energy energy of motion.

Kingdom A subdivision of a domain—group of organisms with very general common features.

Klinefelter syndrome in human males, XXY chromosome combination, which leads to specific anomalies.

Knee root part of a root that projects as a low buckle above the substrate.

Krebs cycle cyclic series of chemical reactions in mitochondria in which acetyl CoA is converted to carbon dioxide, and hydrogen atoms are transferred to carrier molecules, with the formation of an ATP molecule.

Lactase enzyme involved in the digestion of the carbohydrate lactose.

Lacteal small, blind-ending lymphatic vessel in villi of small intestine; absorbs lipids.

Lamina leaf blade.

Large intestine part of the mammalian digestive system in which water is reabsorbed from undigested food and bacterial decomposition results in the formation of vitamin K.

Larva (plural larvae) immature, independent form of an animal which undergoes metamorphosis.

Larynx 'voice box' located at the anterior end of the trachea, where movement of air over the vocal cords produces sound.

Latent heat of fusion measure of heat energy lost when a liquid is converted to a solid.

Latent heat of vaporisation measure of heat energy required to convert a liquid to a gas.

Latent learning learning not associated with an immediate reward.

Latitudinal zonation changes in plant community structure due to climatic conditions associated with latitude.

Law a scientific theory which has been continually upheld by experimentation.

Law of dominance Mendelian law which states that when homozygous parents with contrasting expressions of a given trait are crossed, only the dominant allele will be expressed in the offspring.

Law of independent assortment Mendelian law which states that each allele pair segregates independently during gamete formation. Applies when genes for two traits are located on different pairs of homologous chromosomes.

Layering method of artificial propagation of plants by forced stolon formation.

Leader animal which coordinates group behaviour.

Learning change in behaviour as a result of experience.

Left atrium chamber of tetrapod heart which receives oxygenated blood from the pulmonary veins.

Lens a transparent structure lying just behind the pupil of the vertebrate eye, which focuses the image onto the retina.

Lenticel specialised area of tissue in the corky bark of woody plant stems which allows gas exchange.

Lethal gene gene which causes the death of the individual.

Leucocytes (white blood cells) nucleated cells in the blood specialised for antibody, inflammatory, allergic or phagocytic functions.

Leucoplast colourless plastid found in plant cells; concerned with starch or oil storage.

Lichen an organism formed from a mutualistic relationship between a fungus and an alga.

Light-dependent reactions chemical reactions in the chloroplast, involving excitation of chlorophyll electrons by energy transfer from specific wavelengths of light, and resulting in splitting of water to release hydrogen for dark reactions and formation of ATP.

Light-independent reactions second stage in photosynthesis, in which carbon dioxide is reduced by the hydrogen formed in the light reactions, with the input of energy from ATP, to form glucose. These reactions are not dependent upon the presence of light.

Lignotuber plant root specialised to store excess nutrients or water; allows regeneration of the plant after adverse environmental conditions such as fire.

Limited growth growth in which there is a maximum size for a particular species.

Limiting factor any factor which limits the growth of a population.

Line intercept an ecological technique used to estimate relative densities of a species, by counting the number of individuals that lie on a straight line cutting through the community under study.

Linked genes genes that are located on the same chromosome.

Lipase general term for enzymes which are involved in the hydrolysis of lipids.

Lipid an ester of fatty acids and glycerol.

Littoral describes the zone between water and land, which may be affected by tidal action.

Liver large organ of assimilation in mammals.

Lock-and-key hypothesis hypothesis explaining the interaction between an enzyme and its substrate in terms of the shapes of the molecules.

Locomotion movement of an organism from place to place.

Locus position of a gene on a chromosome.

Long-day plants plants which flower only when day length exceeds ten hours.

Longitudinal section section taken along the long axis of an organism, from anterior to posterior.

Longitudinal zonation changes in community structure associated with environmental changes with longitude.

Loop of Henle area between proximal and distal convoluted tubules of nephron in the mammalian kidney; is a counter-current multiplier whereby high salt concentration in the interstitial fluid is maintained, resulting in diffusion of water from the filtrate to the surrounding blood capillaries.

Luminescence light production as a result of chemical reactions utilising oxygen within the body.

Luteinising hormone (LH) hormone secreted by anterior pituitary; responsible for ovulation, and formation and maintenance of the corpus luteum.

Lymph tissue fluid containing a high volume of white blood cells which has been taken up by the lymphatic vessels to be returned to the blood vascular system.

Lymph node organ on the course of major lymph vessels containing cells involved in the immune response.

Lymphocyte a type of vertebrate white blood cell involved in the immune system.

Lysosome organelle containing digestive enzymes concerned with intracellular digestion.

Macromolecule a large organic molecule composed of many monomers.

Macrophage phagocytic cell in mammalian blood.

Magnetic stripes layers in iron-bearing rock with different magnetic bearings; related to the orientation of the earth's magnetic field during solidification of the rock.

Maintenance sustained conditions necessary for continued existence.

Malleus one of three bones in the middle ear involved in the transmission of sound.

Maltase enzyme involved in the hydrolysis of maltose.

Mammal a tetrapod vertebrate with body covering of hair; females produce milk for the nourishment of the young.

Mangrove refers to a range of plants adapted to specific conditions and to the community in which these species dominate.

Mantle external tissue of visceral mass of molluscs which secretes the shell.

Marsupial a type of mammal in which development of the young is completed outside the mother's body, usually in her abdominal pouch.

Mass flow movement of dissolved solutes in the plant due to a turgor pressure gradient.

Mast cell connective tissue cell which produces histamines and heparin.

Master gland pituitary gland; term refers to the range of hormones it produces, directly or indirectly.

Matrix intercellular substance in which cells are embedded; fluid contents of an organelle such as a mitochondrion.

Matter anything that has mass and takes up space.

Mechanical (physical) digestion breakdown of food into small units by crushing or cutting actions of teeth, mandibles, muscles etc.

Medulla inner layer of a structure, e.g. of the vertebrate kidney, containing loops of Henle and collecting tubules.

Medullary ray thin, vertical plate of parenchyma cells running radially through the xylem and phloem.

Medusa bell-shaped, free-swimming form of the phylum Cnidaria.

Meiosis nuclear division resulting in daughter cells having half as many chromosomes, but the same types, as the parent cell; a reduction division, from the diploid to the haploid condition.

Memory cell cell containing antibodies to a specific antigen, produced by lymphocytes as a result of infection by a pathogen.

Menopause time, in human female, when the ovaries ceases their reproductive function.

Menstrual cycle cycle of events resulting in formation of an ovum, its release, preparation of the uterus for pregnancy, and subsequent breakdown of uterine tissue if fertilisation does not occur; under hormonal control.

Menstruation (menses) flow of degenerated uterine tissue from the body of the female.

Meristem group of undifferentiated plant cells which retain their ability to divide.

Merozoite individual in the life cycle of the malaria-causing *Plasmodium* formed by multiple fission in red blood cells.

Mesoderm primary germ layer of triploblastic animals which develops into muscle, organ and connective tissues.

Mesoglea jelly-like acellular substance between endoderm and ectoderm in diploblastic animals.

Mesophyll plant tissue of two types — palisade and spongy — specialised for photosynthesis.

Mesophyte terrestrial plant growing in well-watered soil.

Messenger RNA (mRNA) ribonucleic acid which conveys information from DNA that is to be translated into a particular polypeptide chain.

Metabolic pathway series of chemical reactions undertaken in a metabolic reaction.

Metabolism chemical reaction occurring within a cell.

Metameric segmentation body divided into a series of primarily identical segments which act in a coordinated manner.

Metamorphic rock rock which has been changed from another form as a result of heat or pressure.

Metamorphosis period of rapid transformation from larval to adult form.

Metaphase stage of mitosis or meiosis where the chromosomes are arranged on the spindle of the equator.

Methylation addition of a methyl group to bases of DNA after replication.

Micro-environment an area within a general habitat with specialised environmental conditions, e.g. a hollow log.

Microfilaments solid rods of actin protein found in the cytoplasm, cilia and flagella of eukaryotic cells.

Microphagous feeding on small particles suspended in water, e.g. filter feeders.

Micropyle opening in the integuments of ovule or testa of a seed; allows exchange of materials.

Microtubules protein strands in cytoplasm; involved in cell transport and structure.

Microvillus projection from surface of cells; forms a brush border.

Middle lamella mineral cement between cell walls of plant cells, holding them together.

Mimicry protective adaptation in which one organism (the mimic) resembles another organism (the model).

Mineral a naturally occurring substance, sometimes an element but more often a metallic compound, that forms crystals under the right conditions.

Miscarriage ejection of an undeveloped fetus that may occur spontaneously or due to deliberate human intervention (abortion).

Mitochondrion (plural mitochondria) membrane-bound cellular organelle; has inner membrane forming folds (cristae) on which are found enzymes for aerobic respiration, and a fluid matrix.

Mitosis nuclear division resulting in daughter cells with chromosomes of exactly the same types and number as in the parent cell.

Modifier gene a gene that influences the expression of another gene.

Molar back cheek teeth of mammals adapted to their type of diet.

Molecular compounds compounds formed by covalent bonds.

Molecule smallest part of an element or compound that can exist alone.

Monera kingdom into which prokaryotic organisms are grouped.

Monoclonal antibody an antibody produced by artificial cloning techniques that is specific to a particular antigen.

Monocotyledonae subclass of the flowering plants distinguished by parallel leaf venation, single cotyledon in seed and other structural differences.

Monoculture culture of a single organism.

Monocyte phagocytic white blood cell.

Monoecious angiosperms in which each plant contains both male and female reproductive structures; may be in the same flower (hermaphrodite), or in separate male and female flowers on the same plant.

Monohybrid cross genetic cross between two individuals, both heterozygous for a specific trait.

Monohybrid ratio ratio of offspring obtained by crossing two heterozygotes for a single characteristic.

Monomer basic building block of an organic compound.

Monosaccharide monomer of carbohydrates.

Monotreme egg-laying mammal.

Monozygotic (identical) twin twins resulting from separation of cells from a single fertilised egg early in embryonic development.

Morphogenesis development of form or structure during embryonic development.

Morphology external features of an organism.

Motor neuron nerve cell which transmits information from the central nervous system to an effector organ.

Mould any superficial growth of fungal mycelium, such as mildew; fungus-like organism.

Moult shedding of all or part of the outer body covering, e.g. exoskeleton of arthropods during growth; skin of snakes; feathers of birds, skin and/or hair of mammals.

Movement change of position of a whole organism, or parts of an organism relative to the whole.

Multicellular organism composed of many cells.

Multiple alleles the inheritance of a characteristic governed by more than two allelic forms, e.g. blood groups.

Multiple fission a rapid succession of cell divisions during asexual reproduction, resulting in many 'offspring'.

Multiple gene inheritance inheritance determined by multiple alleles.

Multipolar neuron nerve cell in which the impulse can flow from cell to cell in any direction.

Multipotent stem cell a partly differentiated cell that can give rise to a limited number of cell types.

Murein (peptidoglycan) glycoprotein forming the cell wall of Eubacteria.

Mutagen factor causing mutation.

Mutant gene which has undergone mutation; organism displaying a mutated gene.

Mutation change in chromosome or gene composition.

Mutualism necessary and positive association between two organisms.

Mycelium collective term for the mass of hyphae that form the vegetative part of a fungus.

Mycology study of fungi.

Mycorrhizae fungi found in mutualistic relationship with plants; they break down proteins in humus to amino acids, which are used by the plants.

Myelin sheath a fatty sheath surrounding some nerve fibres formed by Schwann cells.

Myoglobin a variety of haemoglobin found in vertebrate muscles which has a high affinity for oxygen.

Narrow-spectrum antibiotic an antibiotic that specifically acts on one or a few pathogenic bacteria.

Nastes movements made by part of a plant to a unidirectional stimulus.

Natality births.

Natural active immunity immunity developed in the body after recovery from an infection.

Natural passive immunity immunity to certain pathogens obtained by an infant from its mother.

Natural selection the process whereby some individuals of a species, having attributes which enhance their ability to survive, will be more reproductively successful than other individuals; there will thus be a tendency for these attributes to be perpetuated and less suitable attributes to be lost from the population over successive generations.

Navigation a very complex form of taxis using many stimuli (particularly celestial clues) in an animal's movement from one location to another.

Neap tide tide produced when sun and moon are out of phase.

Neck contracted, narrow region joining the anterior and posterior parts of the body.

Negative feedback a change which reverses a particular trend.

Nekton free-swimming organisms of surface waters.

Nematocyst stinging cell ejected (protection/predation) by ectoderm of Cnidaria.

Neo-Darwinism a comprehensive theory of evolution emphasising natural selection and gradualism, with populations as the fundamental units of evolutionary change.

Neotony retention of juvenile character(s).

Nephron functional unit of the vertebrate kidney.

Neritic zone shallow region of the ocean overlying the continental shelves.

Nerve a fibre (dendrite or axon) or group of fibres which carry impulses between the central nervous system and body parts.

Nerve cord/tract solid strand of nervous tissue forming part of the central nervous system.

Nerve net network of nerve cells, diffusely distributed through tissues.

Net primary production amount of energy available for herbivores in an ecosystem.

Neuromuscular junction junction between nerve and muscle cell.

Neuron nerve cell consisting of dendrite(s), cell body and axon(s).

Neutral evolution changes arising from genetic drift in small populations; have an equal chance of being adaptive or non-adaptive.

Neutral solution ionic solution containing equal number of hydrogen and hydroxide ions, with pH 7.

Neutrophil phagocytic white blood cell

Niche 'role' of an organism in a habitat.

Nitrifying bacteria bacteria that convert ammonia to nitrite and nitrite to nitrate.

Nitrogen fixation conversion of atmospheric nitrogen to nitrate by bacteria and cyanobacteria.

Node site on the stem of plants to which leaves are attached. (See also Nodes of Ranvier; Lymph node.)

Nodes of Ranvier regularly repeated constrictions of the myelin sheath of neurons between adjacent Schwann cells.

Non-associative learning change in behaviour which is not reinforced by an external stimulus.

Non-competitive inhibition permanent blockage of the active site of an enzyme to the normal molecule by a poison.

Non-cyclic phosphorylation ATP production during photosynthesis in the presence of NADPH2.

Nondisjunction failure of homologous chromosomes to separate during meiosis.

Non-essential amino acid an amino acid which is able to be synthesised by an organism.

Non-essential nutrient a nutrient which can be synthesised by an organism.

Non-infectious a disease that cannot be transmitted to other organisms.

Noradrenalin chemical secreted by nerve endings of sympathetic nerves; closely related to the hormone adrenalin secreted by the adrenal gland in the 'flight or fight' response.

Norm (set point) point at which a system can be maintained, e.g. population size for a specific environment.

Notochord internal, dorsal stiffening rod of chordates.

Nuclear transfer an artificial process where the nucleus of one cell is removed and placed in another enucleated cell.

Nuclear winter lowered global temperature resulting from the blockage of solar radiation to the earth's surface by large amounts of atmospheric particulate material.

Nuclease general term for the enzymes involved in the hydrolysis of nucleic acids.

Nucleic acid polymerase an enzyme involved in the synthesis of nucleic acid molecules.

Nucleic acids macromolecules which convey genetic information and which are built up from four different types of nucleotide; the two types are DNA and RNA.

Nucleolus found in nucleus; contains DNA, RNA and proteins; functions in ribosome production.

Nucleoplasm protoplasm within the nuclear membrane; contains DNA, RNA and proteins; involved in control of cell activities through protein production and cell division.

Nucleosome complex of eight histone protein molecules around which DNA strand is wrapped 1.75 times.

Nucleotide building block of nucleic acid composed of 5-carbon sugar, an organic nitrogen base and phosphoric acid.

Nucleus control centre of the eukaryotic cell.

Null hypothesis a hypothesis written in the negative form.

Nutrient any substance used as food by an organism.

Nutrient cycle cycling of a particular element between biotic and abiotic ecosystem components.

Nutrition the intake of specific materials by an organism to sustain life.

Obligate anaerobe an organism which cannot survive in the presence of oxygen.

Obligate parasite a parasite which cannot exist without a host.

Oesophagus part of the alimentary canal which transports food from the buccal (mouth) cavity to the stomach.

Oestrogen hormone produced by ovarian tissue, responsible for repair of uterus after menstruation and for female secondary sex characteristics.

Oestrous cycle cycle of events leading to the formation of mature ova in female mammals (except primates).

Oestrus the time at which ovulation occurs in non-primate mammals, accompanied by the secretion of fluids and pheromones; the time of mating.

Omnivore an organism that can utilise a range of nutrients; both herbivorous and carnivorous.

Oncogene a cancer-producing gene.

Oocyte stage in the development of a mature ovum.

Oogenesis formation of ova in animals.

Oogonium female gamete-producing organ in algae.

Open circulation a system where blood is not constantly contained within vessels but passes into a haemocoel.

Operant conditioning learning a voluntary response that gets a desired effect as a result of an animal's own activity.

Operator gene bacterial genes responsible for the production of enzymes which 'unzip' a particular segment of the DNA molecule for transcription.

Operculum bony covering of the gills found in bony fish.

Operon a functional unit of bacterial DNA consisting of a regulator, an operator and a structural gene.

Order subdivision of a class in the classification of an organism.

Organ group of tissues bound together to perform a particular function.

Organ of Corti structure within the inner ear containing sensory cells, each type of which responds to a particular frequency of sound vibration.

Organ system a group of coordinated organs.

Organelle membrane-bound subdivision of the cell, specialised for a specific function.

Organic compounds complex carbon compounds formed by living things; usually macromolecules.

Organism living matter, capable of independent existence, which can grow and reproduce.

Organogeny formation of organs and organ systems.

Orientation behaviour of an animal towards or away from a particular stimulus.

Origin sequence sequence of nucleotides at the beginning of mRNA indicating the start of the polypeptide coding sequence.

Osculum single opening from which water current is ejected in sponges.

Osmoconformer organism which allows the concentration of its body fluid to fluctuate with that of the external environment.

Osmoregulation the physiological regulation of water and salt concentrations within the body.

Osmoregulator organism that regulates the concentration of body fluids.

Osmosis movement of water from a region of low solute concentration to a region of high solute concentration through a selectively permeable membrane to counteract the differences in concentration.

Osmotic/water potential capacity of a solution to lose water molecules through a selectively permeable membrane.

Outbreeding a process in artificial selection where different varieties of closely related species are mated to achieve a desired characteristic.

Ova (singular ovum) female reproductive cells.

Ovary organ that produces female gametes in plants and animals.

Oviduct (Fallopian tube) passageway for ovum from ovary to uterus in female mammal; site of fertilisation.

Ovulation release of an ovum from the ovary.

Ovule macrospore-producing structure of spermatophytes.

Ovum (plural ova) female reproductive cell.

Oxidation chemical reactions which involve loss of electrons; may result from gain of oxygen or loss of hydrogen.

Oxidation–reduction reaction passing of an electron from one molecule to another during a chemical reaction.

Oxygen debt amount of oxygen required to convert lactic acid produced during a period of anaerobic respiration.

Oxygen dissociation curve graphical representation of the percentage saturation of blood with oxygen at different levels of 'environmental' oxygen.

Oxyhaemoglobin haemoglobin which is combined with oxygen.

Oxytocin hormone, produced by the posterior pituitary, which stimulates contraction of the uterus during parturition (birth).

Pacemaker a specialised region of the right atrium of the mammalian heart that determines its rate of contraction.

Palaeontology the study of fossils.

Palisade cells photosynthetic mesophyll cells, usually found below the surface of plant leaves.

Pancreas vertebrate gland near the duodenum; exocrine part secretes digestive enzymes in an alkaline fluid into the duodenum; endocrine part releases into the bloodstream hormones that control blood glucose levels.

Pancreatic duct duct leading from exocrine glands of the pancreas to the duodenum.

Pancreatic juice secretions from the exocrine portion of the pancreas.

Pandemic occurring worldwide.

Pangaea the supercontinent uniting all northern (Laurasia) and southern (Gondwana) landmasses that formed, then fragmented, during the Mesozoic Era.

Parapodia paired, bristled paddles that extend from the segments of polychaete annelids; function in respiration and locomotion.

Parasite organism which derives nourishment from another living organism (its host).

Parasitism association between organisms where one species (the parasite) is completely dependent upon the other (the host), which is usually harmed.

Parasympathetic nervous system section of the autonomic nervous system involved in the unconscious control of body organs.

Parazoa multicellular animals with no true tissues; phylum Porifera.

Parthenogenesis formation of offspring from unfertilised ovum.

Partial anaerobe organism which can undergo a period of anaerobic respiration when oxygen supplies are depleted or in short supply.

Partial metamorphosis the development of a larval form which mostly has features similar to the adult, but in undeveloped form.

Parturition birth process.

Passive transport movement of materials in and out of the cell without the expenditure of energy.

Pathogen any organism capable of causing infection in another organism.

Peg root upwardly projecting roots produced by plants growing in anoxic soils (e.g. mangroves); function in gas exchange with the air.

Pelagic describes large, actively swimming animals found at the ocean surfaces.

Pelagic zone area of the ocean beyond the continental shelf.

Pelvis the funnel-shaped expansion of the ureter before it leaves the kidney; bony girdle supporting the hind limbs of tetrapod vertebrates.

Penis male intromittent organ in mammals.

Pentadactyl describes limb structure of tetrapod vertebrates: hind limb composed of femur, tibia and fibula, tarsals and five toes; forelimb composed of humerus, radius and ulna, carpals and five fingers. Fusion and loss of some elements occurs in some species.

Pentameric symmetry symmetry around five axes; secondarily acquired in echinoderms.

Pepsin enzyme which hydrolyses many proteins to polypeptides.

Pepsinogen inactive precursor of pepsin.

Peptidase the general term for enzymes that hydrolyse peptide bonds to release amino acids.

Peptide bond bond formed from condensation between two amino acids, where hydrogen (H) is lost from the amino group and an hydroxyl group (OH) from the carboxyl group.

Pericardium membranes forming a cavity around the vertebrate heart.

Periodontal fibres fibrous tissue loosely connecting the teeth to the jawbone in mammals.

Peripheral nervous system nerves between effectors/receptors and CNS; subdivided into somatic (outer body tube) and visceral (inner body tube).

Peripheral proteins proteins attached to or partially embedded in the cell membrane.

Peristalsis waves of contraction and relaxation in muscular walls of the alimentary canal, aiding in mechanical digestion and moving food forward through its length.

Persistence length of time a measurable chemical residue remains in the environment.

Pest an organism that causes direct or indirect harm to humans or their resources; an organism in the 'wrong' place.

Pesticide chemical used to kill animal pests.

Petal a modified leaf, usually brightly coloured and conspicuous, forming part of the corolla of a flower.

Petiole leaf-stalk.

pH the concentration of hydrogen ions in a solution, measured on a logarithmic scale ranging from 0 to 14.

Phagocytosis engulfing of solid material by a cell through extension of the cell membrane over it, and formation of a food vacuole; especially in Protozoa and some white blood cells; means 'cell eating'.

Pharynx in mammals, the back of the throat where glottis and oesophageal opening occur; in animals such as fish the pharynx refers to the area encompassed by the gill slits.

Phenotype actual expression of the genotype.

Phenylketonuria a homozygous recessive genetic disease in which one enzyme required for the normal break-down of phenylalanine is lacking. Accumulation of this amino acid and its abnormal waste products affects the developing nervous system and ultimately results in death.

Pheromone a hormone released as an external signal to other members of the species.

Phloem a complex tissue composed of living and dead cells; functional unit consists of sieve element and companion cell. Sieve tubes (composed of sieve elements end-to-end) provide the route for the movement of organic solutes in vascular plants.

Phosphorylation addition of a phosphate group to a molecule. Can be non-cyclic (e.g. formation of ATP) or cyclic (e.g. cyclic flow of electrons along electron transport chain from chlorophyll, the energy release being used in the formation of ATP).

Photochemical smog secondary pollutant produced by chemical reaction between nitrogen oxides and hydrocarbons in the presence of sunlight.

Photoperiodism regulation of flowering in response to day length.

Photoreceptor an organ for detecting light.

Photosynthesis process whereby radiant energy (visible spectrum) is converted to chemical energy of glucose; requires chlorophyll, carbon dioxide, water and a suitable temperature. Occurs in green plants, algae and some bacteria.

Photosystem the light-harvesting unit in photosynthesis located on the grana of the chloroplast.

Phototropism growth in response to light.

Phyllode laterally compressed petiole; foliage 'leaf' that replaces true leaves in most Australian acacias.

Phylum major classification group of the animal kingdom.

Physical (mechanical) digestion breakdown of food into small units by crushing or cutting actions of teeth, mandibles, muscles etc.

Physiological drought condition experienced due to inability to use available water (e.g. freezing of soil water, brackish water).

Physiology study of the way in which organs and systems operate within an organism.

Phytochrome blue plant pigment which absorbs red light.

Phytoplankton small aquatic plants; plant plankton.

Pinna outer ear of mammals; primary division of a leaf.

Pinnule secondary division of a leaf pinna.

Pinocytosis formation, by the cell membrane, of channels that take in fluid at their base; means 'cell drinking'.

Pioneer species species of plants that colonise bare ground.

Placenta tissues formed by embryo and mother which act as a diffusion channel between the two, providing food and oxygen from mother and an avenue for release of wastes from the embryo.

Plankton small organisms found in surface waters, often with limited locomotory powers (drifters and floaters).

Plantae multicellular, eukaryotic, photosynthetic organisms which are generally found living on land.

Plasma fluid part of the blood, composed of serum (water in which proteins and dissolved substances are suspended) and fibrinogen.

Plasma cells cells that produce and secrete antibodies; originate from division of B-lymphocytes in response to the presence of an antigen.

Plasmid small pieces of DNA found in bacterial cells.

Plasmodesmata cytoplasmic bridges between plant cells.

Plasmodium multinucleate mass of material in slime moulds.

Plasmolysis contraction of cytoplasm of a plant cell as a result of osmosis out of the cell.

Plastids organelles in plant cells bound by double membrane; the three types are leucoplasts, chromoplasts and chloroplasts.

Plate tectonics modern geological theory recognising that the earth's crust and part of the upper mantle are divided into a number of plates that move relative to one another.

Platelet cell fragments found in the blood, which are involved in the clotting process.

Pleural cavity potential space surrounding each lung in mammals, bound on all sides by pleural membranes.

Pleural membranes membranes surrounding all sides of the pleural cavity.

Plumule embryonic shoot of plant.

Pluripotent stem cell partly differentiated cells that can give rise to a variety of different types of cells but not a complete organism.

Pneumatophore specialised breathing root, typical of mangroves and other plants in anoxic soils.

Polarised a condition in which there is an unequal distribution of charges between two points (e.g. inside and outside the cell membrane).

Polarity charge on a molecule resulting from uneven distribution of electrons.

Pollen grain male gametophyte in division Spermatophyta.

Pollen tube tube, formed on germination of the pollen grain, that carries the male nuclei to the eggs.

Pollination transfer of pollen from anther to stigma; may be dispersed by wind and water or aided by animals.

Pollution introduction into the environment of substances which have direct or indirect adverse effects on it.

Polygenes a set of genes which together control a quantitative character such as height.

Polymer macromolecule formed by the union of many monomers.

Polymerase chain reaction selective and repeated replication, in vitro, of segments of DNA.

Polymorphism having several different forms.

Polyp sedentary form of members of the phylum Cnidaria.

Polypeptide polymer of many amino acids bonded together.

Polyploidy having three or more times the haploid number of chromosomes.

Polysaccharide complex carbohydrate composed of many monosaccharides bonded together.

Polysome chain of ribosomes which 'read' mRNA.

Population density number of an individual species living in a particular place at a particular time per unit area.

Population growth increase in the size of a population in a particular habitat over time.

Population number of individuals of a species living in a particular place at a particular time.

Portal vein blood vessel which begins and ends in a capillary bed; acts as a short circuit between two organs.

Positive feedback a physiological control mechanism in which a change in some variable triggers mechanisms which amplify the change.

Posterior hind end.

Post-synaptic element the membrane of the structure (e.g. a dendrite) to which an impulse is transferred across a synapse.

Potential energy stored energy.

Predation feeding of one organism (predator) on another (prey).

Predator an organism that captures, kills and feeds on another animal.

Prediction forecast of a future event based on similar known events.

Pregnancy state in which a female mammal is carrying a developing young in the uterus.

Premolar front cheek teeth of mammals, adapted for specific diet.

Pre-synaptic element the axonic knob and its membrane, from which an impulse will pass across a synapse.

Primary culture a sheet of cultured cells, one cell thick, grown on an artificial medium.

Primary follicle a single layered structure in the mammalian ovary containing the primary oocyte.

Primary growth result of cell division, elongation and maturation of apical meristems of plants; produces elongation of the plant.

Primary oocyte a diploid cell developed by an ovarian germ cell in mammals that may later develop into an ovum.

Primary pollutant substance which has a direct adverse effect upon the environment.

Primary protein structure linear sequence of amino acids in a polypeptide chain.

Primary succession development and change in plant communities over time, leading eventually from bare ground to a climax community.

Principle of segregation Mendelian law which states that genes for a characteristic occur in pairs in an individual, one inherited from each parent, and are separated when the reproductive cells are formed.

Prion a particular protein produced by the brain.

Producer (autotrophic) organism forming the base of all food chains; converts simple inorganic chemicals into complex organic molecules (food).

Product rule a law of probability, stating that the chance of two independent events occurring together is equal to the chance of one event occurring alone multiplied by the chance of the other event occurring alone.

Productivity amount of energy fixed in organic compounds; measured by increase of biomass per unit time.

Progesterone female hormone, produced by corpus luteum, which functions in tissue and capillary development in the uterus in preparation for pregnancy; inhibits FSH and LH production.

Proglottid section of a tapeworm which breaks off from the body when mature.

Progressive selection selection for a variant of a characteristic, shifting the mean for that characteristic in a new direction; results from changes in the environment.

Prokaryote organism (Archaea and Eubacteria) without a membrane-bound nucleus or organelles.

Prolactin hormone secreted by anterior pituitary which brings about milk production.

Prop root (stilt root) adventitious root, arising from the trunk of a tree, which functions in support.

Prophase initial stage in mitosis and meiosis in which the chromatin condenses into chromosomes composed of chromatids and the spindle is formed; in meiosis, chromatids also undergo pairing to form tetrads.

Prostaglandins a group of modified fatty acids secreted by virtually all tissues and functioning as messengers.

Prostate gland gland in the male mammalian reproductive system contributing a nutritive fluid medium to the semen.

Protein macromolecules, consisting of one or more polypeptide chains, which may be folded, branched and/or cross-linked at intervals.

Prothallus small, heart-shaped gametophyte of the division Pteridophyta.

Protista (protists) a classification group into which are placed all organisms other than the prokaryotes, plants, fungi and animals.

Protonema thread of cells produced by germinating spores in the division Bryophyta.

Protoplasm living matter.

Protoplast artificially cultured plant cells in which the cell walls have been removed.

Protozoa unicellular animal-like protists.

Proximal convoluted tubule tubule of the kidney nephron arising from Bowman's capsule and leading to the loop of Henle; responsible for the reabsorption of glucose, sodium chloride and water.

Pseudocoelom body cavity bound by mesoderm on one side only; characteristic of the phylum Nematoda.

Pseudopodium (plural pseudopodia) extension of the cell to form a leading edge in locomotion in some Protozoa and mobile cells; means 'false foot'.

Puberty human developmental stage at which the individual becomes sexually mature.

Pulmonary circulation circulation between the heart and the respiratory surfaces.

Pulp connective tissue, blood vessels and nerves found within the central cavity of the mammalian tooth.

Punnett square mathematical device used to calculate probabilities of genetic crosses.

Pupil opening, surrounded by the iris, at the front of the eye.

Pure breeding an individual that is homozygous for a particular characteristic.

Pure culture a culture of organisms of one type only.

Pyloric sphincter muscular ring at the base of the stomach, controlling the movement of chyme from the stomach to the duodenum.

Pyramid bundle of collecting ducts in mammalian kidney.

Pyramid of biomass a model of the amount of living matter transferred through a food chain.

Pyramid of energy a model of the amount of energy transferred through a food chain.

Pyramid of numbers a model of the numbers of organisms at each trophic level of a food chain.

Qualitative descriptive.

Quantitative measured.

Quaternary protein structure structure resulting from cross-bonding of several polypeptide chains.

Race (subspecies) one group of a population which is genetically different from other groups as a result of different ranges.

Rachis main axis of an inflorescence; axis of a pinnately compound leaf to which the pinna are attached; axis of fern frond.

Radial symmetry body plan in which a cut lengthwise through the middle in any direction produces two halves which are mirror images.

Radiant energy energy emitted as radiation, e.g. energy released from chemical reactions within the sun.

Radical polyatomic ion which acts as a single unit in chemical reactions.

Radicle embryonic root of plant.

Radioactive decay the release of particles and energy from the nucleus of unstable isotopes of a chemical element.

Radioactive isotope an unstable isotope which decays over time to a more stable form with the emission of radiation.

Radula rasping, tongue-like structure of animals in the phylum Mollusca.

Rainforest a plant community found in tropical, subtropical and temperate regions with suitable soils where annual rainfall is high and there is a long growing season.

Random sampling sampling of a factor which is unbiased and implies that each measurement has an equal chance of being selected as a part of the sample.

Range the geographic area in which a population lives.

Receptacle swollen top of flower stalk from which whorls originate and which supports the flower.

Receptor structure able to detect stimulus.

Recessive trait allele which can be masked by the dominant allele in the heterozygous condition expressed in the homozygous condition.

Recognition site specific protein on a cell membrane which has an affinity for a particular chemical.

Recombinant DNA DNA formed from the combination of genes from different sources.

Recombination gametes gametes produced as a result of crossing-over of the chromatids of homologous chromosomes during meiosis.

Recovery period the time interval between successive nerve impulses during which the neuron membrane is restored to its resting potential.

Rectum terminal part of alimentary canal where faeces are compacted and stored.

Red blood cell (erythrocyte) cell, found in the blood, specialised for the transport of respiratory gases by the inclusion of the pigment haemoglobin; enucleate in mammals.

Reduction reaction resulting in a gain of electrons; may be through loss of oxygen or gain of hydrogen.

Refactory period time taken for repolarisation of nerve or muscle membranes after the passage of an impulse.

Reflex arc the nervous pathway along which impulses pass from sensory to motor nerves, with little or no coordination by the central nervous system, leading to a reflex behaviour to a specific stimulus.

Regeneration regrowth of parts of certain organisms that are lost due to injury.

Regulator gene a prokaryotic gene that synthesises mRNA to bring about the production of repressor proteins.

Renal artery blood vessel entering the kidney.

Renal vein blood vessel leaving the kidney.

Rennin an enzyme produced in stomach to hydrolyse milk proteins.

Repetitive sequences sequences of DNA in the eukaryote chromosome which act as spaces between genes.

Repressor a protein that links with the prokaryote operator gene, preventing the activation of the structural gene.

Reproduction production of new individuals through coded messages from the parent organism(s).

Reproductive isolation inability of different populations or species to successfully interbreed due to behavioural, structural or physiological features of the organisms.

Reservoir pool large abiotic component of biogeochemical cycle in which matter is only slowly exchanged with organisms.

Residual volume volume of air which remains in the lungs at all times.

Resistant strain a population of an organism resistant to a particular environmental feature.

Resource partitioning division of environmental resources by coexisting species populations such that the niche of each species differs from all others by at least one significant factor.

Respiration cellular process in which glucose is broken down to release energy.

Response reaction of an organism to a particular stimulus.

Resting potential polarised state of neuron membrane due to a sodium pump, resulting in the inside of the membrane being negative relative to the outside.

Restriction nuclease enzyme capable of cutting a DNA molecule at a particular site.

Resurrection plant plant whose cells can be effectively dehydrated and which resume normal functioning when water is available.

Reticular activating system a neural pathway of the mammalian brain which acts as a sensory filter that relays significant information to the cortex; functions in arousal and conscious awareness.

Reticular formation diffuse network of neurons in the brain stem.

Retina light-sensitive layer lining the interior of the vertebrate eye, except at the front.

Rhizoids hyphae specialised for anchoring fungi to the substratum; root-like in structure.

Rhizome modified underground stem, e.g. couch; stem in ferns.

Rhythmic behaviour internally controlled, cyclic behaviour.

Ribonucleic acid (RNA) single-stranded nucleic acid characterised by a ribose sugar in each nucleotide, and the bases adenine, uracil, cytocine and guanine.

Ribosome composed of RNA; produced in nucleolus and found on rough ER or free in cytoplasm; site of protein synthesis in cell.

Right atrium chamber of the tetrapod heart that receives deoxygenated blood from the vena cavae.

Rod a type of light-sensitive nerve cell found in the retina of the vertebrate eye; does not discriminate fine detail but is sensitive to dim light.

Root the part of vascular plants that usually grows downwards into the soil, anchoring the plant and absorbing water and dissolved mineral nutrients; point of attachment of the mammalian tooth to the jawbone.

Root cap protective tissue covering a root tip.

Root cluster group of rootlets forming a dense mat at the soil surface.

Root hair tubular outgrowth of an epidermal cell of the root, which increases the surface area of intimate contact between the root and the soil particles; main area for absorption of water and dissolved mineral ions.

Root nodules small swellings on roots of leguminous plants, produced as a result of infection by nitrogen-fixing bacteria.

Root pressure pressure exerted on water in the roots of plants due to the continued uptake of water from the soil by osmosis; forces water a certain way up the stem of the plant until counteracted by the force of gravity.

Root tuber expanded storage area of a root, capable of vegetative reproduction.

Ruling hypothesis the most successful hypothesis of a particular investigation.

Runner modified above-ground stem, e.g. strawberry.

Sacculus part of the organ of balance found just above the inner ear.

Salinity relative salt concentration of water.

Saliva fluid secreted into the mouth; in mammals, contains mucus and the enzyme amylase.

Salivary glands glands which secrete saliva into the buccal cavity.

Salt neutral metallic compound.

Salt excluder a halophytic plant capable of preventing uptake of salts through its roots.

Salt excretor a halophytic plant which excretes excess salts from special tissues.

Sapwood outer region of xylem in tree trunks which actively conducts water and dissolved mineral nutrients.

Satellite DNA DNA which is located at the centromere and appears to function in replication and nuclear division.

Saturated compound a compound in which only single electrons are shared between any two atoms in the compound.

Savanna a tropical grassland biome with scattered individual trees.

Scavenger an animal that eats a variety of already dead organisms.

Schwann cell cell, rich in fats, which ensheaths peripheral nerve fibres.

Science word derived from Latin, meaning 'to know'; a discipline using a method of investigation to verify hypotheses.

Scientific method testing of hypotheses by controlled experimentation.

Sclerophyte plant with hard leaves.

Scrotum (scrotal sac) sac-like external structure containing the testes of mammals.

Second law of thermodynamics states that every energy transformation results in reduction of the free energy of the system.

Secondary growth growth as a result of cell division, elongation and maturation of cambium or lateral meristems, producing increased girth of plants.

Secondary pollutant a pollutant formed as a result of the interaction between wastes and the environment.

Secondary protein structure folding of a polypeptide chain, e.g. as a helix or pleated sheet.

Secondary succession successive, natural changes in plant communities in an area where a previous community has been removed.

Secretin hormone, produced in the wall of the small intestine, which stimulates release of digestive juices from the pancreas.

Sediment matter which settles out to the bottom of a liquid.

Sedimentary rock a rock formed by compaction and hardening of sediments.

Seed structure formed from the development of the ovule in gymnosperms and angiosperms after fertilisation.

Segmentation repetition of a pattern of the main organ systems of the body along the antero-posterior axis of the body, producing a series of units called segments with fundamentally similar structure.

Self-fertilisation fusion of male and female gametes from the same individual.

Self-pollination transfer of pollen from the anther to the stigma of the same flower, or to the stigma of another flower on the same plant.

Semen fluid ejaculated from male mammal, containing spermatozoa, water and nutrients.

Semilunar valve valve, found at origin of artery in heart, that prevents backflow of blood from the heart during diastole.

Seminal vesicles glands of mammalian male reproductive system; supply nutritive fluid to the semen.

Seminiferous tubules tubules of testes, in which spermatogenesis occurs.

Semipermeable (differentially permeable) describes a barrier, such as the cell membrane, which allows the diffusion of some molecules but not others.

Senescence aging; progression of irreversible change in a living organism, eventually leading to death.

Senility decreased mental competence.

Sensory adaptation temporary accommodation to a particular stimulus.

Sensory neuron a nerve cell which carries information from a receptor to the central nervous system.

Sepal a leaf-like, usually green, part of the calyx of dicotyledonous flowers.

Septum (plural septa) partition between different parts of the body.

Sertoli cells cells in the epithelium of seminiferous tubules of the mammalian testis which protect and nourish the developing spermatozoa.

Serum plasma minus fibrinogen.

Seta stalk of the sporangium in mosses and liverworts; bristle or 'hair' of invertebrates.

Sex chromosomes chromosomes carrying information which determines the sex of the individual.

Sex-influenced gene an autosomal gene, the expression of which is influenced by the sex of the individual.

Sex-limited gene an autosomal gene, the expression of which is limited to a particular sex.

Sex-linked genes genes on the X chromosome.

Sexual reproduction reproduction involving combination of genetic material derived from two individuals of the same species, through fusion of specialised sex cells (gametes); results in genetic variation in offspring.

Short-day plants plants that will flower only if they experience uninterrupted darkness for a particular time period.

Sickle cell anaemia recessive human genetic disease in which the red blood cells have an abnormal shape and thus cannot carry the normal complement of haemoglobin.

Siltation the accumulation of fine sediments in a body of water.

Simple (chemical/molecular) formula a representation showing the number and kinds of atoms in a compound.

Simple diffusion unaided movement of molecules or ions across a differentially permeable membrane along a concentration gradient.

Single circulation type of circulation where blood passes through the heart only once, and there is no separate pulmonary circulation.

Sino-atrial node (pacemaker) tissue which is stimulated by the autonomic nervous system and controls the rate of contraction of the heart.

Sinus venosus thin-walled chamber of the heart of fish and amphibians, lying between the veins and atria.

Skin breathing gas exchange across the general body surface.

Slime mould protist which at some stages of its life cycle is animal-like and at others resembles a fungus.

Small intestine major region of digestion and absorption in the vertebrate alimentary canal.

Social behaviour behaviour in which there is some form of interdependence between individuals.

Social hierarchy an order of dominance among animals which live in close relation, e.g. flocks and herds.

Sodium pump a special transport protein in the membrane of animal cells that transports sodium out of the cell, and potassium into it, against their concentration gradients.

Solute a substance that is dissolved in a solution.

Solution a homogeneous mixture of two or more substances.

Solvent the dissolving agent of a solution.

Somatic cell any cell in a multicellular organism that is not a male or female reproductive cell.

Somatic cell gene therapy technique by which normal alleles are inserted into cells affected by a defective allele.

Somatic mutation genetic alteration in a non-reproductive cell.

Somatic nerves nerves that are associated with the tissues of the outer body tube (outside the body cavity).

Somatic tissues tissues other than those associated with the viscera and blood vessels — make up the outer body tube.

Sorus cluster of sporangia on underside fern fronds.

Southern blotting a technique using DNA hybridisation and gel electrophoresis to obtain a DNA fingerprint.

Special creation doctrine claiming that all species were created separately and the numerous descendants survived through time in unaltered form.

Species taxonomic group, allocated two (genus and specific) names; members of a group of actually or potentially interbreeding natural populations that are reproductively isolated from other populations.

Specific name the descriptive name of a species.

Spermatocyte cell from which spermatozoa are formed.

Spermatogenesis formation of spermatozoa in animals.

Spermatophore small packet of sperm produced by some animals having internal fertilisation.

Spermatozoon (plural spermatozoa) small, motile, usually flagellated male gamete.

Sphincter muscular ring in a canal or duct controlling the flow of matter through it.

Spicules mineralised structures which support sponges and sea cucumbers.

Spinal cord the part of the vertebrate central nervous system within the backbone.

Spinal nerve nerve entering or leaving the spinal cord.

Spindle series of protein threads formed in the cytoplasm and spanning the length of the cell during cell division; site of attachment of the chromosomes.

Spiracle opening of the tracheal tubes of insects.

Spirilla corkscrew-shaped bacteria.

Split gene eukaryote gene composed of sections of coding DNA (exons) separated by non-coding DNA (introns).

Sponge a multicellular animal, belonging to the phylum Porifera, which does not develop true tissues; the cleaned skeleton of some members of the phylum Porifera.

Spontaneous generation theory theory (now obsolete) that organisms form spontaneously from non-living matter.

Sporangiophore hyphae specialised to bear the spore-producing sporangium.

Sporangium (plural sporangia) spore-producing structure of division Zygomycota and plants.

Spore usually microscopic reproductive structure produced in vast numbers by protists, fungi and plants; dormant phase of bacteria.

Sporophyll modified leaf which bears sporangia.

Sporophyte diploid phase in the plant life cycle that produces haploid spores by meiosis.

Sporophyte generation multicellular, diploid plant.

Sporozoite spore stages in the life cycle of the malaria-causing *Plasmodium* within the mosquito vector.

Spring tide tide formed when sun and moon are in phase and thus bringing about a combined gravitational pull, resulting in a greater distance between high and low tides.

Stabilising selection selection for a particular variant (mean) of a characteristic which maintains constancy in a population; occurs in times of environmental stability.

Stamen male reproductive structure of flower, consisting of filament (stalk) and pollen-producing anther.

Standing crop biomass of an organism at any particular moment.

Stapes one of three bones in the middle ear that transmits sound.

Statolith solid inclusion of a cell or organ free to move under the influence of gravity.

Steady state theory a theory of evolution asserting that the earth and all its organisms had no origin; that what is now always was.

Stem cell an undifferentiated or partly differentiated cell that has the potential to grow into other types of cells.

Stepped (punctuated) evolution a theory of evolution suggesting that there were spurts of relatively rapid change followed by long periods of stability.

Stereotyped behaviour innate animal behaviour which is specific to a particular species and situation.

Sterilise to destroy all organisms; to perform an operation to prevent reproduction by an organism.

Sticky end unpaired nucleotide sequences on a piece of cut DNA.

Stigma the sticky tip of the carpel, in a flower, that receives pollen.

Stilt root root (prop root) adventitious root, arising from the trunk of a tree, which functions in support.

Stimulus change in the environment of an organism that brings about a response.

Stipe stalk of fruiting bodies of certain higher fungi; stalk of thallus of brown algae.

Stolon modified above-ground stem, e.g. blackberry; hypha of fungus, which grows along the surface of its food supply.

Stoma (plural stomata) pore in leaf epidermis, bound by guard cells; allows gas exchange and transpiration.

Stomach sac-like part of the alimentary canal, in which proteins are digested in acid conditions and where there is a large amount of mechanical digestion. Also acts as a storage area so that large amounts of food can be eaten quickly and digested later; sterilises food by destruction of microorganisms.

Stomatolite rock made of hardened bands of sediments in which are found primitive cyanobacteria.

Stratification presence of layers, e.g. the community of plants in a forest.

Stroma fluid matrix in the chloroplast, containing enzymes for light-independent reactions of photosynthesis.

Structural formula a formula that shows the number, types and spatial arrangement of atoms in a molecule of a compound.

Structural gene a gene that codes for a particular polypeptide sequence.

Style tubular structure which links stigma to ovary.

Sublittoral describes zone just below low tide level, permanently covered with shallow water.

Subspecies (race) one group of a population which is genetically different from other groups as a result of different ranges.

Succession change in the species composition of a biological community over a period of time, resulting from alteration of abiotic conditions by the previous species.

Succulent type of xerophytic plant that stores water within its tissues.

Sucker a modified plant stem used in vegetative reproduction, e.g. mint.

Sucrase the enzyme that hydrolyses the disaccharide sucrose.

Superior above.

Supralittoral describes zone just above high tide level, which is affected by splash from waves.

Surface tension strong attraction between molecules at the surface of a liquid.

Symbiont an organism in a symbiotic relationship.

Symbiosis living together; a relationship in which two organisms live in close association.

Sympathetic nervous system division of the autonomic nervous system involved in the unconscious control of organs.

Sympatric species species that have evolved intrinsic isolating mechanisms, preventing interbreeding with other closely related species in the same habitat.

Synapse the position where two adjoining neurons meet.

Synaptic cleft the space between the elements in a synapse.

Synaptic fatigue the condition that occurs when no more transmitter substance is available to transmit an impulse across a synapse.

Synaptic knob axonic end of a synapse.

Synaptic vesicles vesicles within the synaptic knob containing transmitter substance.

System group of organs associated to perform a particular function.

Systemic circulation circulation of blood throughout the general body.

Systole contraction of the heart muscles.

Systolic pressure pressure of blood in arteries resulting from contraction of the ventricles.

Taiga evergreen forest biome characterised by considerable snowfall, harsh winters and short summers.

Tap root major single root, usually penetrating deep into soil, which may be expanded as a food reserve and develops from the radicle of the seed.

Taxis movement made by whole or part of an organism (e.g. sperm), directed in relation to a stimulus.

Taxonomy science of classifying things.

Tay-Sachs disease human genetic disease, caused by a recessive allele, leading to inability to move and eventually death.

T-cell lymphocyte that is modified as it passes through the thymus gland; involved in the immune reaction.

Telomere DNA sequence that occurs at the ends of eukaryotic chromosomes.

Telophase terminal stage of nuclear division.

Temperate deciduous forest a plant biome found in temperate regions, characterised by leaf fall over winter.

Temperature a measure of the amount of heat energy conducted from one object to another.

Temperature coefficient refers to the doubling of a chemical reaction rate for every $10^{o}C$ rise in temperature, up to the optimum temperature for that reaction.

Temperature inversion trapping of a cooler layer of air in the atmosphere under a warm layer, preventing the dispersal of heat and other pollutants; a similar situation occurs in deep, still water areas.

Terminal growth growth of a plant from the tips of stems, branches and roots.

Terminus sequence nucleotide sequence indicating the end of a coding pattern.

Territorial behaviour social response of defence of a specific area against other individuals.

Territory area defended by an animal.

Tertiary protein structure proteins with globular shape resulting from bonding between R groups of the secondary structure.

Test cross a cross between an organism displaying the recessive trait of a characteristic and one showing the dominant trait, to determine whether the dominant phenotype is due to a homozygous or heterozygous genotype.

Testis male gamete-producing organ in animals.

Testosterone hormone produced in the testes and responsible for male secondary sex characteristics.

Tetrad homologous chromosomes, each consisting of two chromatids, lying side by side.

Tetrapod terrestrial vertebrate with a four-legged body plan.

Thalloid describes a plant with no specialised roots, stems or leaves.

Thallus the entire body of a lichen, alga or liverwort.

Theory amalgamation of several ruling hypotheses to explain a general concept.

Therapeutic cloning cloning an embryo from an adult cell in order to obtain stem cells that could be used to treat that adult.

Thermotropism growth in response to temperature.

Thigmotropism growth in response to touch.

Thorax in terrestrial vertebrates, the region of the body containing the heart and lungs; in insects, the three fused segments behind the head from which arise three pairs of legs.

Threshold stimulus minimum stimulation required to initiate a nerve impulse.

Tidal volume volume of air moving in and out of the lungs during normal breathing.

Tide movement of water in response to the gravitational pull of the moon and sun.

Tight junction a type of intercellular junction that prevents the leakage of materials between animal cells.

Tissue group of similar cells with specialisation for a particular function.

Tissue culture a technique for maintaining and growing fragments of plant or animal tissues, or separated cells, after their removal from the organism.

Tissue fluid fluid formed from plasma pushed out through the walls of capillaries under arterial pressure; surrounds cells, providing a medium for exchange between the blood and cells.

Topography surface land features of a locality.

Torpor physiological state of an animal in which the metabolism is decreased and the body temperature is maintained at a lower level than normal.

Totipotent cell a cell that has the potential to grow into any other type of cell.

Toxin by-product of metabolism which is poisonous to another organism.

Trachea 'windpipe'; the tube which conveys air from the pharynx to the bronchi.

Tracheal tubes system of tubes, found in insects, in which gases are conveyed between the external environment and the cells.

Tracheid xylem cell with perforated end walls.

Tracheole terminal branch of the trachea of insects, pervading all the tissues and though which gas exchange occurs.

Transamination transfer of an amino group from one chemical to another.

Transdifferentiation the artificial transformation of one cell type into another.

Transect a measured length or strip of terrain in an environment along which individual organisms or environmental parameters are recorded.

Transfer RNA (tRNA) ribonucleic acid which conveys a specific amino acid to a complementary site on mRNA during polypeptide formation.

Transformation alteration of the genetic composition of an organism by deliberate insertion of a gene from another organism.

Transgenic describes a cell or organism which has had its genetic composition deliberately altered.

Translation production of a polypeptide sequence from an mRNA codon.

Translocation movement of organic solutes in the phloem in any direction; chromosome aberration in which a segment of DNA has been moved to another chromosome.

Transmitter a means of conducting communication, essentially chemical in nature, be it a hormone or a substance released at the ends of nerve cells.

Transpiration evaporation of water from the stomata of leaves.

Transpiration stream the water column from the roots of the plant to the intercellular spaces of a leaf.

Transpirational check any factor that will decrease transpirational water loss.

Transport system a system of vessels responsible for the movement of materials through an organism.

Transposon (jumping gene) transposable elements of eukaryotic DNA which can be replicated and the copy inserted into another location.

Transverse section a thin slice of an organism cut perpendicular to its long axis.

Trial-and-error learning a form of conditioning which may be externally or internally motivated; the animal learns by its mistakes after repeated attempts.

Tricuspid valve atrioventricular valve between right atrium and ventricle, with three flaps; prevents back-flow of blood into the atrium when the ventricle contracts.

Trimming the removal of extra nucleotide sequences at the beginning and end of an mRNA molecule before it leaves the nucleus.

Triploblastic describes body organisation of an animal based on three primary germinal cell layers: endoderm, mesoderm and ectoderm.

Trophic level a feeding level in a food chain, e.g. producer, herbivore.

Tropic hormones hormones which bring about changes in growth patterns.

Tropism directional growth movement.

Trypsin enzyme, secreted into the duodenum, which hydrolyses proteins to polypeptides.

Trypsinogen inactivated form of trypsin.

Tubal ligation the tying or removal of a section of the oviduct in human female sterilisation.

Tube foot hollow structures on the underside of echinoderms that are extensions of the water vascular system, used in locomotion, food getting and gas exchange.

Tube nucleus one of the nuclei produced in the pollen grain, controlling the growth of the pollen tube through the tissues of the stigma.

Tuber modified underground stem (e.g. potato) or modified root (e.g. dahlia).

Tundra a biome found at the northernmost limits of plant growth or at high altitude; characterised by low shrubs and mat-like vegetation.

Turgor pressure pressure exerted on plant cells due to presence of cell wall.

Turner syndrome a series of symptoms associated with nondisjunction of the sex chromosomes resulting in XO females.

Tympanic membrane membrane separating the external and middle ear that vibrates at the same frequency as the air in the outer ear and so transmits sound.

Ultrafiltration removal of most of the plasma and its contents from a capillary under high pressure, e.g. in the kidney.

Ultrasonography use of reflection of high-frequency sound waves to detect anomalies.

Ultrasound high-frequency sound waves.

Umbilical cord allantoic stalk connecting fetus to placenta.

Unconditioned reflex a response to a known stimulus.

Unipolar describes neurons in which the impulse passes in one direction only.

Universal donor a person with type O blood which has no antibodies to antigens A and B, thus this blood can be donated in small quantities to individuals of all other blood groups.

Universal recipient a person with type AB blood which has both A and B antigens, and so can receive small quantities of all other blood groups.

Unlimited growth growth of an organism which continues until death.

Unsaturated compound a substance in which two or more electrons are shared between adjoining atoms in a molecule.

Upwelling upward movement of deep water to replace warm surface water as it is moved by currents.

Urea a water-soluble, nitrogenous excretory product of protein breakdown.

Ureotelic describes animals that excrete urea as a nitrogenous waste.

Ureter duct which leads from the kidney to the bladder.

Urethra tube running from bladder to exterior; in females functions to eliminate urine; in males the vas deferens joins the urethra, which therefore functions in elimination of semen as well as urine.

Uricotelic describes animals that excrete uric acid as a nitrogenous waste.

Urine excretory fluid produced in the kidney containing metabolic wastes (urea, salts) in a watery solution.

Uterus (womb) muscular expansion of the female reproductive tract in which, in mammals, the embryo develops.

Utriculus part of the organ of balance found just above the inner ear.

Vacuole cellular inclusion; small in animals (food storage and/or digestion); large in plants (storage and osmotic control).

Vacuum activity the release of a behaviour pattern without the appropriate sign stimulus.

Vagina muscular duct of the female mammal, opening to the exterior, which receives the penis during copulation.

Valency the number of electrons lost, gained or shared by an atom in forming a stable molecule or compound.

Variable factor (experimental variable) the single factor under investigation in a controlled experiment.

Variety a group which distinctly differs from other varieties within the species, e.g. a poodle and a Great Dane.

Vas deferens tube linking epididymis to urethra in mammals.

Vascular bundle longitudinal strand of conducting vessels in plants, consisting of xylem and phloem.

Vascular cambium undifferentiated tissue between the xylem and phloem, responsible for secondary growth through the production of new xylem and phloem.

Vasectomy removal of a section of the vas deferens in human male sterilisation.

Vector an external agent involved in the transfer of an organism or part of an organism from one individual to another.

Vegetative reproduction form of asexual reproduction in plants, involving modified stems, roots and leaves.

Vein blood vessel which begins in a capillary bed and enters the heart; vascular bundle of a leaf.

Venom a poisonous fluid injected from one organism into another.

Ventilation body movements which result in the passage of air over respiratory surfaces.

Ventral the lower surface of a bilaterally symmetrical animal.

Ventricle muscular chamber of the heart which receives blood from atrium and pumps it out through arteries under pressure.

Venule vessel which directly connects capillaries to veins.

Vernalisation control of flowering by a prerequisite period of cold.

Vertebra (plural vertebrae) individual bone of the vertebrate backbone, through which the spinal cord runs.

Vertebrate an animal with a backbone and cranium.

Vertical stratification presence of different canopy levels within a plant community.

Vertical zonation distribution of organisms in zones along a vertical gradient of environmental conditions.

Vestigial organ reduction of a particular structure.

Vibrio comma-shaped bacterium.

Villus (plural villi) finger-like projection of the lining of the small intestine which increases surface area for absorption.

Virion the fully-formed, mature transmission stage of a virus.

Virus a non-cellular, obligatory parasite of cells, consisting of a coil of nucleic acid surrounded by a protein coat.

Viscera collective term for internal organs of an animal.

Visceral associated with the organs of the body cavity and the inner body tube (alimentary canal).

Visible spectrum those wavelengths of the electromagnetic spectrum which can be perceived by the human eye.

Vital capacity the maximum volume of air that can be ventilated during forced breathing.

Viviparous (noun vivipary) having embryos which develop within, and derive nutrients from, the maternal organism.

Vocal cords specialised tissues, found in the larynx, the tension can be altered, causing vibrations which produce sound.

Voluntary response learning resulting from an animal's activities.

Volva cup-like base at the stem of some mushrooms.

Vulva collective term for the two external lips which surround the human female vagina.

Wallum community named from its dominant species, the wallum oak, *Banksia aemula*.

Water mould fungus-like protists consisting of a network of filaments permeating their food substrate, particularly dead algae and animals in fresh water.

Water vascular system part of coelom of echinoderms; a system of fluid-filled tubes surrounding the mouth and passing into the arms and tube feet.

Weed a plant growing in a place set aside for other plants.

White blood cells (leucocytes) nucleated cells in the blood specialised for antibody, inflammatory, allergic or phagocytic functions.

White matter myelinated neurons within the central nervous system.

Wild type the most common phenotype for a feature in a population.

X chromosome female sex chromosome in vertebrates and some other animals.

X inactivation the condensation, and thus inhibition, of one of the pairs of X chromosomes in female vertebrates.

Xerophyte plant showing adaptations to living in regions subject to fire and drought.

Xylem a complex tissue composed of living and dead cells; the tracheids and vessels are the non-living components through which water and dissolved mineral nutrients pass from the roots to the leaves in the transpiration stream.

Xylem vessels cells in which end walls have degenerated and which thus are open.

Y chromosome the male sex chromosome in vertebrates and some other animals.

Zoology the study of animals.

Zooplankton small aquatic animals; animal plankton.

Zygospore diploid zygote with a tough outer shell.

Zygote diploid cell formed by fusion of male and female gametes during fertilisation.

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