H

Haber, Fritz (1868–1934) German chemist who worked at the Karlsruhe Technical Institute, where he developed the *Haber process in 1908. As a Jew, he left Germany in 1933 to go into exile in Britain, working in Cambridge at the Cavendish Laboratory. For his Haber process, he was awarded the 1918 Nobel Prize for chemistry.

Haber process An industrial process for producing ammonia by reaction of nitrogen with hydrogen:

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

The reaction is reversible and exothermic, so that a high yield of ammonia is favoured by low temperature (*see* LE CHATELIER'S PRINCIPLE). However, the rate of reaction would be too slow for equilibrium to be reached at normal temperatures, so an optimum temperature of about 450°C is used, with a catalyst of iron containing potassium and aluminium oxide promoters. The higher the pressure the greater the yield, although there are technical difficulties in using very high pressures. A pressure of about 250 atmospheres is commonly employed.

The process is of immense importance for the fixation of nitrogen for fertilizers. It was developed in 1908 by Fritz Haber and was developed for industrial use by Carl Bosch (1874–1940), hence the alternative name **Haber–Bosch process**. The nitrogen is obtained from liquid air. Formerly, the hydrogen was from *water gas and the water-gas shift reaction (the **Bosch process**) but now the raw material (called **synthesis gas**) is obtained by steam *reforming natural gas.

habit *See* CRYSTAL.

habitat The place in which an organism lives, which is characterized by its physical features or by the dominant plant types. Freshwater habitats, for example, include streams, ponds, rivers, and lakes. *See also* MICROHABITAT.

habituation **1.** A simple type of learning consisting of a gradual waning in the response of an animal to a continuous or repeated stimulus that is not associated with *reinforcement. **2.** The condition of being psychologically, but not physically, dependent on a drug.

Hadean The earliest eon in the history of the earth, from the time of the accretion of planetary material, around 4600 million years ago, to the date of the oldest known rocks – and hence the beginning of the geological record – about 3900 million years ago. The young earth was probably a rocky planet with a hot interior and a moist surface with oceans of liquid water. No evidence of life has been found. *Compare* ARCHAEAN.

hadron Any of a class of subatomic particles that interact by the strong interaction (*see* FUNDAMENTAL INTERACTIONS). The class includes protons, neutrons, and pions. Hadrons are believed to have an internal structure and to consist of quarks; they are therefore not truly elementary. Hadrons are either *baryons, which decay into protons and are believed to consist of three quarks, or *mesons, which decay into *leptons and photons or into proton pairs and are believed to consist of a quark and an antiquark. *See* ELEMENTARY PARTICLES.

haem (heme) An iron-containing molecule that binds with proteins as a *cofactor or *prosthetic group to form the **haemoproteins**. These are *haemoglobin, *myoglobin, and the *cytochromes. Essentially, haem comprises a *porphyrin with its four nitrogen atoms holding the iron(II) atom as a chelate. This iron can reversibly bind oxygen (as in haemoglobin and myoglobin) or (as in the cytochromes) conduct electrons by conversion between iron(II) and iron(III) species.

haemagglutination *See* AGGLUTINATION.

haematin test (Teichmann test) A test for blood using the presence of characteristic haematin crystals. It was introduced in 1853 by Ludwig Teichmann.

haematite A mineral form of iron(III) oxide, Fe_2O_3. It is the most important ore of iron and usually occurs in two main forms: as a massive red kidney-shaped ore (**kidney ore**) and as grey to black metallic

crystals known as **specular iron ore**. Haematite is the major red colouring agent in rocks; the largest deposits are of sedimentary origin. In industry haematite is also used as a polishing agent (jeweller's rouge) and in paints.

haematoxylin A compound used in its oxidized form (**haematein**) as a blue dye in optical microscopy, particularly for staining smears and sections of animal tissue. It stains nuclei blue and is frequently used with *eosin as a counterstain for cytoplasm. Haematoxylin requires a mordant, such as iron alum, which links the dye to the tissue. Different types of haematoxylin can be made up depending on the mordant used, the method of oxidation, and the pH. Examples are **Delafield's haematoxylin** and **Ehrlich's haematoxylin**.

haemochromogen test (Takayama test) A test used to confirm the presence of blood. It is a microcrystal test exploiting the characteristic appearance of haemochromogen crystals observed under a microscope. The test was introduced in Japan in 1912 by Masao Takayama.

haemocoel The body cavity of arthropods and molluscs, which is filled with blood. The haemocoel is an enlarged blastocoel (*see* BLASTULA), which greatly reduces the coelom (this is restricted to the cavities of the gonads and excretory organs). The haemocoel can act as a *hydrostatic skeleton.

haemocyanin (hemocyanin) Any of a group of copper-containing respiratory proteins found in solution in the blood of certain arthropods and molluscs. Haemocyanins contain two copper atoms that reversibly bind oxygen, changing between the colourless deoxygenated form (CuI) and the blue oxygenated form (CuII). In some species, haemocyanin molecules form giant polymers with molecular weights of several million.

haemoglobin One of a group of globular proteins occurring widely in animals as oxygen carriers in blood. Vertebrate haemoglobin is contained in the red blood cells (erythrocytes). It comprises two pairs of polypeptide chains, known as α-chains and β-chains (forming the **globin** protein), with each chain folded to provide a binding site for a *haem group. Each of the four haem groups binds one oxygen molecule to form **oxyhaemoglobin**. Dissociation occurs in oxygen-depleted tissues: oxygen is released and haemoglobin is reformed (*see* OXYGEN DISSOCIATION CURVE). The haem groups also bind other inorganic molecules, including carbon monoxide (to form *carboxyhaemoglobin).

haemolysis The breakdown of red blood cells. It can be due to the action of disease-causing microorganisms, poisons, antibodies in mismatched blood transfusions, or certain allergic reactions. It produces anaemia.

haemophilia A hereditary sex-linked disease (*see* SEX LINKAGE) in which there is a deficiency or defect of *Factor VIII, causing the blood to clot very slowly. There may be prolonged bleeding following injury and, in severe cases, spontaneous bleeding into the joints and muscles. The disorder is due to a defective recessive allele of the Factor VIII gene, which is located on the X chromosome. Female carriers of the defective allele are unaffected, whereas all males who inherit a defective allele exhibit the disease.

haemopoietic tissue The tissue that gives rise to blood cells in the process of **haemopoiesis**. The haemopoietic tissue of the embryo and fetal stage of vertebrates is the bone marrow, lymph nodes, yolk sac, liver, spleen, and thymus but after birth haemopoiesis occurs in the red bone marrow (*see* MYELOID TISSUE). The different types of *stem cells in haemopoietic tissue that give rise to erythrocytes and leucocytes are all originally derived from **haemopoietic stem cells** (or **haemocytoblasts**). The formation of the different types of blood cell is under the control of **haemopoietic growth factors**, which include hormones and *cytokines.

hafnium Symbol Hf. A silvery lustrous metallic *transition element; a.n. 72; r.a.m. 178.49; r.d. 13.3; m.p. 2227±20°C; b.p. 4602°C. The element is found with zirconium and is extracted by formation of the chloride and reduction by the Kroll process. It is used in tungsten alloys in filaments and electrodes and as a neutron absorber. The metal forms a passive oxide layer in air. Most of its compounds are hafnium(IV) complexes; less stable hafnium(III) complexes also exist. The element was first reported by Urbain in 1911, and its existence was finally established by

Dirk Coster (1889–1950) and George de Hevesey (1885–1966) in 1923.

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Hahn, Otto (1879–1968) German chemist, who studied in London (with William *Ramsay) and Canada (with Ernest *Rutherford) before returning to Germany in 1907. In 1917, together with Lise *Meitner, he discovered protactinium. In the late 1930s he collaborated with Fritz Strassmann (1902–) and in 1938 bombarded uranium with slow neutrons. Among the products was barium, but it was Meitner (now in Sweden) who the next year interpreted the process as *nuclear fission. In 1944 Hahn received the Nobel Prize for chemistry.

hahnium *See* TRANSACTINIDE ELEMENTS.

hair **1.** A multicellular threadlike structure, consisting of many dead keratinized cells, that is produced by the epidermis in mammalian *skin. The section of a hair below the skin surface (the **root**) is contained within a *hair follicle, the base of which produces the hair cells. Hair assists in maintaining body temperature by reducing heat loss from the skin. Bristles and whiskers are specialized types of hair. **2.** Any of various threadlike structures on plants, such as a *trichome.

hair follicle A narrow tubular depression in mammalian skin containing the root of a *hair. It is lined with epidermal cells and extends down through the epidermis and dermis to its base in the subcutaneous tissue. The ducts of *sebaceous glands empty into hair follicles.

half cell An electrode in contact with a solution of ions, forming part of a *cell. Various types of half cell exist, the simplest consisting of a metal electrode immersed in a solution of metal ions. Gas half cells have a gold or platinum plate in a solution with gas bubbled over the metal plate. The commonest is the *hydrogen half cell. Half cells can also be formed by a metal in contact with an insoluble salt or oxide and a solution. The *calomel half cell is an example of this. Half cells are commonly referred to as **electrodes**.

half-life *See* DECAY; THERAPEUTIC HALF-LIFE.

half sandwich *See* SANDWICH COMPOUND.

half-thickness The thickness of a specified material that reduces the intensity of a beam of radiation to half its original value.

half-wave plate *See* RETARDATION PLATE.

half-wave rectifier *See* RECTIFIER.

half-width The width of a spectral line measured at half its height. In some contexts, the term is used for half the width of the line measured at half its height.

halide A compound of a halogen with another element or group. The halides of typical metals are ionic (e.g. sodium fluoride, Na^+F^-). Metals can also form halides in which the bonding is largely covalent (e.g. aluminium chloride, $AlCl_3$). Organic compounds are also sometimes referred to as halides; e.g. the alkyl halides (*see* HALOALKANES) and the *acyl halides. Halides are named **fluorides**, **chlorides**, **bromides**, or **iodides**.

halite (rock salt) Naturally occurring *sodium chloride (common salt, NaCl), crystallizing in the cubic system. It is chiefly colourless or white (sometimes blue) when pure but the presence of impurities may colour it grey, pink, red, or brown. Halite often occurs in association with anhydrite and gypsum.

Hall effect The production of an e.m.f. within a conductor or semiconductor through which a current is flowing when there is a strong transverse magnetic field. The potential difference develops at right angles to both the current and the field. It is caused by the deflection of charge carriers by the field and was first discovered by Edwin Hall (1855–1938). The strength of the electric field E_H produced is given by the relationship $E_H = R_H jB$, where j is the current density, B is the magnetic flux density, and R_H is a constant called the **Hall coefficient**. The value of R_H can be shown to be $1/ne$, where n is the number of charge carriers per unit volume and e is the electronic charge. The effect is used to investigate the nature of charge carriers in metals and semiconductors, in the **Hall probe** for the measurement of magnetic fields, and in magnetically operated switching devices. *See also* QUANTUM HALL EFFECT.

Halley, Edmund (1656–1742) British astronomer and mathematician, who published a catalogue of southern stars in 1679, made improvements to barometers, and investigated the optics of *rainbows. In 1705

he calculated the orbit of *Halley's comet and in 1718 discovered the *proper motion of the stars.

Halley's comet A bright *comet with a period of 75–76 years. Its last visit to the inner solar system was in 1986. This comet was the first short-period comet to be recognized. Its orbit was first calculated in 1705 by Edmund Halley, after whom it is named. The comet moves around the sun in the opposite direction to the planets and is associated with two meteor showers, the Eta Aquarids (May) and the Orionids (October).

Hall–Heroult cell An electrolytic cell used industrially for the extraction of aluminium from bauxite. The bauxite is first purified by dissolving it in sodium hydroxide and filtering off insoluble constituents. Aluminium hydroxide is then precipitated (by adding CO_2) and this is decomposed by heating to obtain pure Al_2O_3. In the Hall–Heroult cell, the oxide is mixed with cryolite (to lower its melting point) and the molten mixture electrolysed using graphite anodes. The cathode is the lining of the cell, also of graphite. The electrolyte is kept in a molten state (about 850°C) by the current. Molten aluminium collects at the bottom of the cell and can be tapped off. Oxygen forms at the anode, and gradually oxidizes it away. The cell is named after the US chemist Charles Martin Hall (1863–1914), who discovered the process in 1886, and the French chemist Paul Heroult (1863–1914), who discovered it independently in the same year.

hallucinogen A drug or chemical that causes alterations in perception (usually visual), mood, and thought. Common hallucinogenic drugs include *lysergic acid diethylamide (LSD) and mescaline. There is no common mechanism of action for this class of compounds although many hallucinogens are structurally similar to *neurotransmitters in the central nervous system, such as serotonin and the catecholamines.

hallux The innermost digit on the hindlimb of a tetrapod vertebrate. In man it is the big toe and contains two phalanges. The hallux is absent in some mammals and in many birds it is directed backwards as an adaptation to perching. *Compare* POLLEX.

halo **1.** A luminous ring that sometimes can be observed around the sun or the moon. It is caused by diffraction of their light by particles in the earth's atmosphere; the radius of the ring is inversely proportional to the predominant particle radius. **2. (galactic halo)** A region of a galaxy, especially a spiral galaxy, forming a spheroidal extension beyond the main aggregation of stars close to the galactic plane or the galactic bulge.

haloalkanes (alkyl halides) Organic compounds in which one or more hydrogen atoms of an alkane have been substituted by halogen atoms. Examples are chloromethane, CH_3Cl, dibromoethane, CH_2BrCH_2Br, etc. Haloalkanes can be formed by direct reaction between alkanes and halogens using ultraviolet radiation. They are usually made by reaction of an alcohol with a halogenating agent.

halocarbons Compounds that contain carbon and halogen atoms and (sometimes) hydrogen. The simplest are compounds such as tetrachloromethane (CCl_4), tetrabromomethane (CBr_4), etc. The *haloforms are also simple halocarbons. The *chlorofluorocarbons (CFCs) contain carbon, chlorine, and fluorine. Similar to these are **hydrochlorofluorocarbons** (HCFCs), which contain carbon, chlorine, fluorine, and hydrogen, and the **hydrofluorocarbons** (HFCs), which contain carbon, fluorine, and hydrogen. The *halons are a class of halocarbons that contain bromine.

haloform reaction A reaction for producing haloforms from methyl ketones. An example is the production of chloroform from propanone using sodium chlorate(I) (or bleaching powder):

$$CH_3COCH_3 + 3NaOCl \rightarrow CH_3COCl_3 + 3NaOH$$

The substituted ketone then reacts to give chloroform (trichloromethane):

$$CH_3COCCl_3 + NaOH \rightarrow NaOCOCH_3 + CHCl_3$$

The reaction can also be used for making carboxylic acids, since $RCOCH_3$ gives the product NaOCOR. It is particularly useful for aromatic acids as the starting ketone can be made by a Friedel–Crafts acylation.

The reaction of methyl ketones with sodium iodate(I) gives iodoform (triiodomethane), which is a yellow solid with a characteristic smell. This reaction is used in the **iodoform test** to identify methyl ketones. It also gives a positive result with a secondary alcohol of the formula $RCH(OH)CH_3$ (which is first oxidized to a methylketone) or

with ethanol (oxidized to ethanal, which also undergoes the reaction).

haloforms The four compounds with formula CHX_3, where X is a halogen atom. They are **chloroform** ($CHCl_3$), and, by analogy, **fluoroform** (CHF_3), **bromoform** ($CHBr_3$), and **iodoform** (CHI_3). The systematic names are trichloromethane, trifluoromethane, etc.

halogenating agent *See* HALOGENATION.

halogenation A chemical reaction in which a halogen atom is introduced into a compound. Halogenations are described as **chlorination**, **fluorination**, **bromination**, etc., according to the halogen involved. Halogenation reactions may take place by direct reaction with the halogen. This occurs with alkanes, where the reaction involves free radicals and requires high temperature, ultraviolet radiation, or a chemical initiator; e.g.

$$C_2H_6 + Br_2 \rightarrow C_2H_5Br + HBr$$

Halogenation of aromatic compounds can be effected by electrophilic substitution using an aluminium chloride catalyst:

$$C_6H_6 + Cl_2 \rightarrow C_6H_5Cl + HCl$$

Halogenation can also be carried out using compounds, such as phosphorus halides (e.g. PCl_3) or sulphur dihalide oxides (e.g. $SOCl_2$), which react with –OH groups. Such compounds are called **halogenating agents**. Addition reactions are also referred to as halogenations; e.g.

$$C_2H_4 + Br_2 \rightarrow CH_2BrCH_2Br$$

halogens (group 17 elements) A group of elements in the *periodic table (formerly group VIIB): fluorine (F), chlorine (Cl), bromine (Br), iodine (I), and astatine (At). All have a characteristic electron configuration of noble gases but with outer ns^2np^5 electrons. The outer shell is thus one electron short of a noble-gas configuration. Consequently, the halogens are typical nonmetals; they have high electronegativities – high electron affinities and high ionization energies. They form compounds by gaining an electron to complete the stable configuration; i.e. they are good oxidizing agents. Alternatively, they share their outer electrons to form covalent compounds, with single bonds.

All are reactive elements with the reactivity decreasing down the group. The electron affinity decreases down the group and other properties also show a change from fluorine to astatine. Thus, the melting and boiling points increase; at 20°C, fluorine and chlorine are gases, bromine a liquid, and iodine and astatine are solids. All exist as diatomic molecules.

The name 'halogen' comes from the Greek 'salt-producer', and the elements react with metals to form ionic halide salts. They also combine with nonmetals, the activity decreasing down the group: fluorine reacts with all nonmetals except nitrogen and the noble gases helium, neon, and argon; iodine does not react with any noble gas, nor with carbon, nitrogen, oxygen, or sulphur. The elements fluorine to iodine all react with hydrogen to give the acid, with the activity being greatest for fluorine, which reacts explosively. Chlorine and hydrogen react slowly at room temperature in the dark (sunlight causes a free-radical chain reaction). Bromine and hydrogen react if heated in the presence of a catalyst. Iodine and hydrogen react only slowly and the reaction is not complete. There is a decrease in oxidizing ability down the group from fluorine to iodine. As a consequence, each halogen will displace any halogen below it from a solution of its salt, for example:

$$Cl_2 + 2Br^- \rightarrow Br_2 + 2Cl^-$$

The halogens also form a wide variety of organic compounds in which the halogen atom is linked to carbon. In general, the aryl compounds are more stable than the alkyl compounds and there is decreasing resistance to chemical attack down the group from the fluoride to the iodide.

Fluorine has a valency of only 1, although the other halogens can have higher oxidation states using their vacant *d*-electron levels. There is also evidence for increasing metallic behaviour down the group. Chlorine and bromine form compounds with oxygen in which the halogen atom is assigned a positive oxidation state. Only iodine, however, forms positive ions, as in $I^+NO_3^-$.

halon A compound obtained by replacing the hydrogen atoms of a hydrocarbon by bromine along with other halogen atoms (*see* HALOCARBONS), for instance halon 1211 is bromochlorodifluoromethane (CF_2BrCl) and halon 1301 is bromotrifluoromethane (CF_3Br). Halons are very stable and unreactive and are widely used in fire extinguishers. There is concern that they are being broken down in the atmosphere to bromine, which reacts with ozone, leading to depletion of the *ozone layer, and their use is being curtailed.

Although more *chlorofluorocarbons are present in the atmosphere, halons are between three and ten times more destructive of ozone.

halo nucleus A type of nucleus in which there are many more neutrons (or, more rarely, more protons) than are present in stable isotopes of that element. Sometimes, a few of the extra neutrons are only weakly bound to the rest of the nucleus and are relatively far from the centre of the nucleus. Halo nuclei are highly unstable; examples include beryllium–11 and carbon–19.

halophyte A plant that can tolerate a high concentration of salt in the soil. Such conditions occur in salt marshes and mudflats. Halophytes possess some of the structural modifications of *xerophytes; for example, many of them are *succulents. In addition, they are physiologically adapted to withstand the high salinity of the soil water: their root cells have a higher than normal concentration of solutes, which enables them to take up water by osmosis from the surrounding soil. Examples of halophytes are mangrove trees (*see* MANGROVE SWAMP), thrift (*Armeria*), sea lavender (*Limonium*), and rice grass (*Spartina*). *Compare* HYDROPHYTE; MESOPHYTE.

Hamilton, Sir William Rowan (1805–65) Irish mathematician and physicist. Hamilton invented what is now known as the *Hamiltonian formulation of Newtonian mechanics. In doing so, he discovered that there is a very close analogy between Newtonian mechanics and geometrical (ray) optics. He also invented *quaternions in mathematics and found a number of applications of quaternions in physics.

Hamiltonian Symbol *H*. A function used to express the energy of a system in terms of its momentum and positional coordinates. In simple cases this is the sum of its kinetic and potential energies. In **Hamiltonian equations**, the usual equations used in mechanics (based on forces) are replaced by equations expressed in terms of momenta. This method of formulating mechanics (**Hamiltonian mechanics**) was first introduced by Sir William Rowan *Hamilton.

haploid Describing a nucleus, cell, or organism with a single set of unpaired chromosomes. The haploid number is designated as *n*. Reproductive cells, formed as a result of *meiosis, are haploid. Fusion of two such cells (*see* FERTILIZATION) restores the normal (*diploid) number.

haplotype **1.** (in genetics) **a.** A set of linked genes or other genetic markers that are generally inherited together as a unit. This occurs because during meiosis there is little or no *recombination with the corresponding region on the homologous chromosome, and hence shuffling of alleles between the homologous regions is rare. The stretch of DNA containing a haplotype is called a **haplotype block**. **b.** The entire set of genes occurring on a single chromosome, or haploid set of chromosomes. Hence an individual has two haplotypes for each chromosome, one derived from its mother and one from its father. **2.** (in medicine) **a.** The antigenic constitution of an individual (i.e. antigenic phenotype) resulting from the inheritance of a particular haploid combination of histocompatibility alleles at the HLA locus. **b.** The set of phenotypic features associated with either the paternal or maternal alleles inherited by an individual.

hapticity Symbol η. The number of electrons in a ligand that are directly coordinated to a metal.

haptotropism *See* THIGMOTROPISM.

hard acid *See* HSAB PRINCIPLE.

hard base *See* HSAB PRINCIPLE.

hardening of oils The process of converting unsaturated esters of *fatty acids into (more solid) saturated esters by hydrogenation using a nickel catalyst. It is used in the manufacture of margarine from vegetable oils.

hard ferromagnetic materials *See* SOFT IRON.

hardness of water The presence in water of dissolved calcium or magnesium ions, which form a scum with soap and prevent the formation of a lather. The main cause of hard water is dissolved calcium hydrogencarbonate ($Ca(HCO_3)_2$), which is formed in limestone or chalk regions by the action of dissolved carbon dioxide on calcium carbonate. This type is known as **temporary hardness** because it is removed by boiling:

$$Ca(HCO_3)_2(aq) \rightarrow CaCO_3(s) + H_2O(l) + CO_2(g)$$

The precipitated calcium carbonate is the 'fur' (or 'scale') formed in kettles, boilers,

pipes, etc. In some areas, hardness also results from dissolved calcium sulphate ($CaSO_4$) or calcium fluoride (CaF_2). These compounds can not be removed by boiling (**permanent hardness**).

Hard water causes problems in washing and by reducing the efficiency of boilers, heating systems, and certain industrial processes. Various methods of **water softening** are used. In public supplies, temporary hardness can be removed by adding lime (calcium hydroxide), which precipitates calcium carbonate

$$Ca(OH)_2(aq) + Ca(HCO_3)_2(aq) \rightarrow 2CaCO_3(s) + 2H_2O(l)$$

This is known as the **Clark process** (or as **clarking**). It does not remove permanent hardness. Both temporary and permanent hardness can be treated by precipitating calcium carbonate by added sodium carbonate – hence its use as washing soda and in bath salts. Calcium (and other) ions can also be removed from water by ion-exchange using zeolites (e.g. **Permutit**). This method is used in small domestic water-softeners. Another technique is to complex the Ca^{2+} ions and prevent them reacting further. For domestic use polyphosphates (containing the ion $P_6O_{18}^{6-}$, e.g. **Calgon**) are added. Other sequestering agents are also used for industrial water. *See also* SEQUESTRATION.

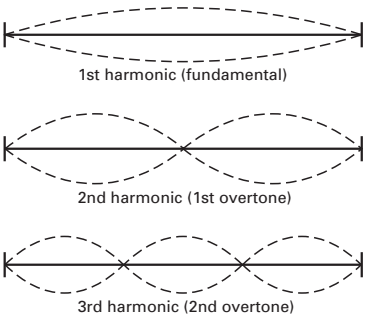
hard radiation Ionizing radiation of high penetrating power, usually gamma rays or short-wavelength X-rays. *Compare* SOFT RADIATION.

hardware *See* COMPUTER.

hardwood *See* WOOD.

Hargreaves process *See* POTASSIUM SULPHATE.

harmonic An oscillation having a frequency that is a simple multiple of a **fundamental** sinusoidal oscillation. The fundamental frequency of a sinusoidal oscillation is usually called the **first harmonic**. The **second harmonic** has a frequency twice that of the fundamental and so on (see illustration). A taut string or column of air, as in a violin or organ, will sound upper harmonics at the same time as the fundamental sounds. This is because the string or column of air divides itself into sections, each section then vibrating as if it were a whole. The upper harmonics are also called **overtones**, but the second harmonic is the first overtone, and so on. Musicians, however, often regard harmonic and overtone as synonymous, not counting the fundamental as a harmonic.



Harmonics.

harmonic mean *See* MEAN.

harmonic motion *See* SIMPLE HARMONIC MOTION.

harmonic oscillator A system (in either *classical physics or *quantum mechanics) that oscillates with *simple harmonic motion. The harmonic oscillator is exactly soluble in both classical mechanics and quantum mechanics. Many systems exist for which harmonic oscillators provide very good approximations. An example in classical mechanics is a simple *pendulum, while at low temperatures atoms vibrating about their mean positions in molecules or crystal lattices can be regarded as good approximations to harmonic oscillators in quantum mechanics. Even if a system is not exactly a harmonic oscillator the solution of the harmonic oscillator is frequently a useful starting point for solving such systems using *perturbation theory. *Compare* ANHARMONIC OSCILLATOR.

harmonic series (harmonic progression) A series or progression in which the reciprocals of the terms have a constant difference between them, e.g. $1 + 1/2 + 1/3 + 1/4 \ldots + 1/n$.

Harvard classification *See* SPECTRAL CLASS.

harvesting **1.** The processes involved in gathering in ripened crops (*see* AGRICULTURE). **2.** The collection of cells from cell cultures or of organs from donors for the purpose of transplantation (*see* GRAFT).

Harvey, William (1578–1657) English physician, who worked at St Bartholomew's Hospital, London, from 1609 and from 1618 was court physician. He is best known for discovering the *circulation of the blood, which he announced in 1628.

hashish *See* CANNABIS.

hassium Symbol Hs. A radioactive transactinide element; a.n. 108. It was first made in 1984 by Peter Armbruster and a team in Darmstadt, Germany. It can be produced by bombarding lead-208 nuclei with iron-58 nuclei. Only a few atoms have ever been produced. The name comes from the Latinized form of Hesse, the German state where it was first synthesized.

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haustorium A specialized structure of certain parasitic plants and fungi that penetrates the cells of the host plant to absorb nutrients. In parasitic fungi haustoria are formed from enlarged hyphae and in parasitic flowering plants, such as the dodder (*Cuscuta*), they are outgrowths of the stem.

Haversian canals Narrow tubes within compact *bone containing blood vessels and nerves. They generally run parallel to the bone surface. Each canal surrounded by a series of rings of bone (**lamellae**) is known as a **Haversian system**. Haversian systems are joined to each other by bone material. They are named after Clopton Havers (1650–1702).

Hawking, Stephen William (1942–) British cosmologist and physicist, who in 1979 became the Lucasian Professor of mathematics at Cambridge University. Working with Roger Penrose (1931–), who had shown how a singularity results from a *black hole, Hawking postulated that the original big bang must have come from a singularity (*see* BIG-BANG THEORY). He also showed how black holes can emit particles by the *Hawking process. Hawking is the author of such popular science works as *A Brief History of Time* (1988) and *The Universe in a Nutshell* (2001).

Hawking process Emission of particles by a *black hole as a result of quantum-mechanical effects. The process was first suggested by Stephen Hawking. The gravitational field of the black hole causes production of particle–antiparticle pairs in the vicinity of the event horizon (the process is analogous to that of pair production). One member of each pair (either the particle or the antiparticle) falls into the black hole, while the other escapes. To an external observer it appears that the black hole is emitting radiation (**Hawking radiation**). The energy of the particles that fall in is negative and exactly balances the (positive) energy of the escaping particles. This negative energy reduces the mass of the black hole and the net result of the process is that the emitted particle flux appears to carry off the black-hole mass. It can be shown that the black hole radiates like a *black body, with the energy distribution of the particles obeying *Planck's radiation law for a temperature that is inversely proportional to the mass of the hole. For a black hole of the mass of the sun, this temperature is only about 10^{-7} K, so the energy loss is negligible. However, for a 'mini' black hole, such as might have been formed in the early universe, with a mass of order 10^{12} kg (and a radius of order 10^{-15} m), the temperature would be of order 10^{11} K and the hole would radiate copiously (at a rate of about 6×10^9 W) a flux of gamma rays, neutrinos, and electron–positron pairs. (The observed levels of cosmic gamma rays put strong constraints on the number of such 'mini' black holes, suggesting that there are too few of them to solve the *missing-mass problem.)

hazchem code (emergency action code; EAC) A code designed to be displayed when hazardous chemicals are transported or stored in bulk. It is used to help the emergency services to take action quickly in any accident. The code consists of a number followed by one or two letters. The number indicates the type of substance to be used in treating the accident (e.g. stream of water, fine spray, foam, dry agent). The first letter indicates the type of protective clothing needed along with information about the possibility of violent reaction on whether the substance should be contained or diluted. The second letter, where it exists, is letter E, indicating that people have to be evacuated from the neighbourhood of the incident. In the UK, the code is usually displayed as part of a panel, which includes an international UN number for the substance, a telephone number for specialist advice, the company name, and a symbol indicating the danger (e.g. a skull and crossbones for toxic substances).

HCFC (hydrochlorofluorocarbon) *See* HALOCARBONS.

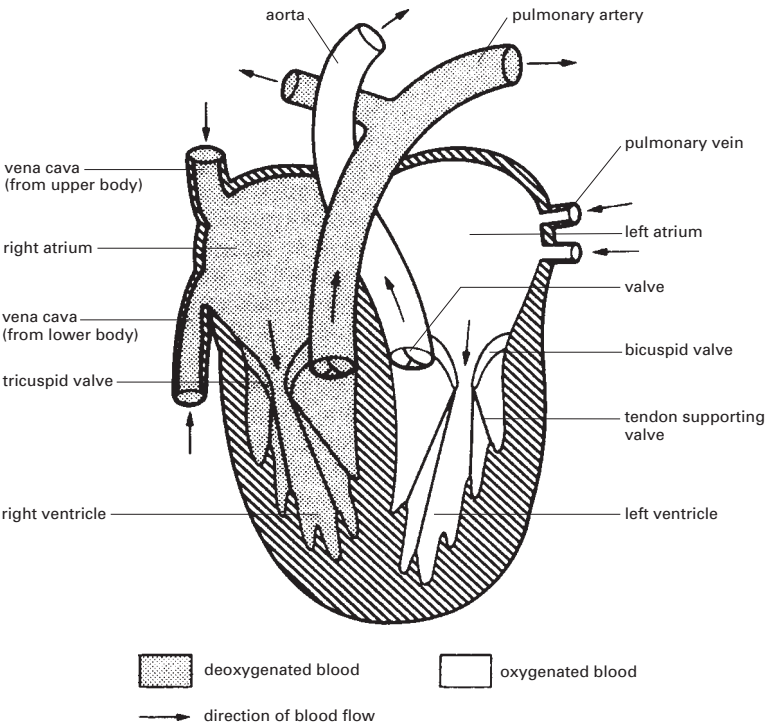
h.c.p. Hexagonal close packing. *See* CLOSE PACKING.

headspace The space above a sample held in a sealed container. Headspace analysis is used in forensic science to investigate the volatile constituents of a sample.

health physics The branch of medical physics concerned with the protection of medical, scientific, and industrial workers from the hazards of ionizing radiation and other dangers associated with atomic physics. Establishing the maximum permissible *dose of radiation, the disposal of radioactive waste, and the shielding of dangerous equipment are the principal activities in this field.

hearing The sense by which sound is detected. In vertebrates the organ of hearing is the *ear. In higher vertebrates variation in air pressure caused by sound waves are amplified in the outer and middle ears and transmitted to the inner ear, where sensory cells in the *cochlea register the vibrations. The resulting information is transmitted to the brain via the auditory nerve. The ear can distinguish between sounds of different intensity (*loudness) and frequency (*pitch).

heart A hollow muscular organ that, by means of regular contractions, pumps blood through the circulatory system. The vertebrate heart is composed of a specialized muscle (*see* CARDIAC MUSCLE). Mammals have a four-chambered heart consisting of two atria and two ventricles; the right and left sides are completely separate from each other so there is no mixing of oxygenated and deoxygenated blood (see illustration). Oxygenated blood from the pulmonary veins



Heart. Structure of the mammalian heart.

enters the heart through the left atrium, passes to the left ventricle, and leaves the heart through the *aorta. Deoxygenated blood from the *venae cavae enters the right atrium and is pumped through the right ventricle to the pulmonary artery, which conveys it to the lungs for oxygenation. The tricuspid and bicuspid valves ensure that there is no backflow of blood. The contractions of the heart are initiated and controlled by the sinoatrial node (*see* PACEMAKER); an average adult human heart contracts about 70 times per minute. *See also* CARDIAC CYCLE; CARDIAC OUTPUT.

The hearts of other vertebrates are similar except in the number of atria and ventricles (there may be one or two) and in the degree of separation of oxygenated and deoxygenated blood. Invertebrates, however, show great variation in the form and functioning of the heart.

heartwood (duramen) The wood at the centre of a tree trunk or branch. It consists of dead *xylem cells heavily thickened with lignin and provides structural support. Many heartwood cells contain oils, gums, and resins, which darken the wood. *Compare* SAPWOOD.

heat The process of energy transfer from one body or system to another as a result of a difference in temperature. The energy in the body or system before or after transfer is also sometimes called heat.

A body in equilibrium with its surroundings contains energy (the kinetic and potential energies of its atoms and molecules) but this is called **internal energy**, U, rather than heat. When such a body changes its temperature or phase there is a change in internal energy, ΔU, which (according to the first law of *thermodynamics) is given by $\Delta U = Q - W$, where Q is the heat absorbed by the body from the surroundings and W is the work done simultaneously on the surroundings. To use the word 'heat' for both U and Q is clearly confusing. Note also that certain physical quantities are described as *heat of atomization, *heat of combustion, etc. What is usually used is a standard molar *enthalpy change for the process under consideration. The units are kJ mol^{-1}; a negative value indicates that energy is liberated. *See also* HEAT CAPACITY; HEAT TRANSFER; LATENT HEAT.

heat balance **1.** A balance sheet showing all the heat inputs to a system (such as a chemical process, furnace, etc.) and all the heat outputs. **2.** The equilibrium that exists on the average between the radiation received from the sun by the earth and its atmosphere and that reradiated or reflected by the earth and the atmosphere. In general, the regions of the earth nearer the equator than about 35°N or S receive more energy from the sun than they are able to reradiate, whereas those regions polewards of 35°N or S receive less energy than they lose. The excess of heat received by the low latitudes is carried to the higher latitudes by atmospheric and oceanic circulations.

heat capacity (thermal capacity) The ratio of the heat supplied to an object or specimen to its consequent rise in temperature. The **specific heat capacity** is the ratio of the heat supplied to unit mass of a substance to its consequent rise in temperature. The **molar heat capacity** is the ratio of the heat supplied to unit amount of a substance to its consequent rise in temperature. In practice, heat capacity (C) is measured in joules per kelvin, specific heat capacity (c) in J K^{-1} kg^{-1}, and molar heat capacity (C_m) in J K^{-1} mol^{-1}. For a gas, the values of c and C_m are commonly given either at **constant volume**, when only its *internal energy is increased, or at **constant pressure**, which requires a greater input of heat as the gas is allowed to expand and do work against the surroundings. The symbols for the specific and molar heat capacities at constant volume are c_v and C_v, respectively; those for the specific and molar heat capacities at constant pressure are c_p and C_p.

heat death of the universe The condition of the universe when *entropy is maximized and all large-scale samples of matter are at a uniform temperature. In this condition no energy is available for doing work and the universe is finally unwound. The condition was predicted by Rudolf Clausius, who introduced the concept of entropy. Clausius's dictum that "the energy of the universe is constant, its entropy tends to a maximum" is a statement of the first two laws of thermodynamics. These laws apply in this sense only to closed systems and, for the predicted heat death to occur, the universe must be a closed system.

heat engine A device for converting heat into work. The heat is derived from the combustion of a fuel. In an *internal-combustion engine the fuel is burnt inside the engine, whereas in a *steam engine or steam turbine,

examples of external-combustion engines, the fuel is used to raise steam outside the engine and then some of the steam's internal energy is used to do work inside the engine. Engines usually work on cycles of operation, the most efficient of which would be the *Carnot cycle. This cannot be realized in practice, but the *Rankine cycle is approximated by some engines.

heat exchanger A device for transferring heat from one fluid to another without permitting the two fluids to contact each other. A simple industrial heat exchanger consists of a bundle of parallel tubes, through which one fluid flows, enclosed in a container, through which the other fluid flows in the opposite direction (a **counter-current heat exchanger**).

heat of atomization The energy required to dissociate one mole of a given substance into atoms.

heat of combustion The energy liberated when one mole of a given substance is completely oxidized.

heat of crystallization The energy liberated when one mole of a given substance crystallizes from a saturated solution of the same substance.

heat of dissociation The energy absorbed when one mole of a given substance is dissociated into its constituent elements.

heat of formation The energy liberated or absorbed when one mole of a compound is formed in their *standard states from its constituent elements.

heat of neutralization The energy liberated in neutralizing one mole of an acid or base.

heat of reaction The energy liberated or absorbed as a result of the complete chemical reaction of molar amounts of the reactants.

heat of solution The energy liberated or absorbed when one mole of a given substance is completely dissolved in a large volume of solvent (strictly, to infinite dilution).

heat pump A device for transferring heat from a low temperature source to a high temperature region by doing work. It is essentially a refrigerator with a different emphasis. The working fluid is at one stage a vapour, which is compressed by a pump adiabatically so that its temperature rises. It is then passed to the radiator, where heat is given out to the surroundings (the space to be heated) and the fluid condenses to a liquid. It is then expanded into an evaporator where it takes up heat from its surroundings and becomes a vapour again. The cycle is completed by returning the vapour to the compressor. Heat pumps are sometimes adapted as dual-purpose space-heating-in-winter and air-conditioning-in-summer devices.

heat radiation (radiant heat) Energy in the form of electromagnetic waves emitted by a solid, liquid, or gas as a result of its temperature. It can be transmitted through space; if there is a material medium this is not warmed by the radiation except to the extent that it is absorbed. Although it covers the whole electromagnetic spectrum, the highest proportion of this radiation lies in the infrared portion of the spectrum at normal temperatures. *See* BLACK BODY.

heat shield A specially prepared surface that prevents a spacecraft or capsule from overheating as it re-enters the earth's atmosphere. The surface is coated with a plastic impregnated with quartz fibres, which is heated by friction with air molecules as the craft enters the atmosphere, causing the outer layer to vaporize. In this way about 80% of the energy is reradiated and the craft is safeguarded from an excessive rise in temperature.

heat-shock protein (HSP) *See* MOLECULAR CHAPERONE.

heat transfer The transfer of energy from one body or system to another as a result of a difference in temperature. The heat is transferred by *conduction (*see also* CONDUCTIVITY), *convection, and radiation (*see* HEAT RADIATION).

Heaviside–Kennelly layer *See* EARTH'S ATMOSPHERE.

Heaviside–Lorentz units A system of units for electric and magnetic quantities based upon c.g.s. electrostatic and electromagnetic units. They are the rationalized forms of *Gaussian units and, like the latter, are widely used in particle physics and relativity in preference to the *SI units now employed for general purposes in physics. They are named after Oliver Heaviside (1850–1925) and Hendrik Lorentz (1853–1928).

heavy-fermion system A solid in which the electrons have a very high effective mass; i.e. they act as if they had masses several hundred times the normal mass of the electron. An example of a heavy-fermion system is the cerium–copper–silicon compound $CeCuSi_2$. The electrons with high effective mass are *f*-electrons in narrow energy bands associated with strong many-body effects. Substances containing such electrons have unusual thermodynamic, magnetic, and superconducting properties, which are still not completely understood. The *superconductivity of such materials has a more complicated mechanism than that for metals described by the BCS theory, since the Cooper pairs are formed from *quasiparticles with very high effective masses rather than from electrons.

heavy hydrogen *See* DEUTERIUM.

heavy metal A metal with a high relative atomic mass. The term is usually applied to common transition metals, such as copper, lead, and zinc. These metals are a cause of environmental *pollution (**heavy-metal pollution**) from a number of sources, including lead in petrol, industrial effluents, and leaching of metal ions from the soil into lakes and rivers by acid rain.

heavy spar A mineral form of *barium sulphate, $BaSO_4$.

heavy water (deuterium oxide) Water in which hydrogen atoms, ^1H, are replaced by the heavier isotope deuterium, ^2H (symbol D). It is a colourless liquid, which forms hexagonal crystals on freezing. Its physical properties differ from those of 'normal' water; r.d. 1.105; m.p. 3.8°C; b.p. 101.4°C. Deuterium oxide, D_2O, occurs to a small extent (about 0.003% by weight) in natural water, from which it can be separated by fractional distillation or by electrolysis. It is useful in the nuclear industry because of its ability to reduce the energies of fast neutrons to thermal energies (*see* MODERATOR) and because its absorption cross-section is lower than that of hydrogen and consequently it does not appreciably reduce the neutron flux. In the laboratory it is used for *labelling other molecules for studies of reaction mechanisms. Water also contains the compound HDO.

hecto- Symbol h. A prefix used in the metric system to denote 100 times. For example, 100 coulombs = 1 hectocoulomb (hC).

Heisenberg, Werner Karl (1901–76) German physicist, who became a professor at the University of Leipzig and, after World War II, at the Kaiser Wilhelm Institute in Göttingen. In 1923 he was awarded the Nobel Prize for physics for his work on *matrix mechanics. But he is best known for his 1927 discovery of the *uncertainty principle.

Heisenberg uncertainty principle *See* UNCERTAINTY PRINCIPLE.

heliacal rising The first appearance of a star, a constellation, a planet, or the moon above the eastern horizon just before dawn following a period of invisibility during which the object had been rising in daylight. Heliacal risings of the same star or constellation happen one year apart.

helicate A type of inorganic molecule containing a double helix of bipyridyl-derived molecules formed around a chain of up to five copper(I) ions. *See also* SUPRAMOLECULAR CHEMISTRY.

heliocentric universe A conception of the universe in which the sun is taken to be at its centre. Aristarchus of Samos (310–230 BC) was the first formally to propose the heliocentric model, but it failed to predict what was actually observed and thus made little headway against the rival, more intuitive *geocentric universe, which held sway throughout the Middle Ages. Nicolaus Copernicus revived an essentially heliocentric view, which was upheld by Galileo against strong opposition from the church on the grounds that if the earth was not at the centre of the universe man's position in God's creation was diminished. In the modern view the sun is at the centre of the *solar system, but the sun, with its family of planets and other bodies, is just one of an enormous number of stars in the Galaxy, which is itself one of an enormous number of *galaxies.

helioseismology The study of waves in the sun. The waves studied in helioseismology are not seismic waves, as in geophysics, but pressure waves generated by turbulence in the solar convection layer. These cause slight changes in the pattern of light from the sun and the pattern of pressure waves can be inferred from these changes, leading to information about conditions within the sun.

heliosphere The vast bubble-like region enveloping the *solar system and carried with it through space, within which the *solar wind plays a dominant role.

heliotropism *See* PHOTOTROPISM.

helium Symbol He. A colourless odourless gaseous nonmetallic element belonging to group 18 of the periodic table (*see* NOBLE GASES); a.n. 2; r.a.m. 4.0026; d. 0.178 g dm^{-3}; m.p. –272.2°C (at 20 atm.); b.p. –268.93°C. The element has the lowest boiling point of all substances and can be solidified only under pressure. Natural helium is mostly helium–4, with a small amount of helium–3. There are also two short-lived radioactive isotopes: helium–5 and –6. It occurs in ores of uranium and thorium and in some natural-gas deposits. It has a variety of uses, including the provision of inert atmospheres for welding and semiconductor manufacture, as a refrigerant for superconductors, and as a diluent in breathing apparatus. It is also used in filling balloons. Chemically it is totally inert and has no known compounds. It was discovered in the solar spectrum in 1868 by Joseph Lockyer (1836–1920).

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Helmholtz, Hermann Ludwig Ferdinand von (1821–94) German physiologist and physicist. In 1850 he measured the speed of a nerve impulse and in 1851 invented the ophthalmoscope. In physics, he discovered the conservation of energy (1847), introduced the concept of *free energy, and invented *vortex dynamics.

Helmholtz coils Two coaxial parallel flat coils with the same radius placed a distance apart that is equal to the radius. If the same current is flowing in both coils then the value of the magnetic field strength is approximately uniform between the coils. Coils of this type are used to create fields and, in some cases, are employed to counter the effect of the earth's magnetic field. Helmholtz coils are also used in magnetic measurement, with the coils connected to a *fluxmeter. If a small magnet is placed between the coils and then removed, the integrated signal on the fluxmeter is proportional to the magnet's magnetic moment.

Helmholtz free energy *See* FREE ENERGY.

helper T cell *See* T CELL.

heme *See* HAEM.

hemiacetals *See* ACETALS.

hemicellulose A *polysaccharide found in the cell walls of plants. The branched chains of this molecule bind to cellulose microfibrils, together with pectins, forming a network of cross-linked fibres.

hemihedral form The form of a crystal in which only half the number of faces required for the symmetry are present. *Compare* HOLOHEDRAL FORM.

hemihydrate A crystalline hydrate containing two molecules of compound per molecule of water (e.g. $2CaSO_4.H_2O$).

hemiketals *See* KETALS.

Hemiptera An order of insects comprising the true bugs. Hemipterans typically have oval flattened bodies with two pairs of wings, which are folded back across the abdomen at rest. The forewings are hardened, either at their bases only (in the suborder Heteroptera) or uniformly (in the suborder Homoptera). The mouthparts are modified for piercing and sucking, with long slender stylets forming a double tube. Many bugs feed on plant sap and are serious agricultural pests, including aphids, leaf-hoppers, scale insects, mealy bugs, etc. Others are carnivorous, and the order contains many aquatic species, such as the water boatmen, which have legs adapted for swimming and the exchange of respiratory gases.

henry Symbol H. The *SI unit of inductance equal to the inductance of a closed circuit in which an e.m.f. of one volt is produced when the electric current in the circuit varies uniformly at a rate of one ampere per second. It is named after Joseph Henry.

Henry, Joseph (1797–1878) US physicist, who became professor of natural philosophy at Princeton in 1832. In 1829 he made an *electric motor, and used insulated windings to produce a powerful *electromagnet. A year later he discovered *electromagnetic induction (independently of *Faraday), and in 1832 he discovered self-induction (*see* INDUCTANCE). In 1835 he invented the electric *relay.

Henry's law At a constant temperature the mass of gas dissolved in a liquid at equilibrium is proportional to the partial pressure of the gas. The law, discovered in 1801 by the British chemist and physician William Henry (1775–1836), is a special case of the partition law. It applies only to gases that do not react with the solvent.

heparin A glycosaminoglycan (muco-

polysaccharide) with *anticoagulant properties, occurring in vertebrate tissues, especially the lungs and blood vessels. Pharmaceutical preparations of heparin are administered to prevent or dissolve blood clots.

hepatic Of or relating to the liver. For example, the **hepatic portal vein** (*see* HEPATIC PORTAL SYSTEM) and the **hepatic artery** supply blood to the liver, and the **hepatic vein** carries blood away from the liver.

Hepaticae *See* HEPATOPHYTA.

hepatic portal system The vein (**hepatic portal vein**) or veins that transport blood containing the absorbed products of digestion from the intestine directly to the liver.

Hepatophyta (Marchantiophyta) A phylum comprising the liverworts – simple plants that lack vascular tissue and possess rudimentary rootlike organs (rhizoids). Liverworts occur in moist situations (including fresh water) and as epiphytes on other plants. Like the mosses (*see* BRYOPHYTA), liverworts show marked alternation of generations between haploid gamete-bearing forms (gametophytes) and diploid spore-bearing forms (sporophytes), the latter being dependent on the former for nutrients, etc. The plant body (gametophyte) may be a thallus, growing closely pressed to the ground (thallose liverworts, e.g. *Pellia*), or it may bear many leaflike lobes (leafy liverworts). It gives rise to leafless stalks bearing capsules (sporophytes). Spores formed in the capsules are released and grow to produce new plants.

Liverworts were formerly placed in the class Hepaticae in the phylum Bryophyta, which now contains only the mosses.

heptadecanoic acid (margaric acid) A white crystalline carboxylic acid with a linear chain of carbon atoms, $C_{16}H_{33}COOH$; m.p. 59–61°C; b.p. 227°C (100 mm Hg). It is present in certain natural fats.

heptahydrate A crystalline hydrate that has seven moles of water per mole of compound.

heptane A liquid straight-chain alkane obtained from petroleum, C_7H_{16}; r.d. 0.684; m.p. –90.6°C; b.p. 98.4°C. In standardizing *octane numbers, heptane is given a value zero.

heptaoxodiphosphoric(V) acid *See* PHOSPHORIC(V) ACID.

heptavalent (septivalent) Having a valency of seven.

herb **1.** A *herbaceous plant, i.e. a seed-bearing plant that does not form hard woody tissue. **2.** A plant with medicinal or culinary uses. Culinary herbs are usually plants whose leaves are used for flavouring food.

herbaceous Describing a plant that contains little permanent woody tissue. The aerial parts of the plant die back after the growing season. In *annuals the whole plant dies; in *biennials and herbaceous *perennials the plant has organs (e.g. bulbs or corms) that survive beneath the soil in unfavourable conditions.

herbal cannabinoids *See* CANNABINOIDS.

herbicide *See* PESTICIDE.

Herbig–Haro object (HH object) A strange bright region in interstellar space. It contains gas and dust that is excited to emit electromagnetic radiation by a jet of gas, which may be the *bipolar outflow from a young *T Tauri star or other protostar.

herbivore An animal that eats vegetation, especially any of the plant-eating mammals, such as ungulates (cows, horses, etc.). Herbivores are characterized by having teeth adapted for grinding plants and alimentary canals specialized for digesting cellulose (*see* CAECUM).

heredity The transmission of characteristics from parents to offspring via the chromosomes. The study of heredity (*genetics) was first undertaken by Gregor Mendel, who derived a series of laws that govern heredity (*see* MENDEL'S LAWS).

Hermann–Mauguin system (international system) A notation used to describe the symmetry of point groups. In contrast to the *Schoenflies system, which is used for isolated molecules (e.g. in spectroscopy), the Hermann–Mauguin system is used in *crystallography. Some of the categories are the same as the Schoenflies system. n is the same group as C_n. nmm is the same group as C_{nv}. There are two ms because of two distinct types of mirror plane containing the n-fold axis. $n22$ is the same group as D_n. The other categories do not coincide with the Schoenflies system. $\bar{n}$ is a group with an n-fold rotation–inversion axis and includes C_{3h} as $\bar{6}$, S_4 as $\bar{4}$, S_6 as $\bar{3}$, and S_2 as $\bar{1}$. n/m is the same group as C_{nh} except that C_{3h} is regarded as $\bar{6}$. $n2m$ is the same group as D_{nd},

except that D_{3h} is regarded as $62m$. $n/m\,2/m\,2/m$, abbreviated to n/mmm, is the same group as D_{nh}, except that D_{3h} is regarded as $6\bar{2}m$. (Unlike the Schoenflies system, the Hermann–Mauguin system regards the three-fold axis as a special case.) As regards the cubic groups, O_h is denoted $m3m$ (or $4/m\,\bar{3}\,2/m$), O is denoted 432, T_h is denoted $m3$ (or $2/m\,\bar{3}$), T_d is denoted $\bar{4}3m$, and T is denoted 23. In the Hermann–Mauguin system all the cubic groups have 3 as the second number because of the three-fold axis that occurs in all cubic groups. It is named after the German crystallographer Carl Hermann (1898–1961) and the French minerologist Charles-Victor Mauguin (1878–1958).

hermaphrodite (bisexual) **1.** An animal, such as the earthworm, that has both male and female reproductive organs. **2.** A plant whose flowers contain both stamens and carpels. This is the usual arrangement in most plants. *Compare* MONOECIOUS; DIOECIOUS.

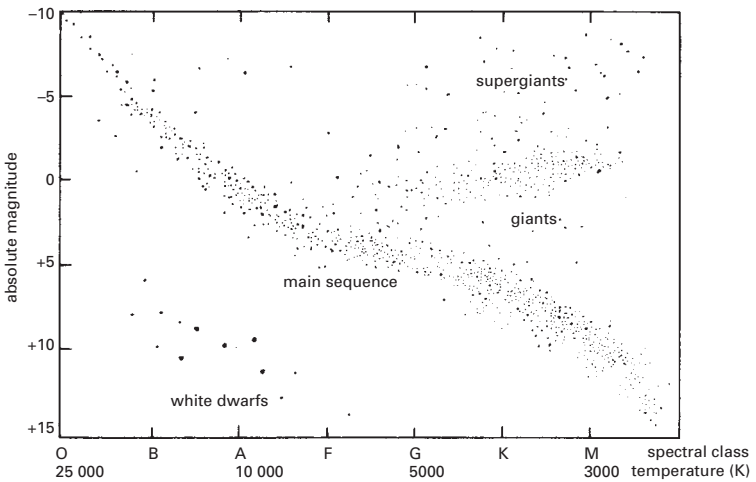
heroin (diacetylmorphine) A *narcotic compound that is a synthetic derivative of morphine (*see* OPIATE). The compound is easily absorbed by the brain and is used as a powerful *analgesic. Highly addictive, it is abused by drug users.

herpesvirus One of a group of complex DNA-containing viruses causing infections in man and most other vertebrates that tend to recur. The group includes **herpes simplex**, the agent of cold sores; **herpes varicella/zoster**, the virus causing chickenpox and shingles; **Epstein–Barr** (**EB**) **virus**, the causal agent of glandular fever and also implicated in the cancer Burkitt's lymphoma; and the *cytomegalovirus.

hertz Symbol Hz. The *SI unit of frequency equal to one cycle per second. It is named after Heinrich Hertz.

Hertz, Heinrich Rudolf (1857–94) German physicist, who worked as an engineer before attending Berlin University. He is best known for his 1888 discovery of *radio waves, as predicted by James Clerk *Maxwell. The SI unit of frequency is named after him.

Hertzsprung–Russell diagram (H–R diagram) A graphical representation of the absolute magnitude of stars (usually along the *y*-axis) plotted against the spectral class or colour index (*x*-axis): see illustration. The *y*-axis then represents the energy output of the star and the *x*-axis its surface temperature. The majority of stars on such a diagram fall on a band running from the top left to the bottom right of the graph. These are called **main-sequence stars** (the sun falls into this class). The few stars falling in the lower left portion are called *white dwarfs. The *giant



Hertzsprung–Russell diagram.

stars fall in a cluster above the main sequence and the *supergiants are above them. The diagram, which was first devised in 1911 by Ejnar Hertzsprung (1873–1969) and in 1913 by Henry Russell (1897–1957), forms the basis of the theory of *stellar evolution.

hesperidium *See* BERRY.

Hess's law If reactants can be converted into products by a series of reactions, the sum of the heats of these reactions (with due regard to their sign) is equal to the heat of reaction for direct conversion from reactants to products. More generally, the overall energy change in going from reactants to products does not depend on the route taken. The law can be used to obtain thermodynamic data that cannot be measured directly. For example, the heat of formation of ethane can be found by considering the reactions:

$$2C(s) + 3H_2(g) + 3½O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$$

The heat of this reaction is $2\Delta H_C + 3\Delta H_H$, where ΔH_C and ΔH_H are the heats of combustion of carbon and hydrogen respectively, which can be measured. By Hess' law, this is equal to the sum of the energies for two stages:

$$2C(s) + 3H_2(g) \rightarrow C_2H_6(g)$$

(the heat of formation of ethane, ΔH_f) and

$$C_2H_6(g) + 3½O_2 \rightarrow 2CO_2(g) + 3H_2O(l)$$

(the heat of combustion of ethane, ΔH_E). As ΔH_E can be measured and as

$$\Delta H_f + \Delta H_E = 2\Delta H_c + 3\Delta H_H$$

ΔH_f can be found. Another example is the use of the *Born–Haber cycle to obtain lattice energies. The law was first put forward in 1840 by the Russian chemist Germain Henri Hess (1802–50). It is sometimes called the **law of constant heat summation** and is a consequence of the law of conservation of energy.

hetero atom An odd atom in the ring of a heterocyclic compound. For instance, nitrogen is the hetero atom in pyridine.

heterochromatin *See* CHROMATIN.

heterocyclic *See* CYCLIC.

heterodont Describing animals that possess teeth of more than one type (i.e. *incisors, *canine teeth, *premolars, and *molars), each with a particular function. Most mammals are heterodont. *See* DENTITION. *Compare* HOMODONT.

heterodyne Denoting a device or method of radio reception in which *beats are produced by superimposing a locally generated radio wave on an incoming wave. In the *superheterodyne receiver the intermediate frequency is amplified and demodulated. In the **heterodyne wavemeter**, a variable-frequency local oscillator is adjusted to give a predetermined beat frequency with the incoming wave, enabling the frequency of the incoming wave to be determined.

heterogametic sex The sex that is determined by possession of two dissimilar *sex chromosomes (e.g. XY). In humans and many other mammals this is the male sex. The heterogametic sex produces reproductive cells (gametes) of two kinds, half containing an X chromosome and half a Y chromosome. *Compare* HOMOGAMETIC SEX.

heterogeneous Relating to two or more phases, e.g. a heterogeneous *catalyst. *Compare* HOMOGENEOUS.

heterolytic fission The breaking of a bond in a compound in which the two fragments are oppositely charged ions. For example, $HCl \rightarrow H^+ + Cl^-$. *Compare* HOMOLYTIC FISSION.

heteropolar bond *See* CHEMICAL BOND.

heteropoly compound *See* CLUSTER COMPOUND.

heteropolymer *See* POLYMER.

heterosis *See* HYBRID VIGOUR.

heterotrophic nutrition A type of nutrition in which energy is derived from the intake and digestion of organic substances, normally plant or animal tissues. The breakdown products of digestion are used to synthesize the organic materials required by the organism. All animals obtain their food this way: they are **heterotrophs**. *See also* INGESTION. *Compare* AUTOTROPHIC NUTRITION.

heterozygous Describing an organism or cell in which the *alleles at a given locus on *homologous chromosomes are different. The aspect of the feature displayed by the organism will be that determined by the *dominant allele. Heterozygous organisms, called **heterozygotes**, do not breed true. *Compare* HOMOZYGOUS.

heuristic Denoting a method of solving a

problem for which no *algorithm exists. It involves trial and error, as in *iteration.

Heusler alloys Ferromagnetic alloys containing no ferromagnetic elements. The original alloys contained copper, manganese, and tin and were first made by Conrad Heusler (19th-century mining engineer).

Hewish, Antony *See* RYLE, SIR MARTIN.

hexacyanoferrate(II) (ferrocyanide) A complex iron-containing anion, $[Fe(CN_6)]^{4-}$, used as a solution of its potassium salt as a test for ferric iron (iron(III)), with which it forms a dark blue precipitate of Prussian blue. The sodium salt is used as an anticaking agent in common salt.

hexacyanoferrate(III) (ferricyanide) A complex iron-containing anion, $[Fe(CN)_6)]^{3-}$, used as a solution of its potassium salt as a test for ferrous iron (iron(II)), with which it forms a dark blue precipitate of Prussian blue.

hexadecane (cetane) A colourless liquid straight-chain alkane hydrocarbon, $C_{16}H_{34}$, used in standardizing cetane ratings of Diesel fuel.

hexadecanoate *See* PALMITATE.

hexadecanoic acid *See* PALMITIC ACID.

hexagonal close packing *See* CLOSE PACKING.

hexagonal crystal *See* CRYSTAL SYSTEM.

hexahydrate A crystalline compound that has six moles of water per mole of compound.

hexamine (hexamethylene tetramine) A white crystalline compound, $C_6H_{12}N_4$, made by the condensation of methanal with ammonia. It has been used as a solid fuel for camping stoves and as an antiseptic for treating urinary infections in medicine. It is used in the production of *cyclonite.

hexanedioate (adipate) A salt or ester of hexanedioic acid.

hexanedioic acid (adipic acid) A carboxylic acid, $(CH_2)_4(COOH)_2$; r.d. 1.36; m.p. 153°C; b.p. 265°C (100 mmHg). It is used in the manufacture of *nylon 6,6. *See also* POLYMERIZATION.

6-hexanelactam *See* CAPROLACTAM.

hexanitrohexaazaisowurtzitane *See* HNIW.

hexanoate (caproate) A salt or ester of hexanoic acid.

hexanoic acid (caproic acid) A liquid fatty acid, $CH_3(CH_2)_4COOH$; r.d. 0.93; m.p. –2 to –1.5°C; b.p. 205°C. Glycerides of the acid occur naturally in cow and goat milk and in some vegetable oils.

Hexapoda (Insecta) A subphylum (or class) of arthropods comprising about a million known species (many more are thought to exist). They are distributed worldwide in nearly all terrestrial habitats. Ranging in length from 0.5 to over 300 mm, an insect's body consists of a head, a thorax of three segments and usually bearing three pairs of legs and one or two pairs of wings, and an abdomen of eleven segments. The head possesses a pair of sensory *antennae and a pair of large *compound eyes, between which are three simple eyes (*ocelli). The *mouthparts are variously adapted for either chewing or sucking, enabling insects to feed on a wide range of plant and animal material. Insects owe much of their success to having a highly waterproof *cuticle (to resist desiccation) and wings – outgrowths of the body wall that confer the greater mobility of flight. Breathing occurs through a network of tubes (*see* TRACHEA).

Most insect species have separate sexes and undergo sexual reproduction. In some, this may alternate with asexual *parthenogenesis and in a few, males are unknown and reproduction is entirely asexual. The newly hatched young grow by undergoing a series of moults. In the more primitive groups, e.g. *Dermaptera, *Orthoptera, *Dictyoptera, and *Hemiptera, the young (called a *nymph) resembles the adult. More advanced groups, e.g. *Coleoptera, *Diptera, *Lepidoptera, and *Hymenoptera, undergo *metamorphosis, in which the young (called a *larva) is transformed into a quiescent *pupa from which the fully formed adult emerges. Insects are of vital importance in many ecosystems and many are of economic significance – as pests or disease vectors or beneficially as crop pollinators or producers of silk, honey, etc.

SEE WEB LINKS

- This section of the Natural History Museum's website highlights various insect groups and other aspects of entomology

hexose A *monosaccharide that has six carbon atoms in its molecules.

hexyl group (hexyl radical) The organic group $CH_3CH_2CH_2CH_2CH_2CH_2$–, derived from hexane.

HFC (hydrofluorocarbon) *See* HALOCARBONS.

hibernation A sleeplike state in which some animals pass the winter months as a way of surviving food scarcity and cold weather. Various physiological changes occur, such as lowering of the body temperature and slowing of the pulse rate and other vital processes, and the animal lives on its reserve of body fat. Animals that hibernate include bats, hedgehogs, and many fish, amphibians, and reptiles. *See also* DORMANCY. *Compare* AESTIVATION.

hidden matter *See* MISSING MASS.

hidden-variables theory A theory that denies that the specification of a physical system given by a state described by *quantum mechanics is a complete specification. A successful hidden-variables theory has never been constructed. There are important considerations preventing the construction of a simple hidden-variables theory, notably *Bell's theorem.

The only type of hidden-variables theories that appear not to have been ruled out are **non-local hidden-variables theories**, i.e. theories in which hidden parameters can affect parts of the system in arbitrarily distant regions simultaneously. A hidden-variables theory that does not satisfy this definition is called a **local hidden-variables theory**.

hierarchy (in biology) A type of social organization in which individuals are ranked according to their status or dominance relative to other group members. This affects their behaviour in various ways, e.g. by determining their access to food or to mates. Many vertebrate animals and some invertebrates live in hierarchical social groups.

Higgs boson A spin-zero particle with a nonzero mass, predicted by Peter Higgs (1929–) to exist in certain *gauge theories, in particular in *electroweak theory (the Weinberg–Salam model). The Higgs boson has not yet been found but it is thought likely that it will be found by larger *accelerators in the next few years, especially since other associated features of the theory, including W and Z bosons, have been found.

Higgs field The symmetry-breaking field associated with a *Higgs boson. The Higgs field can either be an elementary *scalar quantity or the field associated with a *bound state of two *fermions. In the Weinberg–Salam model (*see* ELECTROWEAK THEORY), the Higgs field is taken to be a scalar field. It is not known whether this assumption is correct, although attempts to construct electroweak theory involving bound states for the Higgs field, known as **technicolour theory**, have not been successful. Higgs fields also occur in many-body systems, which can be expressed in terms of *quantum field theory with Higgs bosons; an example is the BCS theory of *superconductivity, in which the Higgs field is associated with a *Cooper pair, rather than an elementary scalar field.

higher dimensions Dimensions of space or time that exist in addition to the three space dimensions and one time dimension. Higher dimensions can be very small, as in *Kaluza–Klein theory, or large, as in the *brane world. There is no observational evidence for the existence of higher dimensions but they do appear to be a necessary part of certain fundamental theories.

high frequency (HF) A radio frequency in the range 3–30 megahertz; i.e. having a wavelength in the range 10–100 metres.

high-performance liquid chromatography (HPLC) A sensitive technique for separating or analysing mixtures, in which the sample is forced through the chromatography column under pressure.

high-speed steel A steel that will remain hard at dull red heat and can therefore be used in cutting tools for high-speed lathes. It usually contains 12–22% tungsten, up to 5% chromium, and 0.4–0.7% carbon. It may also contain small amounts of vanadium, molybdenum, and other metals.

high-temperature superconductivity *See* SUPERCONDUCTIVITY.

high tension (HT) A high potential difference, usually one of several hundred volts or more. Batteries formerly used in the anode circuits of radio devices using valves were usually called **high-tension batteries** to distinguish them from the batteries supplying the heating filaments.

high-velocity star An old population II star (*see* POPULATION TYPE) that does not orbit the galactic centre but travels far away from the plane of the Galaxy. Such stars

move no faster than the stars near them but appear to do so because of their eccentric orbits.

Hilbert space A linear *vector space that can have an infinite number of dimensions. The concept is of interest in physics because the state of a system in *quantum mechanics is represented by a vector in Hilbert space. The dimension of the Hilbert space has nothing to do with the physical dimension of the system. The Hilbert space formulation of quantum mechanics was put forward by the Hungarian-born US mathematician John von Neumann (1903–57) in 1927. Other formulations of quantum mechanics, such as *matrix mechanics and *wave mechanics, can be deduced from the Hilbert space formulation. Hilbert space is named after the German mathematician David Hilbert (1862–1943), who invented the concept early in the 20th century.

hilum A scar on the seed coat of a plant marking the point at which the seed was attached to the fruit wall by the *funicle. It is a feature that distinguishes seeds from fruits.

hindbrain (rhombencephalon) One of the three sections of the brain of a vertebrate embryo. It develops to form the *cerebellum, *pons, and *medulla oblongata, which control and coordinate fundamental physiological processes (including respiration and circulation of blood). *Compare* FOREBRAIN; MIDBRAIN.

hindgut **1.** The posterior part of the alimentary canal of vertebrates, comprising the posterior section of the colon. **2.** The posterior section of the alimentary canal of arthropods. *See also* FOREGUT; MIDGUT.

hip girdle *See* PELVIC GIRDLE.

hippocampus A part of the vertebrate brain consisting of two ridges, one over each of the two lateral *ventricles. It is highly developed in advanced mammals (primates and whales) and its function seems to be concerned with forming new memories – by encoding information that can be stored as long-term memory elsewhere in the brain.

Hirudinea A class of freshwater and terrestrial annelid worms that comprises the leeches. They have suckers at both anterior and posterior ends but no bristles. Some are blood-sucking parasites of vertebrates and invertebrates but the majority are predators.

histamine A substance that is released during allergic reactions, e.g. hay fever. Formed from the amino acid histidine, histamine can occur in various tissues but is concentrated in connective tissue. It is one of the inflammatory mediators released from mast cells in response to antigen binding to IgE antibodies on the surface of the mast cell. It causes dilation and increased permeability of small blood vessels, which results in such symptoms as localized swelling, itching, sneezing, and runny eyes and nose. The effects of histamine can be countered by the administration of *antihistamine drugs.

histidine *See* AMINO ACID.

histiocyte *See* MACROPHAGE.

histochemistry The study of the distribution of the chemical constituents of tissues by means of their chemical reactions. It utilizes such techniques as *staining, light and electron microscopy, *autoradiography, and *chromatography.

histocompatibility The degree to which tissue from one organism will be tolerated by the immune system of another organism. For any animal, it is essential that its immune system can distinguish its own tissues from foreign cells or tissues, so that only the latter are attacked. This self-recognition is achieved principally by a set of marker molecules, called **histocompatibility proteins** (or **histocompatibility antigens**), which occur on the surfaces of cells. These proteins (in humans also called **human leucocyte antigens**, or **HLAs**) are encoded in vertebrates by a cluster of genes called the *major histocompatibility complex (MHC), which in humans includes the *HLA system. Each species has a unique set of histocompatibility proteins, and there is also wide variation within any given species. This explains why in human transplantation it is very difficult to match donor and recipient tissue exactly. MHC proteins also play a vital role in the immune responses of lymphocytes, notably by enabling *T cells to identify foreign antigens.

histocompatibility protein *See* HISTOCOMPATIBILITY; HLA SYSTEM.

histology The microscopic study of the tissues of living organisms. The study of cells, a specialized branch of histology, is known as *cytology.

histone Any of a group of water-soluble proteins found in association with the *DNA of plant and animal chromosomes. They

contain a large proportion of the basic (positively charged) amino acids lysine, arginine, and histidine. They are involved in the condensation and coiling of chromosomes during cell division, and chemical modification of histones is a key aspect of suppressing or activating gene activity. Histones do not occur in vertebrate sperm cells (*see* PROTAMINE) or in bacteria.

HIV (human immunodeficiency virus) The *retrovirus that causes *AIDS in humans. It has a specific affinity for the helper *T cells of its host, binding to *CD4 antigens on the cell surface and thereby disabling these cells. The membrane envelope glycoproteins encasing the virus show great variability in their amino-acid sequences, hence the difficulty of preparing an effective AIDS vaccine. Two varieties (serovars) are known: HIV-1 and HIV-2. The latter, which is less virulent, is found chiefly in Africa. HIV is thought to have originated from chimpanzees in central Africa.

HLA system (human leucocyte antigen system) A series of gene loci, forming part of the *major histocompatibility complex in humans, that encode a group of proteins that act as antigens and are important in determining the acceptance or rejection by the body of a tissue or organ transplant (*see* GRAFT). These antigens are one group of the so-called **histocompatibility proteins** or **antigens** (*see* HISTOCOMPATIBILITY). Two individuals with identical HLA types are said to be **histocompatible**. Successful transplantation requires a minimum number of HLA differences between the donor's and recipient's tissues.

HMX (octogen; cyclotetramethylenetetranitramine) A colourless crystalline compound, $C_4H_8N_8O_8$; r.d. 1.9; m.p. 276–286°C. It has a structure similar to that of *cyclonite (RDX), but with an eight-membered ring rather than a six-membered ring. An extremely powerful explosive, it is used mainly for military purposes and as a rocket propellant. The name comes from 'High Molecular Weight RDX'.

HNIW (hexanitrohexaazaisowurtzitane) A powerful explosive, $C_6N_{12}O_{12}$. It has a three-dimensional bridged structure containing six N–NO_2 groups. Also known as **CL20**, it is extremely sensitive and so far has not been produced in bulk.

hnRNP *See* RIBONUCLEOPROTEIN.

hoar frost A deposit of interlocking ice crystals formed on objects (such as branches of trees and hedgerows) that are exposed to air in which there is *supersaturation with water vapour. The formation of hoar frost is similar to the formation of dew with the difference that the temperature of the object on which the hoar frost forms is below freezing temperature, whereas this is not the case with dew.

Hodgkin, Sir Alan *See* ECCLES, SIR JOHN CAREW.

HOE *See* HOLOGRAPHIC OPTICAL ELEMENT.

Hogness box *See* TATA BOX.

hole A vacant electron position in the lattice structure of a solid that behaves like a mobile positive *charge carrier with a negative *rest energy. *See* SEMICONDUCTOR.

holmium Symbol Ho. A soft silvery metallic element belonging to the *lanthanoids; a.n. 67; r.a.m. 164.93; r.d. 8.795 (20°C); m.p. 1474°C; b.p. 2695°C. It occurs in apatite, xenotime, and some other rare-earth minerals. There is one natural isotope, holmium–165; eighteen artificial isotopes have been produced. There are no uses for the element, which was discovered by Per Cleve (1840–1905) and J. L. Soret in 1879.

SEE WEB LINKS

- Information from the WebElements site

Holocene (Recent) The most recent geological epoch of the *Neogene period, comprising roughly the past 11 500 years since the end of the *Pleistocene up to the present. It follows the final glacial of the Pleistocene and thus is sometimes known as the **Postglacial** epoch. Some geologists consider the Holocene to be an interglacial phase of the Pleistocene that will be followed by another glacial.

holocrine secretion *See* SECRETION.

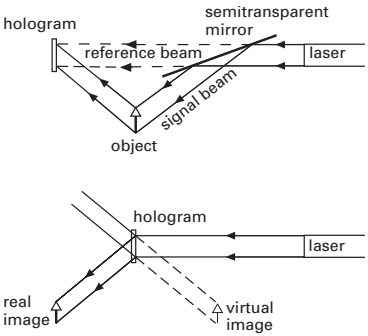
holoenzyme A complex comprising an enzyme molecule and its *cofactor. Only in this state is an enzyme catalytically active. *Compare* APOENZYME.

holographic hypothesis A key principle of *quantum gravity postulating that it is possible to obtain information about the bulk of a system, such as a black hole, from the surface of that system. This hypothesis was suggested as a general feature of quantum gravity in the mid-1990s and found

to hold in superstring theory a few years later.

holographic optical element (HOE) An optical device consisting of a hologram, used to focus or deflect electromagnetic radiation. Holographic optical elements are relatively easy to make and can function as lenses, mirrors, diffraction gratings, beam splitters, etc., in place of more traditional optical components.

holography A method of recording and displaying a three-dimensional image of an object, usually using *coherent radiation from a *laser and photographic plates (see illustration). The light from a laser is divided so that some of it (the reference beam) falls directly on a photographic plate. The other part illuminates the object, which reflects it back onto the photographic plate. The two beams form interference patterns on the plate, which when developed is called the **hologram**. To reproduce the image of the object, the hologram is illuminated by coherent light, ideally the original reference beam. The hologram produces two sets of diffracted waves; one set forms a virtual image coinciding with the original object position and the other forms a real image on the other side of the plate. Both are three-dimensional. The method was invented by Dennis Gabor in 1948. More recent techniques can produce holograms visible in white light.



Holography.

holohedral form The form of a crystal in which the full number of faces required for the symmetry are present. *Compare* HOLOHEDRAL FORM.

holophytic Describing organisms that feed like plants, i.e. that are photoautotrophic. *See* AUTOTROPHIC NUTRITION.

holotype *See* TYPE SPECIMEN.

holozoic Describing organisms that feed by ingesting complex organic matter, which is subsequently digested and absorbed. *See* HETEROTROPHIC NUTRITION; INGESTION.

homeobox A nucleotide sequence containing about 180 base pairs, which are identical or very similar in many eukaryotic organisms, that encodes a series of amino acids known as a **homeodomain**. Present in many eukaryotic regulatory proteins, this sequence is an important region involved in the binding of regulatory proteins to the DNA molecule. A homeobox was first identified in the *homeotic genes of *Drosophila* and has since been found in the homeotic genes of many animals (including humans) and in plants.

homeostasis The regulation by an organism of the chemical composition of its body fluids and other aspects of its *internal environment so that physiological processes can proceed at optimum rates. It involves monitoring changes in the external and internal environment by means of *receptors and adjusting the composition of the body fluids accordingly; *excretion and *osmoregulation are important in this process. Examples of homeostatic regulation are the maintenance of the *acid–base balance and body temperature (*see* HOMOIOTHERMY; POIKILOTHERMY).

homeotic genes A class of genes that play a central role in controlling the early development and differentiation of embryonic tissues in eukaryotic organisms. They include the **Hox genes**, which control the development of structures along the head-to-tail (anteroposterior) axis of a wide range of animals. Homeotic genes code for proteins that bind DNA and regulate the expression of a wide range of other genes. This binding capability resides in a structural domain of the protein called a **homeodomain**, encoded by a nucleotide sequence (*homeobox) that is characteristic of homeotic genes. These genes were first identified in *Drosophila* fruit flies, through the occurrence of mutations that cause the transformation of one organ into another – the phenomenon of **homeosis**. In vertebrates there are four clusters of homeotic genes located on separate chromosomes.

hominid Any member of the primate family Hominidae, which includes humans and their fossil ancestors (**fossil hominids**) in the genus **Homo*. This family is now widely regarded as also including the extant great apes (chimpanzees, gorillas, orang-utan, formerly constituting the family Pongidae) and extinct groups, such as **Australopithecus* and **Dryopithecus*.

SEE WEB LINKS

- Interactive documentary narrated by palaeontologist Donald Johanson and presented by the Institute of Human Origins, Arizona State University

Homo The genus of primates that includes modern humans (*H. sapiens*, the only living representative) and various extinct species. The oldest *Homo* fossils are those of *H. habilis* and *H. rudolfensis*, which first appeared in Africa 2.2–2.4 million years ago. Both species used simple stone tools. *H. habilis* appears to have been 1–1.5 m tall and had more human-like features and a larger brain than **Australopithecus*. *H. erectus* diverged from *H. ergaster* in Africa and subsequently spread to Asia between 1.8 and 1.5 million years ago. Fossils of *H. erectus*, which was formerly called *Pithecanthropus* (ape man), include Java man and Peking man. They are similar to present-day humans except that there was a prominent ridge above the eyes and no forehead or chin. They used crude stone tools and fire. *H. ergaster* may also have given rise to *H. heidelbergensis* (represented by Heidelberg man and Boxgrove man). This species now contains all hominid specimens with a mixture of 'erectus-like' and 'modern' characters, dating from some 800 000 years ago to the emergence of *H. sapiens* between 130 000 and 90 000 years ago. Among them are the ancestors of both *H. neanderthalensis* (*Neanderthal man) and *H. sapiens*. *See also* CROMAGNON MAN.

homocyclic *See* CYCLIC.

homodont Describing animals whose teeth are all of the same type. Most vertebrates except mammals are homodont. *Compare* HETERODONT.

homogametic sex The sex that is determined by possession of two similar *sex chromosomes (e.g. XX). In humans and many other mammals this is the female sex. All the reproductive cells (gametes) produced by the homogametic sex have the same kind of sex chromosome (i.e. an X chromosome). *Compare* HETEROGAMETIC SEX.

homogamy The condition in a flower in which the male and female reproductive organs mature at the same time, allowing self-fertilization. *Compare* DICHOGAMY.

homogeneous Relating to only one phase, e.g. a homogeneous mixture, a homogeneous *catalyst. *Compare* HETEROGENEOUS.

homoiothermy The maintenance by an animal of its internal body temperature at a relatively constant value by using metabolic processes to counteract fluctuations in the temperature of the environment. Homoiothermy occurs in birds and mammals, which are described as *endotherms. The heat produced by their tissue metabolism and the heat lost to the environment are balanced by various means to keep body temperature constant: 36–38°C in mammals and 38–40°C in birds. The *hypothalamus in the brain monitors blood temperature and controls thermoregulation by both nervous and hormonal means. This produces both short-term responses, such as shivering or sweating, and long-term adjustments to metabolism according to seasonal changes in climate (acclimatization). Endotherms generally possess insulating feathers or fur. Their relatively high internal temperature permits fast action of muscles and nerves and enables them to lead highly active lives even in cold climates. However, in certain animals, homoiothermy is abandoned during periods of *hibernation. *Compare* POIKILOTHERMY.

homoleptic compound A chemical complex with only one type of ligand, as in nickel carbonyl or lead tetraethyl.

homologous (in biology) Describing a character that is shared by a group of species because it is inherited from a common ancestor. Such characters, called **homologies**, are used in *cladistics to determine the evolutionary relationships of species or higher taxa. They are divided into two types: a **shared derived homology** is unique to a particular group and may be used to define a *monophyletic group; a **shared ancestral homology** is not unique to the group, or may not be exhibited by all descendants of the ancestor in which it arose. Even though homologous features share the same evolutionary origin, they may have developed

different functions. For example the wings of a bat, the flippers of a dolphin, and the arms of a human are homologous organs, having evolved from the paired pectoral fins of a fish ancestor. *Compare* ANALOGOUS.

homologous chromosomes Chromosomes having the same pattern of genes along their lengths although the nature of the genes may differ (*see* ALLELE). In *diploid nuclei, pairs of homologous chromosomes form bivalents at the start of *meiosis (*see* PAIRING). One member of each pair comes from the female parent and the other from the male.

homologous series A series of related chemical compounds that have the same functional group(s) but differ in formula by a fixed group of atoms. For instance, the simple carboxylic acids: methanoic (HCOOH), ethanoic (CH_3COOH), propanoic (C_2H_5COOH), etc., form a homologous series in which each member differs from the next by CH_2. Successive members of such a series are called **homologues**.

homolytic fission The breaking of a bond in a compound in which the fragments are uncharged free radicals. For example, $Cl_2 \rightarrow Cl\cdot + Cl\cdot$. *Compare* HETEROLYTIC FISSION.

homoplasy The similarity of a particular character in two different, yet often related, groups of organisms that is not the result of common ancestry. Such a similarity may arise due to convergent or parallel evolution, and is therefore potentially misleading when examining shared characters in constructing phylogenetic trees (*see* CLADISTICS). For example, wings in bats and birds are a convergent, and therefore homoplasic, character.

homopolar bond *See* CHEMICAL BOND.

homopolar generator A simple electric generator consisting of a metal disc rotating between two poles of a magnet. Contacts are made to the axle and the rim of the disc. A radial e.m.f. is produced. At constant rotational speed, the device produces a steady direct current and generators of this type are used in certain specialized applications. It can also be used as a simple motor if a direct current is supplied. A device of this type (known as the **Barlow wheel**) was invented in 1822 by the physicist Peter Barlow (1776–1862). This had a star-shaped wheel with the points of the star dipping into a pool of mercury to give the electrical contact. A generator with a disc was used by Michael Faraday in his experiments, and the device is sometimes known as the **Faraday disc**.

homopolymer *See* POLYMER.

homozygous Describing an organism or cell in which the *alleles at a given locus on homologous chromosomes are identical (they may be either dominant or recessive). Homozygous organisms, which are called **homozygotes**, breed true when crossed with genetically identical organisms. *Compare* HETEROZYGOUS.

Hooke, Robert (1635–1703) English physicist, who worked at Oxford University, where he assisted Robert *Boyle. Among his many achievements were the law of elasticity (*see* HOOKE'S LAW), the watch balance wheel, and the compound *microscope. In 1665, using his microscope to study vegetable tissues, he saw 'little boxes', which he named 'cells'.

Hooke's law The *stress applied to any solid is proportional to the *strain it produces within the elastic limit for that solid. The ratio of longitudinal stress to strain is equal to the Young modulus of elasticity (*see* ELASTIC MODULUS). The law was first stated by Robert Hooke in the form "Ut tensio, sic vis."

hormone **1.** A substance that is manufactured and secreted in very small quantities into the bloodstream by an *endocrine gland or a specialized nerve cell (*see* NEUROHORMONE) and regulates the growth or functioning of a specific tissue or organ in a distant part of the body. For example, the hormone *insulin controls the rate and manner in which glucose is used by the body. Other hormones include the *sex hormones, *corticosteroids, *adrenaline, *thyroxine, and *growth hormone. **2.** *See* PLANT HORMONE.

hornblende Any of a group of common rock-forming minerals of the amphibole group with the generalized formula:

$$(Ca,Na)_2(Mg,Fe,Al)_5(Al,Si)_8O_{22}(OH,F)_2$$

Hornblendes consist mainly of calcium, iron, and magnesium silicate.

horsepower (hp) An imperial unit of power originally defined as 550 foot-pound force per second; it is equal to 745.7 watts.

horsetails *See* SPHENOPHYTA.

horst *See* GRABEN.

host An organism whose body provides nourishment and shelter for a parasite (*see* PARASITISM). A **definitive** (or **primary**) **host** is one in which an animal parasite becomes sexually mature; an **intermediate** (or **secondary**) **host** is one in which the parasite passes the larval or asexual stages of its life cycle.

host–guest chemistry *See* SUPRAMOLECULAR CHEMISTRY.

hot-wire instrument An electrical measuring instrument (basically an ammeter) in which the current to be measured is passed through a thin wire and causes its temperature to rise. The temperature rise, which is proportional to the square of the current, is measured by the expansion of the wire. Such instruments can be used for either direct current or alternating current.

***Hox* genes** *See* HOMEOTIC GENES.

Hoyle, Sir Fred (1915–2001) British astronomer, who in 1958 became a professor of astronomy at Cambridge University. He is best known for his proposal in 1948, with Hermann Bondi (1919–2005) and Thomas Gold (1920–2004), of the *steady-state theory of the universe. He also carried out theoretical work on the formation of elements in stars.

HPLC *See* HIGH-PERFORMANCE LIQUID CHROMATOGRAPHY.

HSAB principle A method of classifying Lewis acids and bases (*see* ACID) developed by Ralph Pearson in the 1960s. The acronym stands for 'hard and soft acids and bases'. It is based in empirical measurements of stability of compounds with certain ligands. **Hard acids** tend to complex with halide ions in the order

$$F^- > Cl^- > Br^- > I^-$$

Soft acids complex in the opposite order. Compounds that complex with hard acids are **hard bases**; ones that more readily form complexes with soft acids are called **soft bases**. In general, soft acids and bases are more easily polarized than hard acids and bases and consequently have more covalent character in the bond. The idea is an extension of the *type A and B metals concept to compounds other than metal complexes.

HTML (hypertext markup language) The computer data format used to transfer and display data on the *World Wide Web. It involves a set of rules for codes inserted into text files to indicate such things as special typefaces, paragraph breaks, illustration positions, and links to other *hypertext pages.

SEE WEB LINKS

- The HTML (version 4.01) specification

HTTP Hypertext transport protocol: an application-level protocol with the lightness and speed necessary for distributed collaborative hypermedia information systems. It is generic, stateless, and object-oriented, with typing and negotiation of data representation, allowing systems to be built independently of the data being transferred. By extension of its request methods (commands), it can be used for many tasks, such as name servers and distributed object-management systems. HTTP has been in use by the *World Wide Web since 1990.

SEE WEB LINKS

- The HTTP (version 1.1) specification

Hubble, Edwin Powell (1889–1953) US astronomer, who worked at both the Yerkes Observatory and the Mount Wilson Observatory. Most of his studies involved nebulae and galaxies, which he classified in 1926. In 1929 he established the *Hubble constant, which enabled him to estimate the age of the universe. The *Hubble space telescope is named after him.

Hubble constant The rate at which the velocity of recession of the galaxies increases with distance as determined by the *redshift. The value is not agreed upon but current measurements indicate that it lies between 49 and 95 km s^{-1} per megaparsec. The reciprocal of the Hubble constant, the **Hubble time**, is a measure of the age of the universe, assuming that the expansion rate has remained constant. In fact, it is necessary to take account of the fact that the expansion of the universe is accelerating to get an accurate determination of its age.

Hubble space telescope An orbiting telescope managed by the US National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) and launched in April 1990, operating in the ultraviolet, visible, and near-infrared regions of the spectrum at high resolution free from the distorting effects of the earth's atmosphere. After five servicing missions (1993–2009), the telescope continues to add to the wealth of spectacular images and other data

that it had already provided, expanding our understanding of the universe, especially its early phases.

Hückel rule *See* AROMATIC COMPOUND.

hue *See* COLOUR.

Hulse–Taylor pulsar A binary system discovered in 1974 consisting of a pulsar orbiting with a companion star. It was used to demonstrate, by measurements of a period of time, that the system was emitting gravitational waves. It is named after the US physicists Russell Hulse (1950–) and Joseph Taylor (1941–).

human chorionic gonadotrophin (hCG) *See* GONADOTROPHIN.

Human Genome Project A coordinated international project, begun in 1988, to map the entire human *genome so that the genes could be isolated and sequenced (*see* DNA SEQUENCING). It involved the production of a *DNA library. The haploid human genome contains about 3×10^9 nucleotide base pairs, but only 22 000 – 25 000 genes. The full draft sequence was completed in 2000 and published in February 2001, and the high-quality finished sequence was completed in April 2003, two years ahead of schedule.

human growth hormone (hGH) *See* GROWTH HORMONE.

human immunodeficiency virus *See* HIV.

Hume-Rothery rules A set of empirical rules put forward in 1926 by the British metallurgist William Hume-Rothery (1899–1968) to describe how one metal dissolves in another metal. He found that one metallic element will not dissolve in another if the difference in their atomic radii is greater than 15 per cent or if the electronegativities of the two elements differ substantially. Also, a metal with a lower valency is more likely to dissolve in one with a higher valency, than vice versa. These rules were subsequently justified by the quantum theory of electrons in solids.

humerus The long bone of the upper arm of tetrapod vertebrates. It articulates with the *scapula (shoulder blade) at the *glenoid cavity and with the *ulna and *radius (via a *condyle) at the elbow.

humidity The concentration of water vapour in the atmosphere. The **absolute humidity** is the mass of water vapour per unit volume of air, usually expressed in kg m^{-3}. **Relative humidity** is the ratio, expressed as a percentage, of the moisture in the air to the moisture it would contain if it were saturated at the same temperature and pressure. **Specific humidity** is also sometimes used: this is the mass of water vapour in the atmosphere per unit mass of air. *See also* HYGROMETER.

humoral Relating to the blood or other body fluids. For example, **humoral immunity** is immunity conferred by the antibodies present in the blood, lymph, and tissue fluids (*see* IMMUNITY).

humus The dark-coloured amorphous colloidal material that constitutes the organic component of soil. It is formed by the decomposition of plant and animal remains and excrement (*see* LITTER) and has a complex and variable chemical composition. Being a colloid, it can hold water and therefore improves the water-retaining properties of soil; it also enhances soil fertility and workability. Acidic humus (**mor**) is found in regions of coniferous forest, where the decay is brought about mainly by fungi. Alkaline humus (**mull**) is typically found in grassland and deciduous forest: it supports an abundance of microorganisms and small animals (e.g. earthworms).

Hund coupling cases *See* COUPLING.

Hund's rules Empirical rules in atomic *spectra that determine the lowest energy level for a configuration of two equivalent electrons (i.e. electrons with the same n and l quantum numbers), in a many-electron atom. (1) The lowest energy state has the maximum *multiplicity consistent with the *Pauli exclusion principle. (2) The lowest energy state has the maximum total electron *orbital angular momentum quantum number, consistent with rule (1). These rules were put forward by the German physicist Friedrich Hund (1896–1997) in 1925.

hunting The oscillation of a gauge needle or engine speed about a mean value. In a rotating mechanism, set to operate at a constant speed, pulsation above and below the set speed can occur, especially if the speed is controlled by a governor. It can be corrected using a damping device.

hurricane **1.** A *tropical cyclone with surface wind speeds in excess of 64 knots (117 km/h) that occurs in the North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and eastern and central North Pacific Ocean

(east of the dateline). (Tropical cyclones that occur in the North Pacific Ocean are known as **typhoons**.) Hurricanes cause widespread damage over land areas and are a considerable hazard to shipping. In order for a hurricane to form, an extensive area of ocean (at least 5° of latitude from the equator) must have a surface temperature in excess of 27°C. At the earth's surface a hurricane appears as a roughly circular vortex with the **eye** at the centre, in which pressure is very low. Winds spiral around this core at great speed in an anticlockwise direction in the northern hemisphere. A hurricane is usually accompanied by deep clouds and torrential rain over a wide area. **2.** *See* BEAUFORT WIND SCALE.

Hutton, James (1726–97) British geologist, born in Scotland. He studied law, medicine, and industrial chemistry before returning to Edinburgh in 1768 to devote himself to geology. He advocated the theory that contemporary geological processes are the same as those that have always prevailed. This theory was not generally accepted until popularized by John Playfair (1748–1819) and championed by Charles *Lyell.

Huxley, Sir Andrew *See* ECCLES, SIR JOHN CAREW.

Huygens, Christiaan (1629–95) Dutch astronomer and physicist. Born in the Hague, he made several visits to Paris between 1655 and 1681 and in 1666 became a founding member of the French Academy of Sciences. In 1657 he designed the first pendulum clock and wrote a description of it. He had already made improvements to astronomical telescopes, with which he discovered Saturn's satellite Titan in 1655 and the true shape of Saturn's rings in 1659. His greatest achievement, however, was the wave theory of light, announced in 1690 (*see* HUYGENS' CONSTRUCTION).

Huygens' construction (Huygens' principle) Every point on a wavefront may itself be regarded as a source of secondary waves. Thus, if the position of a wavefront at any instant is known, a simple construction enables its position to be drawn at any subsequent time. The construction was first used by Christiaan Huygens.

hyaline cartilage *See* CARTILAGE.

hyaluronic acid A *glycosaminoglycan (mucopolysaccharide) that is part of the *ground substance of connective tissue. Hyaluronic acid is a major component of articular cartliage, helping in tissue repair and the lubrication of joints. It also plays a role in cell movement and proliferation.

hyaluronidase Any of a family of enzymes that break down *hyaluronic acid, thereby decreasing its viscosity and increasing the permeability of connective tissue. They are used in medicine to increase the absorption and diffusion of drugs administered by injection or application.

hybrid The offspring of a mating in which the parents differ in at least one characteristic. The term is usually used of offspring of widely different parents, e.g. different varieties or species. Hybrids between different animal species are usually sterile. *See also* HYBRID VIGOUR.

hybridization **1.** The production of one or more *hybrid organisms by the mating of genetically different parents. **2.** The production of hybrid cells. *See* CELL FUSION (somatic cell hybridization). **3.** *See* DNA HYBRIDIZATION.

hybridoma A type of hybrid cell that is produced by the fusion of a tumour cell (a myeloma cell) with a normal antibody-producing *B cell (*see* CELL FUSION). The resulting hybrid cell line is able to produce large amounts of normal antibody, which is described as monoclonal (*see* MONOCLONAL ANTIBODY) as it results from a cloned cell line.

hybrid orbital *See* ORBITAL.

hybrid vigour (heterosis) The increased vigour displayed by the offspring from a cross between genetically different parents. Hybrids from crosses between different crop varieties (F_1 hybrids) are often stronger and produce better yields than the original varieties. Mules, the offspring of mares crossed with donkeys, have greater strength and resistance to disease and a longer lifespan than either parent.

hydathode A pore found in the *epidermis of the leaves of certain plants. Like *stomata, hydathodes are surrounded by two crescent-shaped cells but these, unlike guard cells, do not regulate the size of the aperture. Hydathodes secrete water under conditions in which *transpiration is inhibited; for example, when the atmosphere is very humid. This process of water loss is called **guttation**.

hydracid *See* BINARY ACID.

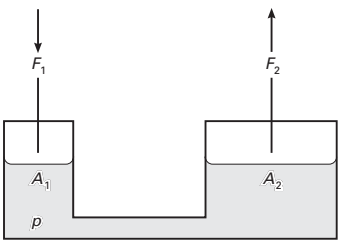
hydrate A substance formed by combination of a compound with water. *See* WATER OF CRYSTALLIZATION.

hydrated alumina *See* ALUMINIUM HYDROXIDE.

hydrated aluminium hydroxide *See* ALUMINIUM HYDROXIDE.

hydration *See* SOLVATION.

hydraulic press A device in which a force (F_1) applied to a small piston (A_1) creates a pressure (p), which is transmitted through a fluid to a larger piston (A_2), where it gives rise to a larger force (F_2): see illustration. This depends on Pascal's principle that the pressure applied anywhere in an enclosed fluid is transmitted equally in all directions. The principle of the hydraulic press is widely used in jacks, vehicle brakes, presses, and earth-moving machinery, usually with oil as the working fluid.



Hydraulic press.

hydraulics The study of water or other fluids at rest or in motion, particularly with respect to their engineering uses. The study is based on the principles of *hydrostatics and *hydrodynamics.

hydrazine A colourless liquid or white crystalline solid, N_2H_4; r.d. 1.01 (liquid); m.p. 1.4°C; b.p. 113.5°C. It is very soluble in water and soluble in ethanol. Hydrazine is prepared by the **Raschig synthesis** in which ammonia reacts with sodium(I) chlorate (sodium hypochlorite) to give NH_2Cl, which then undergoes further reaction with ammonia to give N_2H_4. Industrial production must be carefully controlled to avoid a side reaction leading to NH_4Cl. The compound is a weak base giving rise to two series of salts, those based on $N_2H_5^+$, which are stable in water (sometimes written in the form $N_2H_4.HCl$ rather than $N_2H_5^+Cl^-$), and a less stable and extensively hydrolysed series based on $N_2H_6^{2+}$. Hydrazine is a powerful reducing agent and reacts violently with many oxidizing agents, hence its use as a rocket propellant. It reacts with aldehydes and ketones to give *hydrazones.

hydrazoic acid *See* HYDROGEN AZIDE.

hydrazones Organic compounds containing the group $=C:NNH_2$, formed by condensation of substituted hydrazines with with aldehydes and ketones (see illustration). **Phenylhydrazones** contain the group $=C:NNHC_6H_5$.

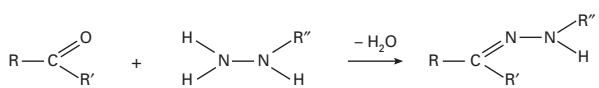
SEE WEB LINKS

- Information about IUPAC nomenclature

hydride A chemical compound of hydrogen and another element or elements. Nonmetallic hydrides (e.g. ammonia, methane, water) are covalently bonded. The alkali metals and alkaline earths (**s*-block elements) form salt-like hydrides containing the hydride ion H^-, which produce hydrogen on reacting with water. Hydride-forming *transition elements form interstitial hydrides, with the hydrogen atoms 'trapped' within the gaps in the lattice of metal atoms. Complex hydrides, such as *lithium tetrahydroaluminate(III), have hydride ions as *ligands; many are powerful reducing agents.

hydriodic acid An acid made by dissolving *hydrogen iodide in water. On standing in air it is slowly oxidized to iodine (making the solution brown); it finds use as a reducing agent.

hydrobromic acid *See* HYDROGEN BROMIDE.



Hydrazones. Formation of a hydrazone from a ketone; the same reaction occurs with an aldehyde (R′ = H). If R″ = C_6H_5, the product is phenylhydrazone.

hydrocarbons Chemical compounds that contain only carbon and hydrogen. A vast number of hydrocarbon compounds exist, the main types being the *alkanes, *alkenes, *alkynes, and *arenes.

hydrochloric acid *See* HYDROGEN CHLORIDE.

hydrochloride *See* AMINE SALTS.

hydrochlorofluorocarbon (HCFC) *See* HALOCARBONS.

hydrocortisone *See* CORTISOL.

hydrocyanic acid *See* HYDROGEN CYANIDE.

hydrodynamics The study of the motion of incompressible fluids and the interaction of such fluids with their boundaries.

hydroelectric power Electric power generated by a flow of water. A natural waterfall provides a source of energy, in the form of falling water, which can be used to drive a water *turbine. This turbine can be coupled to a generator to provide electrical energy. Hydroelectric generators can be arranged to work in reverse so that during periods of low power demand current can be fed to the generator, which acts as a motor. This motor drives the turbine, which then acts as a pump. The pump then raises water to an elevated reservoir so that it can be used to provide extra power at peak-load periods.

hydrofluoric acid *See* HYDROGEN FLUORIDE.

hydrofluorocarbon (HFC) *See* HALOCARBONS.

hydrogen Symbol H. A colourless odourless gaseous chemical element; a.n. 1; r.a.m. 1.008; d. 0.0899 g dm^{-3}; m.p. –259.14°C; b.p. –252.87°C. It is the lightest element and the most abundant in the universe. It is present in water and in all organic compounds. There are three isotopes: naturally occurring hydrogen consists of the two stable isotopes hydrogen–1 (99.985%) and *deuterium. The radioactive *tritium is made artificially. The gas is diatomic and has two forms: **orthohydrogen**, in which the nuclear spins are parallel, and **parahydrogen**, in which they are antiparallel. At normal temperatures the gas is 25% parahydrogen. In the liquid it is 99.8% parahydrogen. The main source of hydrogen is steam *reforming of natural gas. It can also be made by the Bosch process (*see* HABER PROCESS) and by electrolysis of water. The main use is in the Haber process for making ammonia. Hydrogen is also used in various other industrial processes, such as the reduction of oxide ores, the refining of petroleum, the production of hydrocarbons from coal, and the hydrogenation of vegetable oils. Considerable interest has also been shown in its potential use in a 'hydrogen fuel economy' in which primary energy sources not based on fossil fuels (e.g. nuclear, solar, or geothermal energy) are used to produce electricity, which is employed in electrolysing water. The hydrogen formed is stored as liquid hydrogen or as metal *hydrides. Chemically, hydrogen reacts with most elements. It was discovered by Henry Cavendish in 1776.

SEE WEB LINKS

- Information from the WebElements site

hydrogen acceptor *See* HYDROGEN CARRIER.

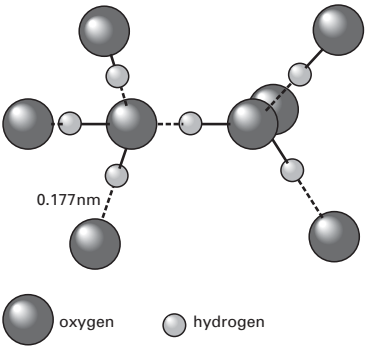
hydrogenation **1.** A chemical reaction with hydrogen; in particular, an addition reaction in which hydrogen adds to an unsaturated compound. Nickel is a good catalyst for such reactions. **2.** The process of converting coal to oil by making the carbon in the coal combine with hydrogen to form hydrocarbons. *See* FISCHER–TROPSCH PROCESS; BERGIUS PROCESS.

hydrogen azide (hydrazoic acid; **azoimide)** A colourless liquid, HN_3; r.d. 1.09; m.p. –80°C; b.p. 37°C. It is highly toxic and a powerful reductant, which explodes in the presence of oxygen and other oxidizing agents. It is prepared by the reaction of sodium amide and sodium nitrate at 175°C followed by distillation of a mixture of the resulting sodium azide and a dilute acid. *See also* AZIDES.

hydrogen bomb *See* NUCLEAR WEAPONS.

hydrogen bond A type of electrostatic interaction between electronegative atoms (fluorine, nitrogen, or oxygen) in one molecule and hydrogen atoms bound to electronegative atoms in another molecule. It is a strong dipole–dipole attraction caused by the electron-withdrawing properties of the electronegative atom. Thus, in the water molecule the oxygen atom attracts the electrons in the O–H bonds. The hydrogen atom has no inner shells of electrons to shield the nucleus, and there is an electrostatic interaction between the hydrogen proton and a lone pair of electrons on an oxygen atom in a neighbouring molecule. Each oxygen atom

has two lone pairs and can make hydrogen bonds to two different hydrogen atoms. The strengths of hydrogen bonds are about one tenth of the strengths of normal covalent bonds. Hydrogen bonding does, however, have significant effects on physical properties. Thus it accounts for the unusual properties of *water and for the relatively high boiling points of H_2O, HF, and NH_3 (compared with H_2S, HCl, and PH_3). It is also of great importance in living organisms. Hydrogen bonding occurs between bases in the chains of DNA (*see* BASE PAIRING). It also occurs between the C=O and N–H groups in proteins, and is responsible for maintaining the secondary structure.



Hydrogen bonds. Shown as dotted lines between water molecules.

hydrogen bromide A colourless gas, HBr; m.p. –88.5°C; b.p. –67°C. It can be made by direct combination of the elements using a platinum catalyst. It is a strong acid dissociating extensively in solution (**hydrobromic acid**).

hydrogencarbonate (bicarbonate) A salt of *carbonic acid in which one hydrogen atom has been replaced; it thus contains the hydrogencarbonate ion HCO_3^-.

hydrogen carrier (hydrogen acceptor) A molecule that accepts hydrogen atoms or ions, becoming reduced in the process (*see* OXIDATION–REDUCTION). The *electron transport system, whose function is to generate energy in the form of ATP during respiration, involves a series of hydrogen carriers, including *NAD and *FAD, which pass on the hydrogen (derived from the breakdown of glucose) to the next carrier in the chain.

hydrogen chloride A colourless fuming gas, HCl; m.p. –114.8°C; b.p. –85°C. It can be prepared in the laboratory by heating sodium chloride with concentrated sulphuric acid (hence the former name **spirits of salt**). Industrially it is made directly from the elements at high temperature and used in the manufacture of PVC and other chloro compounds. It is a strong acid and dissociates fully in solution (**hydrochloric acid**).

hydrogen cyanide (hydrocyanic acid; prussic acid) A colourless liquid or gas, HCN, with a characteristic odour of almonds; r.d. 0.699 (liquid at 22°C); m.p. –14°C; b.p. 26°C. It is an extremely poisonous substance formed by the action of acids on metal cyanides. Industrially, it is made by catalytic oxidation of ammonia and methane with air and is used in producing acrylate plastics. Hydrogen cyanide is a weak acid ($K_a = 2.1 \times 10^{-9}$ mol dm^{-3}). With organic carbonyl compounds it forms *cyanohydrins.

hydrogen electrode *See* HYDROGEN HALF CELL.

hydrogen fluoride A colourless liquid, HF; r.d. 0.99; m.p. –83°C; b.p. 19.5°C. It can be made by the action of sulphuric acid on calcium fluoride. The compound is an extremely corrosive fluorinating agent, which attacks glass. It is unlike the other hydrogen halides in being a liquid (a result of *hydrogen-bond formation). It is also a weaker acid than the others because the small size of the fluorine atom means that the H–F bond is shorter and stronger. Solutions of hydrogen fluoride in water are known as **hydrofluoric acid**.

hydrogen half cell (hydrogen electrode) A type of *half cell in which a metal foil is immersed in a solution of hydrogen ions and hydrogen gas is bubbled over the foil. The standard hydrogen electrode, used in measuring standard *electrode potentials, uses a platinum foil with a 1.0 M solution of hydrogen ions, the gas at 1 atmosphere pressure, and a temperature of 25°C. It is written $Pt(s)|H_2(g), H^+(aq)$, the effective reaction being $H_2 \rightarrow 2H^+ + 2e$.

hydrogenic Describing an atom or ion that has only one electron; for example, H, He^+, Li^{2+}, C^{5+}. Hydrogenic atoms (or ions) do not involve electron–electron interactions and are easier to treat theoretically.

hydrogen iodide A colourless gas, HI;

m.p. –51°C; b.p. –35.38°C. It can be made by direct combination of the elements using a platinum catalyst. It is a strong acid, dissociating extensively in solution (**hydroiodic acid**), and a reducing agent.

hydrogen ion *See* ACID; PH SCALE.

hydrogen molecule ion The simplest type of molecule (H_2^+), consisting of two hydrogen nuclei and one electron. In the *Born–Oppenheimer approximation, in which the nuclei are regarded as being fixed, the *Schrödinger equation for the hydrogen molecule ion can be solved exactly. This enables ideas and approximation techniques concerned with chemical bonding to be tested quantitatively.

hydrogen peroxide A colourless or pale blue viscous unstable liquid, H_2O_2; r.d. 1.44; m.p. –0.41°C; b.p. 150.2°C. As with water, there is considerable hydrogen bonding in the liquid, which has a high dielectric constant. It can be made in the laboratory by adding dilute acid to barium peroxide at 0°C. Large quantities are made commercially by electrolysis of $KHSO_4.H_2SO_4$ solutions. Another industrial process involves catalytic oxidation (using nickel, palladium, or platinum with an anthraquinone) of hydrogen and water in the presence of oxygen. Hydrogen peroxide readily decomposes in light or in the presence of metal ions to give water and oxygen. It is usually supplied in solutions designated by volume strength. For example, 20-volume hydrogen peroxide would yield 20 volumes of oxygen per volume of solution. Although the *peroxides are formally salts of H_2O_2, the compound is essentially neutral. Thus, the acidity constant of the ionization

$$H_2O_2 + H_2O \rightleftharpoons H_3O^+ + HO_2^-$$

is 1.5×10^{-12} mol dm^{-3}. It is a strong oxidizing agent, hence its use as a mild antiseptic and as a bleaching agent for cloth, hair, etc. It has also been used as an oxidant in rocket fuels.

hydrogen spectrum The atomic spectrum of hydrogen is characterized by lines corresponding to radiation quanta of sharply defined energy. A graph of the frequencies at which these lines occur against the ordinal number that characterizes their position in the series of lines, produces a smooth curve indicating that they obey a formal law. In 1885 Johann Balmer (1825–98) discovered the law having the form:

$$1/\lambda = R(1/n_1^2 - 1/n_2^2)$$

This law gives the so-called **Balmer series** of lines in the visible spectrum in which $n_1 = 2$ and $n_2 = 3,4,5,\ldots$, λ is the wavelength associated with the lines, and R is the *Rydberg constant.

In the **Lyman series**, discovered by Theodore Lyman (1874–1954), $n_1 = 1$ and the lines fall in the ultraviolet. The Lyman series is the strongest feature of the solar spectrum as observed by rockets and satellites above the earth's atmosphere. In the **Paschen series**, discovered by Louis Paschen (1865–1947), $n_1 = 3$ and the lines occur in the far infrared. The **Brackett series** ($n_1 = 4$), **Pfund series** ($n_1 = 5$), and **Humphreys series** ($n_1 = 6$) also occur in the far infrared.

SEE WEB LINKS

- A translation of Balmer's 1885 paper on the spectral lines of hydrogen in *Annalen der Physik und Chemie*

hydrogensulphate (bisulphate) A salt containing the ion HSO_4^- or an ester of the type $RHSO_4$, where R is an organic group. It was formerly called **hydrosulphate**.

hydrogen sulphide (sulphuretted hydrogen) A gas, H_2S, with an odour of rotten eggs; r.d. 1.54 (liquid); m.p. –85.5°C; b.p. –60.7°C. It is soluble in water and ethanol and may be prepared by the action of mineral acids on metal sulphides, typically hydrochloric acid on iron(II) sulphide (*see* KIPP'S APPARATUS). Solutions in water (known as **hydrosulphuric acid**) contain the anions HS^- and minute traces of S^{2-} and are weakly acidic. Acid salts (those containing the HS^- ion) are known as **hydrogensulphides** (formerly **hydrosulphides**). In acid solution hydrogen sulphide is a mild reducing agent. Hydrogen sulphide has an important role in traditional qualitative chemical analysis, where it precipitates metals with insoluble sulphides (in acid solution: Cu, Pb, Hg, Cd, Bi, As, Sb, Sn). The formation of a black precipitate with alkaline solutions of lead salts may be used as a test for hydrogen sulphide but the characteristic smell is usually sufficient. Hydrogen sulphide is exceedingly poisonous (more toxic than hydrogen cyanide).

The compound burns in air with a blue flame to form sulphur(IV) oxide (SO_2); solutions of hydrogen sulphide exposed to the air undergo oxidation but in this case only to elemental sulphur. North Sea gas contains some hydrogen sulphide (from S-proteins in

plants) as do volcanic emissions. *See also* CLAUS PROCESS.

hydrogensulphite (bisulphite) A salt containing the ion $^-HSO_3$ or an ester of the type $RHSO_3$, where R is an organic group.

hydrography The study of the waters of the earth's surface, including the oceans, seas, lakes, and rivers. It involves the measurement of these features and the presentation of the information on hydrographic charts.

hydroiodic acid *See* HYDROGEN IODIDE.

hydrolase Any of a class of enzymes that catalyse the addition of water to, or the removal of water from, a molecule. Hydrolases play an important role in the construction and breakdown of storage materials, such as starch.

hydrological cycle (water cycle) The circulation of water between the atmosphere, land, and oceans on the earth (see illustration). Water evaporates from water bodies on earth to form water vapour in the atmosphere. This may condense to form clouds and be returned to the earth's surface as rainfall, hail, snow, etc. Some of this precipitation is returned to the atmosphere directly through evaporation or transpiration by plants; some flows off the land surface as overland flow, eventually to be returned to the oceans via rivers; and some infiltrates the ground to flow underground forming groundwater storage.

hydrology The scientific study of terrestrial water, in particular inland water before its discharge into the oceans or evaporation into the atmosphere. It includes the study of the occurrence and movement of water and ice on or under the earth's surface. The science has many important applications, for example in flood control, irrigation, domestic and industrial uses, and hydroelectric power.

hydrolysis A chemical reaction of a compound with water. For instance, salts of weak acids or bases hydrolyse in aqueous solution, as in

$$Na^+CH_3COO^- + H_2O \rightleftharpoons Na^+ + OH^- + CH_3COOH$$

The reverse reaction of *esterification is another example. *See also* SOLVOLYSIS.

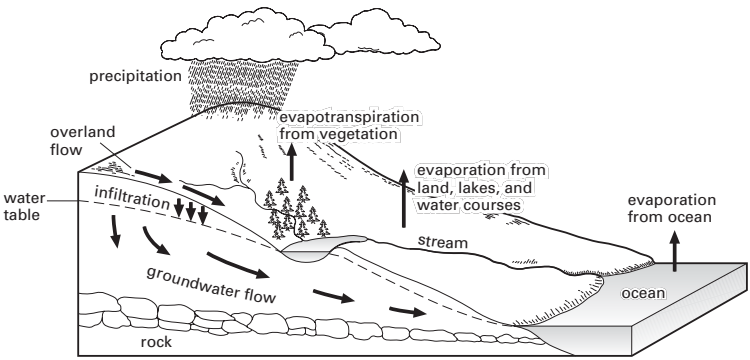
hydromagnesite A mineral form of basic *magnesium carbonate, $3MgCO_3.Mg(OH)_2.3H_2O$.

hydrometer An instrument for measuring the density or relative density of liquids. It usually consists of a glass tube with a long bulb at one end. The bulb is weighted so that the device floats vertically in the liquid, the relative density being read off its calibrated stem by the depth of immersion.

hydronium ion *See* OXONIUM ION.

hydrophilic Having an affinity for water. *See* LYOPHILIC.

hydrophily A rare form of pollination in which pollen is carried to a flower by water. It occurs by one of two methods. In Canadian pondweed (*Elodea canadensis*) the male flowers break off and float downstream until they contact the female flowers. In *Zostera*, a



Hydrological cycle.

marine species, the filamentous pollen grains are themselves carried in the water. *Compare* ANEMOPHILY; ENTOMOPHILY.

hydrophobic Lacking affinity for water. *See* LYOPHOBIC.

hydrophyte Any plant that lives either in very wet soil or completely or partially submerged in water. Structural modifications of hydrophytes include the reduction of mechanical and supporting tissues and vascular tissue, the absence or reduction of a root system, and specialized leaves that may be either floating or finely divided, with little or no cuticle. Examples of hydrophytes are waterlilies and certain pondweeds. *Compare* HALOPHYTE; MESOPHYTE; XEROPHYTE.

hydroponics A commercial technique for growing certain crop plants in culture solutions rather than in soil. The roots are immersed in an aerated solution containing the correct proportions of essential mineral salts. The technique is based on various water culture methods used in the laboratory to assess the effects of the absence of certain mineral elements on plant growth.

hydroquinone *See* BENZENE-1,4-DIOL.

hydrosol A sol in which the continuous phase is water. *See* COLLOIDS.

hydrosphere The water on the surface of the earth. Some 74% of the earth's surface is covered with water, 97% (or some 10^{21} kilograms) of which is in the oceans. Icecaps and glaciers contain about 3×10^{19} kg, rivers about 10^{15} kg, lakes and inland seas about 2×10^{17} kg, and groundwater (down to 4000 metres) about 8×10^{19} kg. Water in the atmosphere contains only about 10^{16} kg.

hydrostatics The study of liquids at rest, with special reference to storage tanks, dams, bulkheads, and hydraulic machinery.

hydrostatic skeleton The system of support found in soft-bodied invertebrates, which relies on the incompressibility of fluids contained within the body cavity. For example, in earthworms the coelomic fluid is under pressure within the coelom and therefore provides support for internal organs.

hydrosulphate *See* HYDROGENSULPHATE.

hydrosulphide *See* HYDROGEN SULPHIDE.

hydrosulphuric acid *See* HYDROGEN SULPHIDE.

hydrotropism The growth of a plant part in response to water. Roots, for example, grow towards water in the soil. *See* TROPISM.

hydroxide A metallic compound containing the ion OH^- (**hydroxide ion**) or containing the group –OH (hydroxyl group) bound to a metal atom. Hydroxides of typical metals are basic; those of *metalloids are amphoteric.

hydroxoacid A type of acid in which the acidic hydrogen is on a hydroxyl group attached to an atom that is not attached to an oxo (=O) group. An example is

$$Si(OH_4) + H_2O \rightarrow Si(OH)_3(O)^- + H_3O^+.$$

Compare OXOACID.

hydroxonium ion *See* OXONIUM ION.

4-hydroxybutanoic acid (gammahydroxybutyric acid; GHB) A naturally occurring carboxylic acid, $HO(CH_2)_3COOH$, found in small amounts in most living things. It is used as a therapeutic drug to treat insomnia, depression, and alcoholism. GHB, as it is commonly known, is also used as an illegal club drug and as a date-rape drug.

hydroxycerussite *See* LEAD(II) CARBONATE HYDROXIDE.

hydroxylamine A colourless solid, NH_2OH, m.p. 33°C. It explodes on heating and may be employed as an oxidizing agent or reducing agent. Hydroxylamine is made by the reduction of nitrates or nitrites, and is used in the manufacture of nylon. With aldehydes and ketones it forms *oximes.

SEE WEB LINKS

- Information about IUPAC nomenclature

hydroxyl group The group –OH in a chemical compound.

2-hydroxypropanoic acid *See* LACTIC ACID.

5-hydroxytryptamine *See* SEROTONIN.

hygrometer An instrument for measuring *humidity in the atmosphere. The mechanical type uses an organic material, such as human hair, which expands and contracts with changes in atmospheric humidity. The expansion and contraction is used to operate a needle. In the electric type, the change in resistance of a hygroscopic substance is used as an indication of humidity. In **dew-point hygrometers** a polished surface is reduced in temperature until water vapour from the atmosphere forms on it. The temperature of this dew point enables the relative humidity

of the atmosphere to be calculated. In the **wet-and-dry bulb hygrometer**, two thermometers are mounted side by side, the bulb of one being surrounded by moistened muslin. The thermometer with the wet bulb will register a lower temperature than that with a dry bulb owing to the cooling effect of the evaporating water. The temperature difference enables the relative humidity to be calculated. Only the dew-point hygrometer can be operated as an absolute instrument; all the others must ultimately be calibrated against this.

hygroscopic Describing a substance that can take up water from the atmosphere. *See also* DELIQUESCENCE.

hymen A fold of mucous membrane that covers the opening of the vagina at birth. It normally perforates at puberty, to allow the flow of menstrual blood, but if the opening is small it may be ruptured during the first occasion of sexual intercourse.

Hymenoptera An order of insects that includes the ants, bees, wasps, ichneumon flies, and sawflies. Hymenopterans generally have a narrow waist between thorax and abdomen. The smaller hindwings are interlocked with the larger forewings by a row of tiny hooks on the leading edges of the hindwings. Some species are wingless. The mouthparts are typically adapted for biting, although some advanced forms (e.g. bees) possess a tubelike proboscis for sucking liquid food, such as nectar. The long slender *ovipositor can serve for sawing, piercing, or stinging. Metamorphosis occurs via a pupal stage to the adult form. *Parthenogenesis is common in the group.

Ants and some bees and wasps live in colonies, often comprising numerous individuals divided into *castes and organized into a coordinated and complex society. The colony of the honeybee (*Apis mellifera*), for example, consists of workers (sterile females), *drones (fertile males), and usually a single fertile female – the queen. The sole concern of the queen is egg laying. She determines the gender of the egg by either withholding or releasing stored sperm. Unfertilized eggs become males; fertilized eggs become females. The workers fulfil a variety of tasks, including nursing the developing larvae, building the wax cells (combs) of the hive, guarding the colony, and foraging for nectar and pollen. The single function of the larger drones is to mate with the young queen on her nuptial flight.

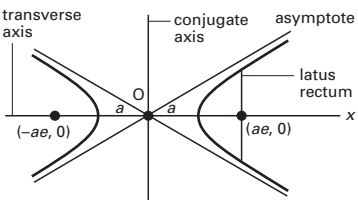
hyoid arch The second of seven bony V-shaped arches that support the gills of primitive vertebrates. In advanced vertebrates, part of the hyoid arch has evolved to form the stapes (one of the *ear ossicles). The rest of it forms the **hyoid bone**, which supports the tongue.

hyper- A prefix denoting over, above, high; e.g. hypersonic, hyperpolarization, hypertonic.

hyperbola A *conic with eccentricity $e > 1$. It has two branches (see graph). For a hyperbola centred at the origin, the **transverse axis** runs along the x-axis between the vertices and has length $2a$. The **conjugate axis** runs along the y-axis and has length $2b$. There are two **foci** on the x-axis at $(ae, 0)$ and $(-ae, 0)$. The **latus rectum**, the chords through the foci perpendicular to the transverse axis, have length $2b^2/a$. The equation of the hyperbola is:

$$x^2/a^2 - y^2/b^2 = 1,$$

and the asymptotes are $y = \pm bx/a$.



Hyperbola.

hyperbolic functions A set of functions, **sinh**, **cosh**, and **tanh**, that have similar properties to *trigonometric functions but are related to the hyperbola in the manner that trigonometric functions are related to the circle. The hyperbolic sine (sinh) of the angle x is defined by:

$$\sinh x = \tfrac{1}{2}(e^x - e^{-x}).$$

Similarly,

$$\cosh x = \tfrac{1}{2}(e^x + e^{-x})$$

$$\tanh x = (e^x - e^{-x})/(e^x + e^{-x})$$

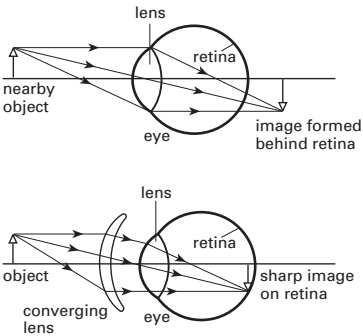
Hyperbolic secant (sech), cosecant (cosech), and cotangent (coth) are the reciprocals of cosh, sinh, and tanh, respectively.

hypercharge A quantized property of *baryons (*see* ELEMENTARY PARTICLES) that

provides a formal method of accounting for the nonoccurrence of certain expected decays by means of the strong interaction (*see* FUNDAMENTAL INTERACTIONS). Hypercharge is in some respects analogous to electric charge but it is not conserved in weak interactions. Nucleons have a hypercharge of +1, and the *pion has a value of 0.

hyperfine structure *See* FINE STRUCTURE.

hypermetropia (hyperopia) Long-sightedness, in which the lens of the eye is unable to accommodate sufficiently to throw the image of near objects onto the retina. It is caused usually by shortness of the eyeball rather than any fault in the lens system. Spectacles with converging lenses are required to focus the image onto the surface of the retina.



Hypermetropia.

hypernetted chain approximation An approximation used in the theory of fluids relating functions that give the correlation between two particles to radial distribution functions.

hypernova An explosive event in which a large star collapses with the formation of a *black hole. An event of this type would be even more violent than a *supernova (in which a star collapses to form a neutron star). Hypernovae may be the cause of gamma-ray bursts.

hyperon A shortlived *elementary particle; it is classified as a *baryon and has a nonzero *strangeness.

hyperplasia Increase in the size of a tissue or organ due to an increase in the number of its component cells. *Compare* HYPERTROPHY.

hypersensitivity Increased or abnormal sensitivity to compounds, which can elicit a specific immune response accompanied by tissue damage. Hypersensitivity reactions include *allergies and *anaphylaxis.

hypersonic Denoting a velocity in excess of Mach 5 (*see* MACH NUMBER). **Hypersonic flight** is flight at hypersonic speeds in the earth's atmosphere.

hypertension *See* BLOOD PRESSURE.

hypertext A technique by which textual documents can be created and viewed on a computer screen so that one or more documents can be browsed in any order by the selection of key words or phrases by the user. The selected text leads (by underlying searches through associated files, indexes, etc.) to the display of another part of the document, or of some other document. **Hypermedia** is an extension of this technique enabling links to be made between text, images, sounds, etc. *See also* WORLD WIDE WEB.

hypertext markup language *See* HTML.

hypertonic solution A solution that has a higher osmotic pressure than some other solution. *Compare* HYPOTONIC SOLUTION.

hypertrophy An increase in the size of a tissue or organ due to an increase in the size of its component cells. Hypertrophy often occurs in response to an increased workload in an organ, which may result from malfunction or disease. *Compare* HYPERPLASIA.

hyperventilation An increase in the amount of air taken into the lungs caused by an increase in the depth or rate of breathing. *See also* VENTILATION.

hypha A delicate filament in fungi many of which may form either a loose network (*mycelium) or a tightly packed interwoven mass of *pseudoparenchyma, as in the fruiting body of mushrooms. Hyphae may be branched or unbranched and may or may not possess cross walls. The cell wall consists of either fungal cellulose or *chitin. The cell wall is lined with cytoplasm, which often contains oil globules and glycogen, and there is a central vacuole. The hyphae produce enzymes that in parasitic fungi digest the host tissue, and in saprotrophic fungi digest dead organic matter.

hypo- A prefix denoting under, below, low; e.g. hypogyny, hyponasty, hypotonic.

hypochlorite *See* CHLORATES.

hypochlorous acid *See* CHLORIC(I) ACID.

hypocotyl The region of the stem beneath the stalks of the seed leaves (*cotyledons) and directly above the young root of an embryo plant. It grows rapidly in seedlings showing *epigeal germination and lifts the cotyledons above the soil surface. In this region (the **transition zone**) the arrangement of vascular bundles in the root changes to that of the stem. *Compare* EPICOTYL.

hypodermis (exodermis) The outermost layer of cells in the plant *cortex, lying immediately below the epidermis. These cells are sometimes modified to give additional structural support or to store food materials or water. After the loss of the *piliferous layer of the root the hypodermis takes over the protective functions of the epidermis.

hypogeal **1.** Describing seed germination in which the seed leaves (cotyledons) remain below ground. Examples of hypogeal germination are seen in oak and runner bean. *Compare* EPIGEAL. **2.** Describing fruiting bodies that develop underground, such as truffles and peanuts.

hypolimnion The lower layer of water in a lake. *See* THERMOCLINE. *Compare* EPILIMNION.

hypophosphorus acid *See* PHOSPHINIC ACID.

hypophysis *See* PITUITARY GLAND.

hyposulphite *See* SULPHINATE.

hyposulphurous acid *See* SULPHINIC ACID.

hypotenuse The longest side of a right-angle triangle.

hypothalamus Part of the vertebrate brain that is derived from the *forebrain and located on the ventral surface below the *thalamus and the *cerebrum. The hypothalamus regulates a wide variety of physiological processes, including maintenance of body temperature, water balance, sleeping, and feeding, via both the *autonomic nervous system (which it controls) and the *neuroendocrine system. Its endocrine functions are largely mediated by the *pituitary gland. The pituitary responds to releasing hormones produced by the hypothalamus, which in this way indirectly controls hormone production in other glands.

hypothesis *See* LAWS, THEORIES, AND HYPOTHESES.

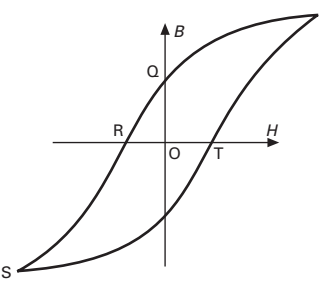
hypothesis test In *statistics, a method of assessing how plausible a null hypothesis or statement is by comparing it with a test sample. For example, a null hypothesis will be accepted in a test carried out at the 10% significance level if the value of the sample is what can be expected from 90% of all random samples.

hypotonic solution A solution that has a lower osmotic pressure than some other solution. *Compare* HYPERTONIC SOLUTION.

hypsometer A device for calibrating thermometers at the boiling point of water. As the boiling point depends on the atmospheric pressure, which in turn depends on the height above sea level, the apparatus can be used to measure height above sea level.

hysteresis A phenomenon in which two physical quantities are related in a manner that depends on whether one is increasing or decreasing in relation to the other. The repeated measurement of *stress against *strain, with the stress first increasing and then decreasing, will produce for some specimens a graph that has the shape of a closed loop. This is known as a **hysteresis cycle**. The most familiar hysteresis cycle, however, is produced by plotting the magnetic flux density (B) within a ferromagnetic material against the applied magnetic field strength (H).

If the material is initially unmagnetized at O it will reach saturation at P as H is increased. As the field is reduced and again increased the loop PQRSTP is formed (see graph). The area of this loop is proportional to the energy loss (**hysteresis loss**) occurring



Hysteresis.

during the cycle. The value of *B* equal to OQ is called the **remanance** (or retentivity) and is the magnetic flux density remaining in the material after the saturating field has been reduced to zero. This is a measure of the tendency of the magnetic domain patterns (*see* MAGNETISM) to remain distorted even after the distorting field has been removed. The value of *H* equal to OR is called the **coercive force** (or coercivity) and is the field strength required to reduce the remaining flux density to zero. It is a measure of the difficulty of restoring the symmetry of the domain patterns.