Q

QCD *See* QUANTUM CHROMODYNAMICS.

QED *See* QUANTUM ELECTRODYNAMICS.

QFD Quantum flavourdynamics. *See* ELECTROWEAK THEORY.

QSG *See* QUASARS.

QSO *See* QUASARS.

QSS *See* QUASARS.

quadrat An ecological sampling unit consisting of a small square area of ground within which all species of interest are noted or measurements taken. Quadrats may be spaced over a larger area to form an overall view when a total survey would be impracticable, or they may be used to sample along a *transect.

quadrate A paired bone in the upper jaw of bony fishes, amphibians, reptiles, and birds that articulates with the lower jawbone. It is absent in mammals, being reduced to a small bone (the incus) in the middle ear (*see* EAR OSSICLES).

quadratic equation An equation of the second degree having the form $ax^2 + bx + c = 0$. Its roots are:

$$x = [-b \pm \sqrt{(b^2 - 4ac)}]/2a.$$

quadrature The position of the moon or an outer planet when the line joining it to the earth makes a right angle with a line joining the earth to the sun.

quadrivalent Having a valency of four.

quadrupole mass spectrometer *See* MASS SPECTROMETRY.

qualitative analysis *See* ANALYSIS.

qualitative variation *See* DISCONTINUOUS VARIATION.

quality of sound (timbre) The quality a musical note has as a result of the presence of *harmonics. A pure note consists only of the fundamental; however, a note from a musical instrument will have several harmonics present, depending on the type of instrument and the way in which it is played. For example, a plucked string (as in a guitar) produces a series of harmonics of diminishing intensity, whereas a struck string (as in a piano) produces a series of harmonics of more nearly equal intensity.

quanglement *See* QUANTUM ENTANGLEMENT.

quantitative analysis *See* ANALYSIS.

quantitative inheritance (multifactorial inheritance, polygenic inheritance) The determination of a particular characteristic, e.g. height or skin colour, by many genes each having a small effect individually (*see* QUANTITATIVE TRAIT). Characteristics controlled in this way show *continuous variation.

quantitative trait Any phenotypic trait that shows *continuous variation and can be measured quantitatively in terms of length, weight, concentration, test score, etc. Such traits, which include height, intelligence, and obesity, are determined by the cumulative effects of numerous genes at **quantitative trait loci**.

quantitative variation *See* CONTINUOUS VARIATION.

quantization The process of constructing a quantum theory for a system, using the original classical theory as a basis. The starting point for such a process is to write the *Lagrangian or *Hamiltonian of the classical system. The formulation of the quantum theory for the system can be performed using a formalism such as *matrix mechanics, or *wave mechanics. The application of these methods leads to the conclusion that energy levels in systems, such as atoms, are discrete (**quantized**) rather than continuous. Before the discovery of quantum mechanics in the mid 1920s, quantization involved a series of ad hoc postulates for atomic systems, such as the *Bohr theory and its extensions.

quantum (*pl.* **quanta**) The minimum amount by which certain properties, such as energy or angular momentum, of a system can change. Such properties do not, therefore, vary continuously, but in integral multiples of the relevant quantum, and are described as **quantized**. This concept forms the basis of the *quantum theory. In waves and fields the quantum can be regarded as an excitation, giving a particle-like interpretation to the wave or field. Thus, the quantum of the electromagnetic field is the *photon and the *graviton is the quantum of the gravitational field. *See* QUANTUM MECHANICS.

quantum chaos The *quantum mechanics of systems for which the corresponding classical system can exhibit *chaos. This subject was initiated by Einstein in 1917, who showed that the quantization conditions associated with the *Bohr theory need to be modified for systems that show chaos in classical mechanics. The subject of quantum chaos is an active field of research in which many basic issues still require clarification. It appears that systems exhibiting chaos in classical mechanics do not necessarily exhibit chaos in quantum mechanics.

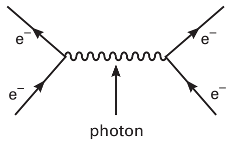
quantum chromodynamics (QCD) A *gauge theory that describes the strong interaction in terms of quarks and antiquarks and the exchange of massless gluons between them (*see also* ELEMENTARY PARTICLES). Quantum chromodynamics is similar to quantum electrodynamics (QED), with colour being analogous to electric charge and the gluon being the analogue of the photon. The gauge group of QCD is non-Abelian and the theory is much more complicated than quantum electrodynamics; the gauge symmetry in QCD is not a *broken symmetry.

QCD has the important property of *asymptotic freedom – that at very high energies (and, hence, short distances) the interactions between quarks tend to zero as the distance between them tends to zero. Because of asymptotic freedom, perturbation theory may be used to calculate the high energy aspects of strong interactions, such as those described by the *parton model.

quantum cloning *See* NO-CLONING THEOREM.

quantum dot A quantum-mechanical system, usually made from a semiconductor, in which electrons can be confined into a small region a few nanometres in size containing a few thousand atoms. Such systems act as 'artificial atoms' with their own sets of quantum states for the electrons. Quantum dots have important potential practical applications.

quantum electrodynamics (QED) The study of the properties of electromagnetic radiation and the way in which it interacts with charged matter in terms of *quantum mechanics. The collision of a moving electron with a proton, in this theory, can be visualized by a space–time diagram (**Feynman diagram**) in which photons are exchanged (see illustration).



Quantum electrodynamics. An example of a Feynman diagram for electron-electron scattering.

*Perturbation-theory calculations using Feynman diagrams enable an agreement between theory and experiment to a greater accuracy than one part in 10^9 to be obtained. Because of this, QED is the most accurate theory known in physical science. Although many of the effects calculated in QED are very small (about 4×10^{-6} eV), such as *energy level splitting in the spectra of *atoms, they are of great significance for demonstrating the physical reality of fluctuations and polarization in the vacuum state.

QED is a *gauge theory for which the gauge *group is Abelian.

quantum electronics The application of *quantum optics and the specifically quantum-mechanical properties of electrons to the design of electronic devices.

quantum entanglement (quanglement) A phenomenon in quantum mechanics in which a particle or system does not have a definite state but exists as an intermediate form of two 'entangled' states. One of these states is realized when a 'measurement' is made. *See* BELL'S THEOREM.

quantum field theory A quantum-mechanical theory applied to systems that have an infinite number of degrees of freedom. In quantum field theories, particles are represented by fields that have quantized normal modes of oscillation. For instance, *quantum electrodynamics is a quantum field theory in which the photon is emitted or absorbed by particles; the photon is the quantum of the electromagnetic field. **Relativistic quantum field theories** are used to describe fundamental interactions between elementary particles. They predict the existence of *antiparticles and also show the connection between spin and statistics that leads to the Pauli exclusion principle (*see* SPIN–STATISTICS THEOREM). In spite of their success, it is not clear whether a quantum field theory can give a completely unified description of all interactions (including the gravitational interaction).

quantum flavourdynamics (QFD) *See* ELECTROWEAK THEORY.

quantum gravity An aspect of *quantum theory that attempts to incorporate the *gravitational field as described by the general theory of *relativity; no such theory has yet been accepted, however. Unlike the *quantum field theories for the other three *fundamental interactions, the procedure of *renormalization does not work for quantum gravity, although there is some evidence that *superstring theory can provide a quantum theory of gravity free of infinities. An approximation to quantum gravity is given by **quantum field theory in curved space–time**, in which the gravitational interactions are treated classically, while all other interactions are treated by *quantum mechanics. An important aspect of quantum field theory in curved space–time is its description of Hawking radiation (*see* HAWKING PROCESS). It is necessary to consider quantum gravity in the very *early universe, just after the *big bang, and the singularities associated with *black holes can also be interpreted as requiring a quantum theory of gravity.

quantum Hall effect A quantum mechanical version of the *Hall effect found at very low temperatures, in which the Hall coefficient R_H is proportional to h/e^2, where h is the Planck constant and e is the charge of the electron. Thus, the Hall coefficient is quantized. There are two types of quantum Hall effect. The **integer quantum Hall effect** has R_H given as an integer with great precision. It can be used for precision measurements of constants such as e and h. In the **fractional quantum Hall effect**, R_H has fractional values.

The integer quantum Hall effect can be understood in terms of noninteracting electrons, whereas the fractional effect is thought to result from many-electron interactions in two-dimensional systems, and to be an example of anyons (*see* QUANTUM STATISTICS).

quantum interferometry The study of interference phenomena in which the interference is caused by the quantum-mechanical wave nature of particles such as electrons and neutrons. Fundamental aspects of quantum mechanics can be examined experimentally using such techniques. *See also* NEUTRON INTERFEROMETER.

quantum jump A change in a system (e.g. an atom or molecule) from one quantum state to another.

quantum mechanics A system of mechanics based on *quantum theory, which arose out of the failure of classical mechanics and electromagnetic theory to provide a consistent explanation of both electromagnetic waves and atomic structure. Many phenomena at the atomic level puzzled physicists at the beginning of the 20th century because there seemed to be no way of explaining them without making use of incompatible concepts. One such phenomenon was the emission of *electrons from the surface of a metal illuminated by light. Einstein realized that the classical description of light as a wave on an electromagnetic field could not explain this *photoelectric effect, as it is called. Experiments showed that electrons would be emitted only if the incident light was of a sufficiently short wavelength, while the intensity of the light appeared not to be relevant. It seemed not to make sense that small ripples of short wavelength could easily knock electrons out of the metal, but a huge tidal wave of long wavelength could not. In 1905 Einstein abandoned classical mechanics and sought an explanation of this photoelectric effect in Planck's work on thermal radiation (*see* PLANCK'S RADIATION LAW). In this work light energy is regarded as being imparted to matter in discrete packets rather than continuously, as one might expect from a wave. Einstein assumed that in the photoelectric effect, light behaves as a shower of particles, each with energy E given by Planck's expression:

$$E = hf,$$

where f is the light's frequency and h is the *Planck constant. Each particle of light, which Einstein called a *photon, would impart its energy to a single electron in the metal. The electron would be liberated only if the photon could impart at least the required amount of energy. However many photons were falling on the surface of the metal, no electrons would be liberated unless individual photons had the required energy (hf) to break the attractive forces holding the electrons in the metal. This elegantly quantified reversion to Newton's corpuscular theory of light by Einstein was one of the milestones in the development of quantum mechanics.

Further verification that light could indeed behave as a shower of particles came from the *Compton effect. In Compton scattering, X-radiation is scattered off an electron in a manner that resembles a particle collision. The momentum imparted to the electron can be predicted by assuming that the X-ray possesses the momentum of a photon. An expression for photon momentum is suggested by the classical theory of radiation pressure. It is known that if energy is transported by an electromagnetic wave at a rate W joules per unit area per second, the wave exerts a radiation pressure W/c, where c is the speed of light. Planck's expression for the energy of photons therefore led to an equivalent expression for the momentum p of these photons:

$$p = h/\lambda,$$

where λ is the wavelength of the light. Experimental studies of the Compton effect produce results in good agreement with this expression.

Both the photoelectric effect and the Compton effect imply that light imparts energy and momentum to matter in the form of packets. It is as if energy and momentum are fundamental 'currencies' of physical interaction, and that these currencies exist in denominations that are all multiples of the Planck constant. These quantities are said to be 'quantized' and a packet of energy or momentum is called a *quantum. Quantum mechanics is essentially concerned with the exchange of these quanta of energy and momentum. For more than a century before the birth of quantum mechanics, experiments had indicated that light behaves as a wave. The successful explanation of the photoelectric and Compton effects demonstrated that in some situations light interacts with matter as if it is a shower of particles. The principle that two models are required to explain the nature of light was called by Niels Bohr *complementarity. This principle was extended by the French aristocrat, Louis de Broglie, who suggested in 1923 that particles of matter might also behave as waves in certain circumstances.

Louis de Broglie received the Nobel Prize for this idea in 1929 after the successful measurement of the *de Broglie wavelength of an electron in 1927 by Clinton Davisson and Lester Germer, who had observed the *diffraction of electrons by single crystals of nickel. The behaviour of individual electrons seemed random and unpredictable, but when a large number had passed through the crystal a typical diffraction pattern emerged. This provided proof that the electron, which until then had been thought of simply as a particle of matter, could under the right circumstances exhibit wavelike properties. Classical mechanics and electromagnetism were based on two kinds of entity: matter and fields. In classical physics, matter consists of particles and waves are oscillations on a field. Quantum mechanics blurs the distinction between matter and field. Modern physicists are forced to concede that the universe is made up of entities that exhibit a *wave–particle duality.

A new representation of matter and field is needed to fully appreciate this wave–particle duality. In quantum mechanics, an electron is represented by a *complex number called a *wave function that depends on time and space coordinates. The wave function behaves like a classical wave displacement on a medium (e.g. on a string), exhibiting wave behaviour, interference, diffraction, etc. However, unlike a classical wave displacement, the wave function is essentially a complex quantity. Since an electron's observable properties do not involve complex numbers, it follows that an electron's wave function cannot itself be identified with a single physical property of the electron. The diffraction of electrons observed by Davisson and Germer revealed that, although the behaviour of the individual electrons is random and unpredictable, when a large number have passed through the apparatus, a diffraction pattern is formed whose intensity distribution is proportional to the intensity of the associated wave function. The intensity of the wave function, Ψ, is the square of its *absolute value $|\Psi|^2$. Therefore, although an electron's wave function itself has no physical significance, the square of its absolute value at a point turns out to be proportional to the probability of finding an electron at that point.

The electron wave function must satisfy a wave equation based on the conservation of energy and momentum for the electron. There are two main ways of treating this wave equation: a classical or a relativistic treatment. The resulting wave equations are called **eigenvalue equations** because they have the same form as equations in a branch of mathematics called **eigenvalue problems**, i.e.

$$\Omega\Psi = \omega\Psi,$$

where Ω is some mathematical operation (multiplication by some number, differentiation, etc.) on the wave function Ψ and ω, called the **eigenvalue** in quantum mechanics, is always a real number. In such an equation the wave function is often called the **eigenfunction**. This form of treatment of quantum mechanics is known as **wave mechanics** (*see also* SCHRÖDINGER EQUATION).

The energy E and momentum p of an electron are associated with the frequency f and wavelength λ of the electron's wave using the expressions $E = hf$ and $p = h/\lambda$. While the wave equation expresses the behaviour of the wavelike properties of a particle, it does not define the physical attributes it has as a particle. As a particle, the electron has an easily defined spatial and temporal position, not possessed by an oscillation of some kind of field, whose influence extends over a region of space and time. The incompatibility of these two views of the electron leads to the Heisenberg *uncertainty principle. Heisenberg recognized that if matter had wavelike properties, the physical attributes normally associated with matter (position, momentum, kinetic energy, etc.) would have to be expressed in a statistical, rather than a deterministic, manner. This is illustrated by the electron diffraction patterns of Davisson and Germer. Individual electrons somehow fell onto the apparatus to form a pattern statistically consistent with the intensity of a wave function. It is as if the final wave function were made up of a superposition of all the possible positions that the electrons could fall onto, the waves of electrons constructively and destructively interfering to form the final diffraction pattern.

It is known that a clever superposition of waves of different wavelengths can lead to a construction of a wave packet of finite extension (*see* FOURIER ANALYSIS). However, to produce a packet that exists at a point of zero width requires an infinite number of waves to superimpose. Heisenberg realized that these packets of waves must account for the way in which matter particles, such as electrons, could retain some semblance of their particle-like qualities. However, this must also mean that there is an inherent uncertainty in position and momentum associated with electrons and indeed all particles of matter (*see* UNCERTAINTY PRINCIPLE). Since waves of different wavelength correspond to different possible momentum values of an electron, a superposition of such waves to form a particle at a point would correspond to an infinite uncertainty in the momentum of the electron. Therefore the more one knows about the position of an electron the less one will know about its momentum and vice versa. A similar uncertainty between the energy of the electron and its temporal position also exists. Quantities that are related by such an uncertainty principle are said to be **incompatible**.

An alternative to the wave mechanical treatment of quantum mechanics is an equivalent formalism called *matrix mechanics, which is based on mathematical operators. *See also* HIDDEN-VARIABLES THEORY; BELL'S THEOREM.

quantum number *See* ATOM; SPIN.

quantum optics The study of those aspects of light that rely on *quantum mechanics. Quantum optics makes use of the *quantum theory of radiation to describe photons, *coherent radiation, and the interaction of photons and atoms. The study of *lasers is an important branch of quantum optics; other applications include photonics and *quantum electronics.

quantum phase transition A phase transition that occurs at absolute zero temperature when some parameter, such as a magnetic field or pressure, is changed. In contrast to ordinary phase transitions, which are associated with thermal fluctuations, quantum phase transitions are associated with quantum fluctuations. There are several systems in condensed matter in which such phase transitions can be observed.

quantum simulation The mathematical modelling of systems of large numbers of atoms or molecules by computer studies of relatively small clusters. It is possible to obtain information about solids and liquids in this way and to study surface properties and reactions.

quantum spin liquid A quantum-mechanical system in which a large number of electron spins are coupled together to give a distinct quantum system. Quantum spin liquids can be used to investigate aspects of the many-body problem in quantum mechanics and have potentially important applications in technology.

quantum state The state of a quantized system as described by its quantum numbers. For instance, the state of a hydrogen *atom is described by the four quantum numbers n, l, m_l, m_s. In the ground state they have values 1, 0, 0, and ½ respectively.

quantum statistics A statistical description of a system of particles that obeys the rules of *quantum mechanics rather than classical mechanics. In quantum statistics, energy states are considered to be quantized. **Bose–Einstein statistics** apply if any number of particles can occupy a given quantum state. Such particles are called **bosons**. Bosons have an angular momentum $nh/2\pi$, where n is zero or an integer and h is the Planck constant. For identical bosons the *wave function is always symmetric. If only one particle may occupy each quantum state, **Fermi–Dirac statistics** apply and the particles are called **fermions**. Fermions have a total angular momentum $(n + ½)h$ and any wave function that involves identical fermions is always antisymmetric.

The relation between the spin and statistics of particles is given by the *spin–statistics theorem.

In two-space dimensions, it is possible that there are particles (or *quasiparticles) that have statistics intermediate between bosons and fermions. These particles are known as **anyons**; for identical anyons the wave function is not symmetric (a phase sign of +1) or antisymmetric (a phase sign of –1), but interpolates continuously between +1 and –1. Anyons may be involved in the fractional *quantum Hall effect.

quantum theory The theory devised by Max Planck in 1900 to account for the emission of the black-body radiation from hot bodies. According to this theory energy is emitted in quanta (*see* QUANTUM), each of which has an energy equal to $h\nu$, where h is the *Planck constant and ν is the frequency of the radiation. This theory led to the modern theory of the interaction between matter and radiation known as *quantum mechanics, which generalizes and replaces classical mechanics and Maxwell's electromagnetic theory. In **nonrelativistic quantum theory** particles are assumed to be neither created nor destroyed, to move slowly relative to the speed of light, and to have a mass that does not change with velocity. These assumptions apply to atomic and molecular phenomena and to some aspects of nuclear physics. **Relativistic quantum theory** applies to particles that travel at or near the speed of light.

quantum theory of radiation The study of the emission and absorption of *photons of electromagnetic radiation by atomic systems using *quantum mechanics. Photons are emitted by atoms when a transition occurs from an excited state to the ground state. If an atom is exposed to external electromagnetic radiation a transition can occur from the ground state to an excited state by absorption of a photon. An excited atom can lose the energy it has gained by *stimulated emission. However, an atom can also emit a photon in the absence of external electromagnetic radiation, a process called *spontaneous emission. The quantum theory of radiation was initiated by Einstein in 1916–17, as an extension of *Planck's radiation law. The theory is quantified by the *Einstein coefficients. The quantum theory of radiation is the basis of the theory behind the operation of *lasers and *masers.

quantum Turing machine A mathematical concept which has the same relation to a quantum computer as a *Turing machine does to a traditional computer. This means that a quantum Turing machine is concerned with the problem of whether systematic algorithms exist for problems in quantum computation.

quantum well A potential well in which electrons in a three-dimensional system are confined to a plane, i.e. to two dimensions. Quantum wells can be made with a semiconductor that is sandwiched between layers of materials with larger energy band gaps. These wells are used to study two-dimensional systems and also have technological applications including a type of *laser (a **quantum well laser**).

quantum wire A linear conductor that is narrow enough for quantum effects to affect the resistance. If the wire diameter is small then the electrons have quantized energy levels for motion perpendicular to the axis. Consequently the resistance of the wire is also quantized. Carbon nanotubes have been investigated as practical implementations of quantum wires.

quantum Zeno effect A phenomenon in which constant observation of an unstable particle prevents it from decaying. In general, such a particle would be expected to decay within a time τ. If numerous measurements are made at intervals within time τ, the wavefunction is constantly collapsed, and the lifetime of the particle is prolonged. It can also be shown that if measurements are made at time intervals longer than τ there is an **anti-Zeno effect** in which the decay rate increases. These effects were predicted theoretically in 1977 and have subsequently been observed to occur in a number of experiments. The name is an allusion to a paradox put forward by the Greek philosopher Zeno of Elea (*b. c.* 490 BC). In the 'arrow paradox' he argued that at every moment of time, a moving arrow is occupying a definitive position. Therefore at every moment, the arrow is immobile, and the arrow never moves.

quarantine A period of isolation imposed on an animal that moves from an area where particular diseases are prevalent to an area where those diseases are not prevalent. In the UK domestic animals or livestock entering the country are quarantined for the necessary incubation period (*see* INFECTION) in order to prevent the spread of a particular disease.

quark *See* ELEMENTARY PARTICLES.

quark confinement The hypothesis that free quarks can never be seen in isolation. It is a result of *quantum chromodynamics, in which the property of *asymptotic freedom means that the interactions between quarks get weaker as the distance between them gets smaller, and tends to zero as the distance between them tends to zero. Conversely, the attractive interactions between quarks get stronger as the distance between them gets greater, and the quark-confinement hypothesis is that the quarks cannot escape from one another. It is possible that at very high temperatures, such as those in the *early universe, quarks may become free. The temperature at which this occurs is called the **deconfinement temperature**. The hypothesis of quark confinement has not been proved theoretically in a conclusive way, although there is a lot of evidence for it.

quark–gluon plasma A state of matter in which quarks and gluons are not confined into baryons and mesons but exist as a hot plasma. It is thought that this state existed in the early universe until there was a phase transition about 10^{-5} s after the big bang when the universe cooled to a sufficiently low temperature that *quark confinement into hadrons occurred. This state was created in the laboratory in the early years of the 21st century.

quart A unit of capacity equal to one quarter of a *gallon.

quarter-wave plate *See* RETARDATION PLATE.

quartile *See* PERCENTILE.

quartz The most abundant and common mineral, consisting of crystalline silica (silicon dioxide, SiO_2), crystallizing in the trigonal system. It has a hardness of 7 on the Mohs' scale. Well-formed crystals of quartz are six-sided prisms terminating in six-sided pyramids. Quartz is ordinarily colourless and transparent, in which form it is known as **rock crystal**. Coloured varieties, a number of which are used as gemstones, include *amethyst, citrine quartz (yellow), rose quartz (pink), milk quartz (white), smoky quartz (grey-brown), *chalcedony, *agate, and *jasper. Quartz occurs in many rocks, especially igneous rocks such as granite and quartzite (of which it is the chief constituent), metamorphic rocks such as gneisses and schists, and sedimentary rocks such as sandstone and limestone. The mineral has the property of being piezoelectric and hence is used to make oscillators for clocks (*see* QUARTZ CLOCK), radios, and radar instruments. It is also used in optical instruments and in glass, glaze, and abrasives.

quartz clock A clock based on a piezoelectric crystal of quartz. Each quartz crystal has a natural frequency of vibration, which depends on its size and shape. If such a crystal is introduced into an oscillating electronic circuit that resonates at a frequency very close to that of the natural frequency of the crystal, the whole circuit (including the crystal) will oscillate at the crystal's natural frequency and the frequency will remain constant over considerable periods (a good crystal will maintain oscillation for a year with an accumulated error of less than 0.1 second). In a quartz clock or watch the alternating current from the oscillating circuit containing such a crystal is amplified and the frequency subdivided until it is suitable to drive a synchronous motor, which in turn drives a gear train to operate hands. Alternatively it is used to activate a digital display.

quasars A class of astronomical objects that appear on optical photographs as starlike but have large *redshifts quite unlike those of stars. They were first observed in 1961 when it was found that strong radio emission was emanating from many of these starlike bodies. Over 200 000 such objects are now known and their redshifts can be as high as 6.4. The redshifts are characteristic of the *expansion of the universe. This **cosmological redshift** is the explanation of the high observed redshifts of quasars favoured by most astronomers. (A few, however, maintain that the redshift could be a local Doppler effect, characteristic of movement relative to the earth and sun of nearby objects in the Galaxy, or a gravitational effect.) If the redshifts are cosmological, quasars are the most distant objects in the universe, some being up to 10^{10} light-years away. The exact nature of quasars is unknown but it is believed that they are the nuclei of galaxies in which there is violent activity. The luminosity of the nucleus is so much greater than that of the rest of the galaxy that the source appears pointlike. It has been proposed that the power source in a quasar is a supermassive *black hole accreting material from the stars and gas in the surrounding galaxy.

The name 'quasar' is today regarded as a contraction of quasistellar object (QSO) or quasistellar galaxy (QSG). However, the first quasars to be discovered were radio sources, and the term was coined as a contraction of 'quasi-stellar radio source'.

q

quasicrystal A type of solid structure in which there is long-range order but in which the symmetry of the structure is not allowed in crystallography. AlMn is an example of a substance that forms quasicrystals.

quasiparticle A long-lived single-particle *excitation in the quantum theory of many-body systems, in which the excitations of the individual particles are modified by their interactions with the surrounding medium.

Quaternary Formerly, the second period of the Cenozoic era, extending from 2 million years ago, following the *Tertiary period, to the present. The beginning of the Quaternary was usually based on the onset of a worldwide cooling. During the period four principal glacial phases occurred in Europe and North America, in which ice advanced towards the equator, separated by interglacials during which conditions became warmer and the ice sheets and glaciers retreated. The last glacial ended about 10 000 years ago. The Quaternary has been replaced by the *Neogene period.

quaternary ammonium compounds *See* AMINE SALTS.

quaternary structure *See* PROTEIN.

quaternion Symbol Q. A mathematical quantity defined by $Q = a + b\boldsymbol{i} + c\boldsymbol{j} + d\boldsymbol{k}$, where a, b, c, and d are real numbers and $\boldsymbol{i}$, $\boldsymbol{j}$, and $\boldsymbol{k}$ are unit vectors in the x, y, and z directions respectively. Quaternions were invented by Sir William *Hamilton in 1843 and have been used extensively in physics, especially for problems involving rotation. Quaternions have close connections with the way in which *spin is analysed in quantum mechanics.

quenching **1.** (in metallurgy) The rapid cooling of a metal by immersing it in a bath of liquid in order to improve its properties. Steels are quenched to make them harder but some nonferrous metals are quenched for other reasons (copper, for example, is made softer by quenching). **2.** (in physics) The process of inhibiting a continuous discharge in a *Geiger counter so that the incidence of further ionizing radiation can cause a new discharge. This is achieved by introducing a quenching vapour, such as methane mixed with argon or with neon, into the tube.

quicklime *See* CALCIUM OXIDE.

quinhydrone electrode A *half cell consisting of a platinum electrode in an equimolar solution of quinone (cyclohexadiene-1,4-dione) and hydroquinone (benzene-1,4-diol). It depends on the oxidation–reduction reaction

$$C_6H_4(OH)_2 \rightleftharpoons C_6H_4O_2 + 2H^+ + 2e$$

quinine A white solid, $C_{20}H_{24}N_2O_2.3H_2O$, m.p. 57°C. It is a poisonous alkaloid occurring in the bark of the South American cinchona tree, although it is now usually produced synthetically. It forms salts and is toxic to the malarial parasite, and so quinine and its salts are used to treat malaria; in small doses it may be prescribed for colds and influenza. In dilute solutions it has a pleasant astringent taste and is added to some types of tonic water.

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

quinone **1.** *See* CYCLOHEXADIENE-1,4-DIONE.

2. Any similar compound containing C=O groups in an unsaturated ring.

quintessence A form of energy postulated to be causing the expansion of the universe to accelerate; i.e. the *dark energy in the universe. Theories of quintessence do not assume that dark energy is described by a *cosmological constant. No convincing theory of quintessence has yet emerged.