E

e The irrational number defined as the limit as n tends to infinity of $(1 + 1/n)^n$. It has the value 2.718 28…. It is used as the base of natural *logarithms and occurs in the *exponential function, e^x.

EAC Emergency action code. *See* HAZCHEM CODE.

ear The sense organ in vertebrates that is specialized for the detection of sound and the maintenance of balance. It can be divided into the *outer ear and *middle ear, which collect and transmit sound waves, and the *inner ear, which contains the organs of balance and (except in fish) hearing (see illustration).

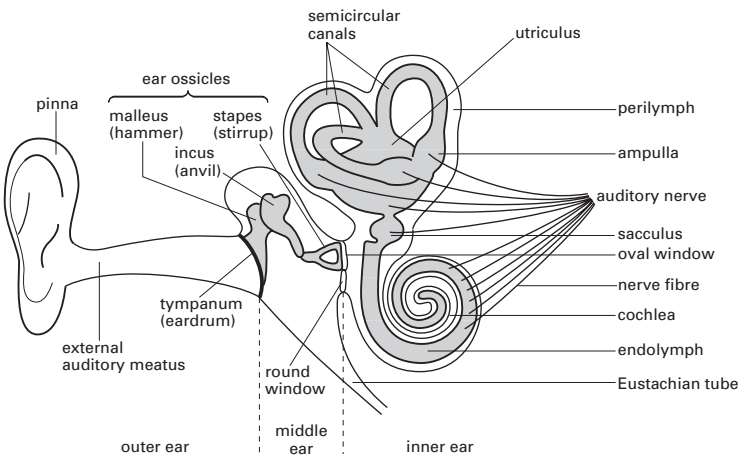
eardrum *See* TYMPANUM.

early universe The study of *cosmology at the time very soon after the *big bang. Theories of the early universe have led to a mutually beneficial interaction between cosmology and the theory of *elementary particles, particularly *grand unified theories.

Because there were very high temperatures in the early universe many of the *broken symmetries in *gauge theories were unbroken symmetries. As the universe cooled after the big bang there is thought to have been a sequence of transitions to broken symmetry states.

Combining cosmology with grand unified theories helps to explain why the observed universe appears to consist of matter with no antimatter. This means that one has a nonzero *baryon number for the universe. This solution relies on the fact that there were nonequilibrium conditions in the early universe due to its rapid expansion after the big bang.

An important idea in the theory of the early universe is that of **inflation** – the idea that the nature of the *vacuum state gave rise, after the big bang, to an exponential expansion of the universe. The hypothesis of the **inflationary universe** solves several long-standing problems in cosmology, such as the flatness and homogeneity of the universe. In particular, it is thought that quantum fluctuations in the early universe



Ear. Structure of the mammalian ear.

were responsible for the emergence of large-scale structures in the universe, such as galaxies.

ear ossicles Three small bones – the **incus** (**anvil**), **malleus** (**hammer**), and **stapes** (**stirrup**) – that lie in the mammalian *middle ear, forming a bridge between the tympanum (eardrum) and the *oval window. The function of the ossicles is to transmit (and amplify) vibrations of the tympanum across the middle ear to the oval window, which transfers them to the *inner ear. Muscles of the middle ear constrict the movement of the ossicles. This serves to safeguard the ear from damage caused by excessively loud noise.

earth The planet that orbits the sun between the planets Venus and Mars at a mean distance from the sun of 149 600 000 km. It has a mass of about 5.974×10^{24} kg and an equatorial diameter of 12 756.3 km. The earth consists of three layers: the gaseous atmosphere (*see* EARTH'S ATMOSPHERE), the liquid *hydrosphere, and the solid *lithosphere. The solid part of the earth also consists of three layers: the **crust** with a mean thickness of about 32 km under the land and 10 km under the seas; the **mantle**, which extends some 2900 km below the crust; and the **core**, part of which is believed to be liquid. The crust has a relative density of about 2.7 to 3.0 and consists largely of sedimentary rocks overlaying igneous rocks. The composition of the crust is: oxygen 47%, silicon 28%, aluminium 8%, iron 4.5%, calcium 3.5%, sodium and potassium 2.5% each, and magnesium 2.2%. Hydrogen, carbon, phosphorus, and sulphur are all present to an extent of less than 1%. The mantle reaches a relative density of about 5.5 at its maximum depth and is believed to consist mainly of silicate rocks. The core is believed to have a maximum relative density of 13 and a maximum temperature of 6400 K. *See also* GEOMAGNETISM; PLATE TECTONICS.

SEE WEB LINKS

- NASA's earth observatory

earthquake A sudden movement or fracturing within the earth's lithosphere, causing a series of shocks. This may range from a mild tremor to a large-scale earth movement causing extensive damage over a wide area. The point at which the earthquake originates is known as the **seismic focus**; the point on the earth's surface directly above this is the **epicentre** (or **hypocentre**). *See* SEISMIC WAVES. Earthquakes result from a build-up of stresses within the rocks until they are strained to the point beyond which they will fracture. They occur in narrow continuous belts of activity, which correspond with the junction of lithospheric plates, including the circum-Pacific belt, the Alpine–Himalayan belt, and mid-ocean ridges. The scale of the shock of an earthquake is known as the magnitude; the most commonly used scale for comparing the magnitude of earthquakes is the logarithmic *Richter scale (9.5 is the highest recorded magnitude on the scale).

earth's atmosphere The gas that surrounds the earth. The composition of dry air at sea level is: nitrogen 78.08%, oxygen 20.95%, argon 0.93%, carbon dioxide 0.03%, neon 0.0018%, helium 0.0005%, krypton 0.0001%, and xenon 0.00001%. In addition to water vapour, air in some localities contains sulphur compounds, hydrogen peroxide, hydrocarbons, and dust particles.

The lowest level of the atmosphere, in which most of the weather occurs, is called the **troposphere**. Its thickness varies from about 7 km at the poles to 28 km at the equator and in this layer temperature falls with increasing height. The next layer is the **stratosphere**, which goes up to about 50 km. Here the temperature remains approximately constant. Above this is the **ionosphere**, which extends to about 1000 km, with the temperature rising and the composition changing substantially. At about 100 km and above most of the oxygen has dissociated into atoms; at above 150 km the percentage of nitrogen has dropped to nil. In the ionosphere the gases are ionized by the absorption of solar radiation. This enables radio transmissions to be made round the curved surface of the earth as the ionized gas acts as a reflector for certain wavelengths. The ionosphere is divided into three layers. The D-layer (50–90 km) contains a low concentration of free electrons and reflects low-frequency radio waves. The E-layer (90–150 km) is also called the **Heaviside layer** or **Heaviside–Kennelly layer** as its existence was predicted independently by Oliver Heaviside (1850–1925) and Arthur E. Kennelly (1861–1939). This layer reflects medium-frequency waves. The F-layer (150–1000 km) is also called the **Appleton layer** after its discoverer Sir Edward Appleton (1892–1965). It has the highest concentration of free electrons and is the most

useful for radio transmission. Wavelengths between 8 mm and 20 m are not reflected by the ionosphere but escape into space. Therefore television transmissions, which utilize this range, require artificial *satellites for reflection (or reception, amplification, and retransmission). From about 400 km, the outermost region of the atmosphere is also called the **exosphere**. See illustration.

earth sciences A group of sciences concerned with the study of the earth. The chief earth sciences are geology, physical geography, oceanography, meteorology, geophysics, and geochemistry.

earthshine Sunlight reflected from the surface of the earth. An observer in space may see nearby objects dimly illuminated by earthshine, as things on earth may be illuminated by moonlight. Under certain conditions near new moon the dark disc of the moon can be seen faintly illuminated by earthshine – a phenomenon called 'the old moon in the new moon's arms'.

earthslide The movement of a layer of dry soil down a slope. The soil layer is inherently unstable and shears, sometimes brought about by the action of water. But if the soil becomes very wet, and the slope is steep, an earthflow may occur. Contributory factors are sparse vegetation and sudden rainfall.

earth's magnetic field *See* GEOMAGNETISM.

earwigs *See* DERMAPTERA.

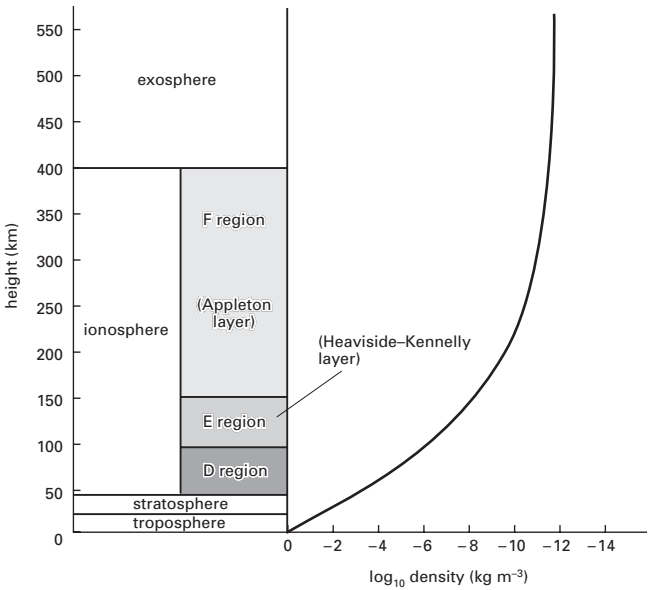
ebonite *See* VULCANITE.

ebullioscopic constant *See* ELEVATION OF BOILING POINT.

ebullioscopy The use of *elevation of boiling point to determine relative molecular masses.

eccentricity *See* CONIC.

Eccles, Sir John Carew (1903–97) Australian physiologist, who was educated in Melbourne and Oxford, and held appointments in Britain, Australia, New Zealand and, finally, the USA. While in Australia he carried out his best-known work, on the transmission of nerve impulses across



Earth's atmosphere.

synapses, which he attributed to the neurotransmitter acetylcholine. He shared the 1963 Nobel Prize for physiology or medicine with Sir Alan Hodgkin (1914–98) and Sir Andrew Huxley (1917–), who worked in the same area of biology.

ecdysis (moulting) **1.** The periodic loss of the outer cuticle of arthropods. It starts with the reabsorption of some materials in the inner part of the old cuticle and the formation of a new soft cuticle. The remains of the old cuticle then split; the animal emerges and absorbs water or swallows air and increases in size while the new cuticle is still soft. This cuticle is then hardened with chitin and lime salts. In insects and crustaceans ecdysis is controlled by the hormone *ecdysone. **2.** The periodic shedding of the outer layer of the epidermis of reptiles (except crocodiles) to allow growth to occur.

ecdysone A steroid hormone, produced by insects and crustaceans, that stimulates moulting (*see* ECDYSIS) and metamorphosis. It acts on specific gene loci, stimulating the synthesis of proteins involved in these bodily changes.

e-cell A computer simulation of a living cell based on information obtained from genomics, proteomics, metabolomics, and other data drawn from real cells.

ECG *See* ELECTROCARDIOGRAM.

echelon A form of *interferometer consisting of a stack of glass plates arranged stepwise with a constant offset. It gives a high resolution and is used in spectroscopy to study hyperfine line structure. In the **transmission echelon** the plates are made equal in optical thickness to introduce a constant delay between adjacent parts of the wavefront. The **reflecting echelon** has the exposed steps metallized and acts like an exaggerated *diffraction grating.

Echinodermata A phylum of marine invertebrates that includes the sea urchins, starfish, brittlestars, and sea cucumbers. Echinoderms have an exoskeleton (**test**) of calcareous plates embedded in the skin. In many species (e.g. sea urchins) spines protrude from the test. A system of water-filled canals (the **water vascular system**) provides hydraulic power for thousands of **tube feet**: saclike protrusions of the body wall used for locomotion, feeding, and respiration. Echinoderms have a long history: fossils of primitive echinoderms are known from rocks over 500 million years old.

SEE WEB LINKS

- Overview of echinoderm characteristics and phylogeny from the Tree of Life Project

echo The reflection of a wave by a surface or object so that a weaker version of it is detected shortly after the original. The delay between the two is an indication of the distance of the reflecting surface. An **echo sounder** is an apparatus for determining the depth of water under a ship. The ship sends out a sound wave and measures the time taken for the echo to return after reflection by the sea bottom. **Sonar** (*so*und *na*vigation *r*anging) is a technique for locating underwater objects by a similar method. Echoes also occur with radio waves; reflection of waves causes an echo in radio transmission and ghosts in television pictures. *See also* RADAR.

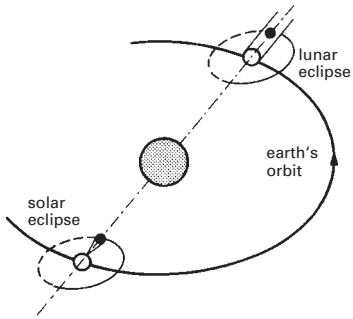
echolocation **1.** *See* RADAR; ECHO. **2.** A method used by some animals (such as bats, dolphins, and certain birds) to detect objects in the dark. The animal emits a series of high-pitched sounds that echo back from the object and are detected by the ear or some other sensory receptor. From the direction of the echo and from the time between emission and reception of the sounds the object is located, often very accurately.

ECL *See* EMITTER-COUPLED LOGIC.

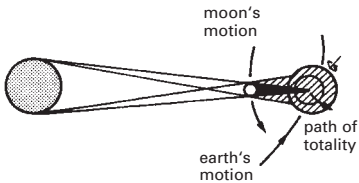
eclipse The obscuring of light from a celestial body as it passes behind or through the shadow of another body. In a **total eclipse**, the light is completely cut off; in a **partial eclipse**, the light is only partly hidden. A **lunar eclipse** occurs when the sun, earth, and moon are in a straight line and the shadow of the earth falls on the moon. A **solar eclipse** occurs when the sun, moon, and earth are aligned in such a way that the moon blocks out light from the sun's *photosphere and casts its shadow on the earth. An **annular eclipse** occurs when the moon is too far away for its shadow to reach the earth: during an eclipse, the rim of the photosphere is visible as a fiery ring (**annulus**) around the dark silhouette of the moon. See illustrations overleaf.

SEE WEB LINKS

- NASA's eclipse Website, a fully comprehensive site maintained by Fred Espenak at the Goddard Space Flight Center, near Washington DC



Solar and lunar eclipses



Moon's shadow in solar eclipse

Eclipse.

eclipsed conformation *See* CONFORMATION.

ecliptic The *great circle on the *celestial sphere that traces the sun's apparent passage through the sky against the background of the *zodiac constellations over the course of a year. In reality, it is the earth that travels around the sun, and so the ecliptic delineates the plane of the earth's orbit. *See also* EQUINOX; SOLSTICE.

ECM **1.** *See* EXTRACELLULAR MATRIX. **2.** *See* ELECTRON CYCLOTRON MASER.

ECMAScript *See* JAVASCRIPT.

E. coli *See* ESCHERICHIA COLI.

ecological niche The status or role of an organism in its environment. An organism's niche is defined by its food supply, predators, temperature tolerances, etc. Two species cannot coexist stably if they occupy identical niches.

ecology The study of the interrelationships between organisms and their natural environment, both living and nonliving. For this purpose, ecologists study organisms in the context of the *populations and *communities in which they can be grouped and the *ecosystems of which they form a part. The study of ecological interactions provides important information on the nature and mechanisms of evolutionary change. Advances made in ecology over the last 30 years have led to increased concern about the effects of human activities on the environment (notably the effects of *pollution), which has resulted in a greater awareness of the importance of *conservation.

ecosystem A biological *community and the physical environment associated with it. Nutrients pass between the different organisms in an ecosystem in definite pathways; for example, nutrients in the soil are taken up by plants, which are then eaten by herbivores, which in turn may be eaten by carnivores (*see* FOOD CHAIN). Organisms are classified on the basis of their position in an ecosystem into various *trophic levels. Nutrients and energy move round ecosystems in loops or cycles (in the case above, for example, nutrients are returned to the soil via animal wastes and decomposition). *See* CARBON CYCLE; NITROGEN CYCLE.

SEE WEB LINKS

- The latest Millennium Ecosystem Assessment Reports commissioned by the United Nations.

ecosystem services The benefits that people receive from ecosystems. These benefits can be classified into several categories. **Provisioning services** include the products that humans derive from ecosystems, such as food, fibres, fuel, drinking water, and medicinal products. **Regulating services** encompass such processes as control of the climate, purification of air and water, amelioration of erosion, reduction of pests and diseases, and provision of pollination mechanisms. **Cultural services** comprise the nonmaterial benefits that accrue from the landscape, such as recreational pursuits, spiritual renewal, and aesthetic experiences. Underlying all these are the fundamental **supporting services** of all ecosystems, such as primary production (i.e. photosynthesis by green plants, algae, etc.), nutrient cycling (e.g. carbon, nitrogen, sulphur cycles), water cycling, and soil formation. In recent decades the widespread degradation of many of the world's ecosystems has seen the concept of ecosystem ser-

vices acquire greater prominence, chiefly as a means of assessing the economic value of particular ecological benefits and the cost of their destruction.

ecotype A subgroup of a species that has characteristic genetically determined adaptations to its local environment. In some cases individuals belonging to different ecotypes cannot interbreed, for example where accumulated genetic differences are too great.

ecstasy (methylenedioxymethamphetamine; MDMA) A designer drug based on methamphetamine (*see* AMPHETAMINE). Originally intended as an appetite suppressant, it produces a feeling of euphoria and is widely used as a club drug. It is a class A drug in the UK.

ectoderm The external layer of cells of the *gastrula, which will develop into the epidermis and the nervous system in the adult. *See also* GERM LAYERS.

ectoparasite A parasite that lives on the outside of its host's body. *See* PARASITISM.

ectoplasm *See* CYTOPLASM.

Ectoprocta *See* BRYOZOA.

ectotherm (poikilotherm) An animal that maintains its body temperature by absorbing heat from the surrounding environment. All animals except mammals and birds are ectotherms; they are often described as being **cold-blooded** and are unable to regulate their body temperature metabolically. *See* POIKILOTHERMY. *Compare* ENDOTHERM.

edaphic factor A factor relating to the physical or chemical composition of the soil found in a particular area. For example, very alkaline soil may be an edaphic factor limiting the variety of plants growing in a region.

Eddington limit A limit for the maximum value of the brightness of a star of a given mass. This limit exists because the radiation pressure caused by the nuclear fusion reactions powering the star has to counter, but not exceed, the gravitational force that would cause gravitational collapse of the star. The existence of this limit was first pointed out by the English astrophysicist Sir Arthur Stanley Eddington (1882–1944).

eddy current A current induced in a conductor situated in a changing magnetic field or moving in a fixed one. Any imagined circuit within the conductor will change its magnetic flux linkage, and the consequent induced e.m.f. will drive current around the circuit. In a substantial block of metal the resistance will be small and the current therefore large. Eddy currents occur in the cores of transformers and other electrical machines and represent a loss of useful energy (the **eddy-current loss**). To reduce this loss to a minimum metal cores are made of insulated sheets of metal, the resistance between these laminations reducing the current. In high-frequency circuits *ferrite cores can be used. Eddy currents in a moving conductor interact with the magnetic field producing them to retard the motion of the conductor. This enables some electrical instruments (moving-coil type) to utilize eddy currents to create damping. Eddy currents are also used in *induction heating.

Edison cell *See* NICKEL–IRON ACCUMULATOR.

EDTA Ethylenediaminetetraacetic acid, $(HOOCCH_2)_2N(CH_2)_2N(CH_2COOH)_2$
A compound that acts as a chelating agent, reversibly binding with iron, magnesium, and other metal ions. It is used in certain culture media bound with iron, which it slowly releases into the medium, and also in some forms of quantitative analysis.

EEG *See* ELECTROENCEPHALOGRAM.

effective temperature *See* LUMINOSITY.

effective value *See* ROOT-MEAN-SQUARE VALUE.

effector A cell or organ that produces a physiological response when stimulated by a nerve impulse. Examples include muscles and glands.

effector neuron A nerve cell, such as a motor neuron, that transmits impulses from the central nervous system to an *effector in order to bring about a physiological response to changes in the environment.

efferent Carrying (nerve impulses, blood, etc.) away from the centre of a body or organ towards peripheral regions. The term is usually applied to types of nerve fibres or blood vessels. *Compare* AFFERENT.

effervescence The formation of gas bubbles in a liquid by chemical reaction.

efficiency A measure of the performance of a machine, engine, etc., being the ratio of the energy or power it delivers to the energy

or power fed to it. In general, the efficiency of a machine varies with the conditions under which it operates and there is usually a load at which it operates with the highest efficiency. The **thermal efficiency** of a heat engine is the ratio of the work done by the engine to the heat supplied by the fuel. For a reversible heat engine this efficiency equals $(T_1 - T_2)/T_1$, where T_1 is the thermodynamic temperature at which all the heat is taken up and T_2 is the thermodynamic temperature at which it is given out (*see* CARNOT CYCLE). For real engines it is always less than this.

efflorescence The process in which a crystalline hydrate loses water, forming a powdery deposit on the crystals.

effusion The flow of a gas through a small aperture. The relative rates at which gases effuse, under the same conditions, is approximately inversely proportional to the square roots of their densities.

egestion The expulsion from the body of waste food materials that have never left the gut, particularly the expulsion of undigested materials from the gut through the anus (*see* DEFECATION). Egestion should not be confused with *excretion, in which the waste materials are produced by metabolic activity in the body's tissues.

egg **1.** The fertilized ovum (*zygote) in egg-laying animals, e.g. birds and insects, after it emerges from the body. The egg is covered by *egg membranes that protect it from environmental damage, such as drying. **2. (egg cell)** The mature female reproductive cell in animals and plants. *See* OOSPHERE; OVUM.

egg membrane The layer of material that covers an animal egg cell. **Primary membranes** develop in the ovary and cover the egg surface in addition to the normal plasma membrane. The primary membrane is called the **vitelline membrane** in insects, molluscs, birds, and amphibians, the **chorion** in tunicates and fish, and the **zona pellucida** in mammals. Insects have a second thicker membrane, also called the chorion. **Secondary membranes** are secreted by the oviducts and parts of the genital system while the egg is passing to the outside. They include the jelly coat of frogs' eggs and the albumen and shell of birds' eggs.

Ehrlich, Paul (1854–1915) German bacteriologist, who graduated as a physician in 1878. After working in a Berlin hospital for nine years he taught at Berlin University (unpaid because he was a Jew). In 1890 he went to work with Robert Koch (1843–1910) to study tuberculosis, cholera, and other diseases. In 1910 he discovered Salvarsan, an arsenical drug effective against syphilis. He was awarded the 1908 Nobel Prize for physiology or medicine for his earlier work on serum therapy.

eigenfunction An allowed *wave function of a system in quantum mechanics. The associated energies are **eigenvalues**.

Einstein, Albert (1879–1955) German-born US physicist, who took Swiss nationality in 1901. A year later he went to work in the Bern patent office. In 1905 he published five enormously influential papers, one on *Brownian movement, one on the *photoelectric effect, one on the special theory of *relativity, and one on energy and inertia (which included the famous expression $E = mc^2$). In 1915 he published the general theory of relativity, concerned mainly with gravitation. In 1921 he was awarded the Nobel Prize for physics. In 1933, as a Jew, Einstein decided to remain in the USA (where he was lecturing), as Hitler had come to power. For the remainder of his life he sought a unified field theory. In 1939 he informed President Roosevelt that an atom bomb was feasible and that Germany might be able to make one.

SEE WEB LINKS

- A comprehensive website about his life and work run by The American Institute of Physics Center for History of Physics

Einstein coefficients Coefficients used in the *quantum theory of radiation, related to the probability of a transition occurring between the ground state and an excited state (or vice versa) in the processes of *induced emission and *spontaneous emission. For an atom exposed to *electromagnetic radiation, the rate of absorption R_a is given by $R_a = B\rho$, where ρ is the density of electromagnetic radiation and B is the **Einstein B coefficient** associated with absorption. The rate of induced emission is also given by $B\rho$, with the coefficient B of induced emission being equal to the coefficient of absorption. The rate of spontaneous emission is given by A, where A is the **Einstein A coefficient of spontaneous emission**. The A and B coefficients are related by $A = 8\pi h\nu^3 B/c^3$, where h is the *Planck constant, ν is the frequency of electromagnetic radiation, and c is the speed of light. The coefficients were put forward by

Albert Einstein in 1916–17 in his analysis of the quantum theory of radiation.

Einstein equation **1.** The mass–energy relationship announced by Einstein in 1905 in the form $E = mc^2$, where E is a quantity of energy, m its mass, and c is the speed of light. It presents the concept that energy has mass. *See also* RELATIVITY. **2.** The relationship

$$E_{max} = hf - W,$$

where E_{max} is the maximum kinetic energy of the electrons emitted in the photoemissive effect, h is the Planck constant, f the frequency of the incident radiation, and W the *work function of the emitter. This is also written $E_{max} = hf - \phi e$, where e is the electronic charge and ϕ a potential difference, also called the work function. (Sometimes W and ϕ are distinguished as **work function energy** and **work function potential**.) The equation can also be applied to photoemission from gases, when it has the form $E = hf - I$, where I is the ionization potential of the gas.

einsteinium Symbol Es. A radioactive metallic transuranic element belonging to the *actinoids; a.n. 99; mass number of the most stable isotope 254 (half-life 270 days). Eleven isotopes are known. The element was first identified by Albert Ghiorso and associates in debris from the first hydrogen bomb explosion in 1952. Microgram quantities of the element did not become available until 1961.

SEE WEB LINKS

- Information from the WebElements site

Einstein shift *See* REDSHIFT.

ejaculation The propulsion of semen out of the erect penis due to powerful rhythmic contractions of the urethra. An ejaculation coincides with the peak of sexual excitement (**orgasm**) and is accompanied by various physiological effects in the body, such as increased respiration rate and heart rate.

ejecta Rocks and other material thrown up when a crater is formed. Some craters and their associated ejecta are volanic in origin, but most (especially on the moon, Mercury, and other planets and their satellites) are caused by the impact of meteorites. Often these are surrounded by an ejecta blanket, which is thickest near the crater's rim.

ekpyrotic universe A model of the universe that postulates that the big bang occurred because of the collision of two parallel branes of a type predicted to occur in string theory (*see* BRANE WORLD). The term 'ekpyrotic' means 'coming out of fire'. It has been developed into a **cyclic model** of the universe, which avoids the problems of entropy associated with the *oscillatory universe. There are some differences between the predictions of the ekpyrotic theory and those of the more established inflationary universe (*see* EARLY UNIVERSE).

Elasmobranchii *See* CHONDRICHTHYES.

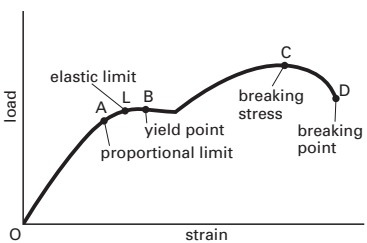
elastance The reciprocal of *capacitance. It is measured in farad^{-1} (sometimes called a 'daraf').

elastic cartilage *See* CARTILAGE.

elastic collision A collision in which the total kinetic energy of the colliding bodies after collision is equal to their total kinetic energy before collision. Elastic collisions occur only if there is no conversion of kinetic energy into other forms, as in the collision of atoms. In the case of macroscopic bodies this will not be the case as some of the energy will become heat. In a collision between polyatomic molecules, some kinetic energy may be converted into vibrational and rotational energy of the molecules, but otherwise molecular collisions appear to be elastic.

elastic fibres *See* ELASTIN.

elasticity The property of certain materials that enables them to return to their original dimensions after an applied *stress has been removed. In general, if a stress is applied to a wire, the *strain will increase in proportion (see *OA* on the illustration) until a certain point called the **limit of proportionality** is reached. This is in accordance with *Hooke's law. Thereafter there is at first a slight increase in strain with increased load until a point L is reached. This is the **elastic**



Elasticity.

limit; up to this point the deformation of the specimen is elastic, i.e. when the stress is removed the specimen returns to its original length. Beyond the point *L* there is permanent deformation when the stress is removed, i.e. the material has ceased to be **elastic** and has become **plastic**. In the plastic stages individual materials vary somewhat; in general, however, at a point *B* there is a sudden increase in strain with further increases of stress – this is the **yield point**. Beyond the point *C*, the **breaking stress**, the wire will snap (which occurs at point *D*).

elastic modulus The ratio of the *stress applied to a body to the *strain produced. The **Young modulus of elasticity**, named after Thomas Young, refers to longitudinal stress and strain. The **bulk modulus** is the ratio of the pressure on a body to its fractional decrease in volume. The **shear** (or **rigidity**) **modulus** is the tangential force per unit area divided by the angular deformation in radians.

elastin A fibrous protein that is the major constituent of the yellow **elastic fibres** of *connective tissue. It is rich in glycine, alanine, proline, and other nonpolar amino acids that are cross-linked, making the protein relatively insoluble. Elastic fibres can stretch to several times their length and then return to their original size. Elastin is particularly abundant in elastic *cartilage, blood-vessel walls, ligaments, and the heart.

elastomer A natural or synthetic rubber or rubberoid material, which has the ability to undergo deformation under the influence of a force and regain its original shape once the force has been removed.

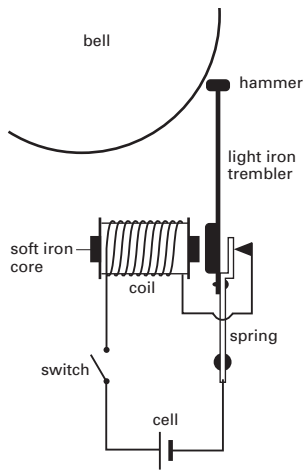
electret A permanently electrified substance or body that has opposite charges at its extremities. Electrets resemble permanent magnets in many ways. An electret can be made by cooling certain waxes in a strong electric field.

electrical energy A form of energy related to the position of an electric charge in an electric field. For a body with charge *Q* and an electric potential *V*, its electrical energy is *QV*. If *V* is a potential difference, the same expression gives the energy transformed when the charge moves through the p.d.

electric arc A luminous discharge between two electrodes. The discharge raises the electrodes to incandescence, the resulting thermal ionization largely providing the carriers to maintain the high current between the electrodes.

electric-arc furnace A furnace used in melting metals to make alloys, especially in steel manufacture, in which the heat source is an electric arc. In the direct-arc furnace, such as the Héroult furnace, an arc is formed between the metal and an electrode. In the indirect-arc furnace, such as the Stassano furnace, the arc is formed between two electrodes and the heat is radiated onto the metal.

electric bell A device in which an electromagnetically operated hammer strikes a bell (see illustration). Pressing the bell-push closes a circuit, causing current to flow from a battery or mains step-down transformer through an electromagnet. The electromagnet attracts a piece of soft iron attached to the hammer, which strikes the bell and at the same time breaks the circuit. The hammer springs back into its original position again, closing the circuit and causing the magnet to attract the soft iron. This process continues until the bell-push is released.



Electric bell.

electric charge *See* CHARGE.

electric constant *See* PERMITTIVITY.

electric current *See* CURRENT.

electric displacement (electric flux den-

sity) Symbol *D*. The charge per unit area that would be displaced across a layer of conductor placed across an *electric field. This describes also the charge density on an extended surface that could be causing the field.

electric field A region in which an electric charge experiences a force usually because of a distribution of other charges. The **electric field strength** or **electric intensity** (*E*) at any point in an electric field is defined as the force per unit charge experienced by a small charge placed at that point. This is equivalent to a potential gradient along the field and is measured in volts per metre. The strength of the field can alternatively be described by its *electric displacement *D*. The ratio D/E for measurements in a vacuum is the electric constant ε_0. In a substance the observed potential gradient is reduced by electron movement so that D/E appears to increase: the new ratio (ε) is called the *permittivity of the substance. An electric field can be created by an isolated electric charge, in which case the field strength at a distance r from a point charge Q is given by $E = Q/4\pi r^2\varepsilon$, where ε is the permittivity of the intervening medium (*see* COULOMB'S LAW). An electric field can also be created by a changing magnetic field.

electric flux Symbol Ψ. In an *electric field, the product of the electric flux density and the relevant area. *See* ELECTRIC DISPLACEMENT.

electric flux density *See* ELECTRIC DISPLACEMENT.

electricity Any effect resulting from the existence of stationary or moving electric charges.

electric lighting Illumination provided by electric currents. The devices used are the **arc lamp**, the **light bulb** (incandescent filament lamp), and the **fluorescent tube**. In the arc lamp, which is no longer used as a general means of illumination, an electric current flows through a gap between two carbon electrodes, between which a high potential difference is maintained. The current is carried by electrons and ions in the vapour produced by the electrodes and a mechanism is required to bring the electrodes closer together as they are vaporized. The device produces a strong white light but has many practical disadvantages. However, arcs enclosed in an inert gas (usually xenon) are increasingly used for such purposes as cinema projectors. The common light bulb is a glass bulb containing a tungsten filament and usually an inert gas. The passage of an electric current through the filament heats it to a white heat. Inert gas is used in the bulb to minimize blackening of the glass by evaporation of tungsten. In the fluorescent tube a glass tube containing mercury vapour (or some other gas) at a low pressure has its inner surface coated with a fluorescent substance. A discharge is created within the tube between two electrodes. Electrons emitted by the cathode collide with gas atoms or molecules and raise them to an excited state (*see* EXCITATION). When they fall back to the *ground state they emit photons of ultraviolet radiation, which is converted to visible light by the coating of phosphor on the inner walls of the tube. In some lamps, such as the *sodium-vapour and *mercury-vapour lamps used in street lighting, no fluorescent substance is used, the light being emitted directly by the excited atoms of sodium or mercury. Vapour lights are more efficient than filament lights as less of the energy is converted into heat.

electric motor A machine for converting electrical energy into mechanical energy. They are quiet, clean, and have a high efficiency (75–95%). They work on the principle that a current passing through a coil within a magnetic field will experience forces that can be used to rotate the coil. In the **induction motor**, alternating current is fed to a stationary coil (the **stator**), which both creates the magnetic field and induces a current in the rotating coil (**rotor**), which it surrounds. The advantage of this kind of motor is that current does not have to be fed through a commutator to a moving part. In the **synchronous motor**, alternating current fed to the stator produces a magnetic field that rotates and locks with the field of the rotor, in this case an independent magnet, causing the rotor to rotate at the same speed as the stator field rotates. The rotor is either a permanent magnet or an electromagnet fed by a direct current through slip rings. In the **universal motor**, current is fed to the stator and, through a commutator, to the rotor. In the series-wound motor the two are in series; in the shunt-wound motor they are in parallel. These motors can be used with either a.c. or d.c. but some small motors use a permanent magnet as the stator and require d.c. for the

rotor (via the commutator). *See also* LINEAR MOTOR.

electric organ An organ occurring on the body or tail of certain fish, such as the electric ray (*Torpedo*) and electric eel (*Electrophorus electricus*). It gives an electric shock when touched and is used either to stun prey or predators or, in some species, to maintain a weak electric field in the surrounding water that is used in navigation. The organ is composed of modified muscle cells (**electroplate cells**), nervous stimulation of which greatly increases the potential difference across the cell. The electroplates are in series so a high overall voltage can be achieved.

electric polarization *See* DIELECTRIC.

electric potential Symbol *V*. The energy required to bring unit electric charge from infinity to the point in an electric field at which the potential is being specified. The unit of electric potential is the volt. The **potential difference** (**p.d.**) between two points in an electric field or circuit is the difference in the values of the electric potentials at the two points, i.e. it is the work done in moving unit charge from one point to the other.

electric power The rate of expending energy or doing work in an electrical system. For a direct-current circuit, it is given by the product of the current passing through a system and the potential difference across it. In alternating-current circuits, the power is given by $VI\cos\phi$, where V and I are the RMS values and ϕ is the *phase angle. $\cos\phi$ is called the **power factor** of the circuit.

electric spark The transient passage of an electric current through a gas between two points of high opposite potential, with the emission of light and sound. *Lightning consists of a spark between a cloud and earth or between two oppositely charged parts of the same cloud.

electric susceptibility *See* SUSCEPTIBILITY.

electrocardiogram (ECG) A tracing or graph of the electrical activity of the heart. Recordings are made from electrodes fastened over the heart and usually on both arms and a leg. Changes in the normal pattern of an ECG may indicate heart irregularities or disease.

electrochemical cell *See* CELL.

electrochemical equivalent Symbol *z*. The mass of a given element liberated from a solution of its ions in electrolysis by one coulomb of charge. *See* FARADAY'S LAWS (of electrolysis).

electrochemical series *See* ELECTROMOTIVE SERIES.

electrochemistry The study of chemical properties and reactions involving ions in solution, including electrolysis and electric cells.

electrochromatography *See* ELECTROPHORESIS.

electrode **1.** A conductor that emits or collects electrons in a cell, thermionic valve, semiconductor device, etc. The **anode** is the positive electrode and the **cathode** is the negative electrode. **2.** *See* HALF CELL.

electrodeposition The process of depositing one metal on another by electrolysis, as in *electroforming and *electroplating.

electrode potential The potential difference produced between the electrode and the solution in a *half cell. It is not possible to measure this directly since any measurement involves completing the circuit with the electrolyte, thereby introducing another half cell. **Standard electrode potentials** $E^{\ominus}$ are defined by measuring the potential relative to a standard *hydrogen half cell using 1.0 molar solution at 25°C. The convention is to designate the cell so that the oxidized form is written first. For example,

$$Pt(s)|H_2(g)H^+(aq)|Zn^{2+}(aq)|Zn(s)$$

The e.m.f. of this cell is –0.76 volt (i.e. the zinc electrode is negative). Thus the standard electrode potential of the $Zn^{2+}|Zn$ half cell is –0.76 V. Electrode potentials are also called **reduction potentials**. *See also* ELECTROMOTIVE SERIES.

electrodialysis A method of obtaining pure water from water containing a salt, as in *desalination. The water to be purified is fed into a cell containing two electrodes. Between the electrodes is placed an array of *semipermeable membranes alternately semipermeable to positive ions and negative ions. The ions tend to segregate between alternate pairs of membranes, leaving pure water in the other gaps between membranes. In this way, the feed water is separated into two streams: one of pure water and the other of more concentrated solution.

electrodynamics The study of electric charges in motion, the forces created by electric and magnetic fields, and the relationship between them. *Compare* ELECTROSTATICS.

electroencephalogram (EEG) A tracing or graph of the electrical activity of the brain. Electrodes taped to the scalp record electrical waves from different parts of the brain. The pattern of an EEG reflects an individual's level of consciousness and can be used to detect such disorders as epilepsy, tumours, or brain damage. *See also* BRAIN DEATH.

electroendosmosis *See* ELECTROOSMOSIS.

electroforming A method of forming intricate metal articles or parts by *electrodeposition of the metal on a removable conductive mould.

electroluminescence *See* LUMINESCENCE.

electrolysis The production of a chemical reaction by passing an electric current through an electrolyte. In electrolysis, positive ions migrate to the cathode and negative ions to the anode. The reactions occurring depend on electron transfer at the electrodes and are therefore redox reactions. At the anode, negative ions in solution may lose electrons to form neutral species. Alternatively, atoms of the electrode can lose electrons and go into solution as positive ions. In either case the reaction is an oxidation. At the cathode, positive ions in solution can gain electrons to form neutral species. Thus cathode reactions are reductions.

SEE WEB LINKS

- Faraday's 1834 paper on electrical decomposition from *Philosophical Transactions of the Royal Society*

electrolyte A liquid that conducts electricity as a result of the presence of positive or negative ions. Electrolytes are molten ionic compounds or solutions containing ions, i.e. solutions of ionic salts or of compounds that ionize in solution. Liquid metals, in which the conduction is by free electrons, are not usually regarded as electrolytes. Solid conductors of ions, as in the sodium–sulphur cell, are also known as electrolytes.

electrolytic capacitor *See* CAPACITOR.

electrolytic cell A cell in which electrolysis occurs; i.e. one in which current is passed through the electrolyte from an external source.

electrolytic corrosion Corrosion that occurs through an electrochemical reaction. *See* RUSTING.

electrolytic gas (detonating gas) The highly explosive gas formed by the electrolysis of water. It consists of two parts hydrogen and one part oxygen by volume.

electrolytic rectifier A *rectifier consisting of two dissimilar electrodes immersed in an electrolyte. By suitable choice of electrodes and electrolyte the cell can be made to pass current easily in one direction but hardly at all in the other. Examples include a lead–aluminium cell with ammonium phosphate(V) electrolyte and a tantalum–lead cell with sulphuric acid as the electrolyte.

electrolytic refining The purification of metals by electrolysis. It is commonly applied to copper. A large piece of impure copper is used as the anode with a thin strip of pure copper as the cathode. Copper(II) sulphate solution is the electrolyte. Copper dissolves at the anode: $Cu \rightarrow Cu^{2+} + 2e$, and is deposited at the cathode. The net result is transfer of pure copper from anode to cathode. Gold and silver in the impure copper form a so-called **anode sludge** at the bottom of the cell, which is recovered.

electrolytic separation A method of separating isotopes by exploiting the different rates at which they are released in electrolysis. It was formerly used for separating deuterium and hydrogen. On electrolysis of water, hydrogen is formed at the cathode more readily than deuterium, thus the water becomes enriched with deuterium oxide.

electromagnet A magnet consisting of a soft ferromagnetic core with a coil of insulated wire wound round it. When a current flows through the wire the core becomes magnetized; when the current ceases to flow the core loses its magnetization. Electromagnets are used in switches, solenoids, electric bells, metal-lifting cranes, and many other applications.

electromagnetic induction The production of an electromotive force in a conductor when there is a change of magnetic flux linkage with the conductor or when there is relative motion of the conductor across a magnetic field. The magnitude of the e.m.f. is proportional (and in modern

systems of units equal) to the rate of change of the flux linkage or the rate of cutting flux $d\Phi/dt$; the sense of the induced e.m.f. is such that any induced current opposes the change causing the induction, i.e. $E = -d\Phi/dt$. *See* FARADAY'S LAWS; LENZ'S LAW; NEUMANN'S LAW; INDUCTANCE.

electromagnetic interaction *See* FUNDAMENTAL INTERACTIONS.

electromagnetic pump A pump used for moving liquid metals, such as the liquid-sodium coolant in a fast nuclear reactor. The liquid is passed through a flattened pipe over two electrodes between which a direct current flows. A magnetic field at right angles to the current causes a force to be created directly on the liquid, along the axis of the tube. The pump has no moving parts and is therefore safe and trouble free.

electromagnetic radiation Energy resulting from the acceleration of electric charge and the associated electric fields and magnetic fields. The energy can be regarded as waves propagated through space (requiring no supporting medium) involving oscillating electric and magnetic fields at right angles to each other and to the direction of propagation. In a vacuum the waves travel with a constant speed (the speed of light) of 2.9979×10^8 metres per second; if material is present they are slower. Alternatively, the energy can be regarded as a stream of *photons travelling at the speed of light, each photon having an energy hc/λ, where h is the Planck constant, c is the speed of light, and λ is the wavelength of the associated wave. A fusion of these apparently conflicting concepts is possible using the methods of *quantum mechanics or *wave mechanics. The characteristics of the radiation depend on its wavelength. *See* ELECTROMAGNETIC SPECTRUM.

electromagnetic spectrum The range of wavelengths over which *electromagnetic radiation extends. The longest waves (10^5–10^{-3} metres) are radio waves, the next longest (10^{-3}–10^{-6} m) are infrared waves, then comes the narrow band (4–7×10^{-7} m) of visible light, followed by ultraviolet waves (10^{-7}–10^{-9} m), X-rays (10^{-9}–10^{-11} m), and gamma rays (10^{-11}–10^{-14} m).

electromagnetic units (e.m.u.) A system of electrical units formerly used in the *c.g.s. system. The e.m.u. of electric current is the **abampere** (all e.m.u. have the prefix *ab-* attached to the names of practical units). The abampere is the current that, flowing in an arc of a circle (1 centimetre in diameter), exerts a force of 1 dyne on unit magnetic pole at the centre of the circle. In e.m.u. the magnetic constant is of unit magnitude. The system has now been replaced by *SI units for most purposes. *Compare* ELECTROSTATIC UNITS; GAUSSIAN UNITS; HEAVISIDE–LORENTZ UNITS.

electromagnetic wave *See* ELECTROMAGNETIC RADIATION; WAVE.

electrometallurgy The uses of electrical processes in the separation of metals from their ores, the refining of metals, or the forming or plating of metals.

electrometer A measuring instrument for determining a voltage difference without drawing an appreciable current from the source. Originally electrostatic instruments based on the electroscope, they are now usually based on operational amplifiers, solid-state devices with high input impedances. Electrometers are also used to measure low currents (nanoamperes), by passing the current through a high resistance.

electromotive force (e.m.f.) The greatest potential difference that can be generated by a particular source of electric current. In practice this may be observable only when the source is not supplying current, because of its *internal resistance.

electromotive series (electrochemical series) A series of chemical elements arranged in order of their *electrode potentials. The hydrogen electrode ($H^+ + e \rightarrow \frac{1}{2}H_2$) is taken as having zero electrode potential. Elements that have a greater tendency than hydrogen to lose electrons to their solution are taken as **electropositive**; those that gain electrons from their solution are below hydrogen in the series and are called **electronegative**. The series shows the order in which metals replace one another from their salts; electropositive metals will replace hydrogen from acids. The chief metals and hydrogen, placed in order in the series, are: potassium, calcium, sodium, magnesium, aluminium, zinc, cadmium, iron, nickel, tin, lead, hydrogen, copper, mercury, silver, platinum, gold. This type of series is sometimes referred to as an **activity series**.

electron An *elementary particle, classed as a *lepton, with a rest mass (symbol m_e) of $9.109\,3897(54) \times 10^{-31}$ kg and a negative

charge of $1.602\ 177\ 33(49) \times 10^{-19}$ coulomb. Electrons are present in all atoms in groupings called shells around the nucleus; when they are detached from the atom they are called **free electrons**. The antiparticle of the electron is the **positron**.

electron affinity Symbol *A*. The energy change occurring when an atom or molecule gains an electron to form a negative ion. For an atom or molecule X, it is the energy released for the electron-attachment reaction

$$X(g) + e \rightarrow X^-(g)$$

Often this is measured in electronvolts. Alternatively, the molar enthalpy change, ΔH, can be used.

electron biprism An arrangement of fields that splits a beam of electrons or other charged particles in an analogous way to an optical biprism.

electron capture **1.** The formation of a negative ion by an atom or molecule when it acquires an extra free electron. **2.** A radioactive transformation in which a nucleus acquires an electron from an inner orbit of the atom, thereby transforming, initially, into a nucleus with the same mass number but an atomic number one less than that of the original nucleus (capture of the electron transforms a proton into a neutron). This type of capture is accompanied by emission of an X-ray photon or Auger electron as the vacancy in the inner orbit is filled by an outer electron.

electron counting rules Rules for counting the numbers of electrons that give rise to stable structures in atoms, molecules, and solids. For example, the result that the number of electrons in a full electronic shell in an atom is n^2, where n is the principal quantum number associated with the shell, is an example of an electron counting rule. Various rules exist for predicting stable structures in chemical compounds, especially in certain types of cluster compound.

electron cyclotron maser (ECM) A type of *maser in which the operation is based on the stimulated emission of radiation caused by the motion of high-energy electrons moving as in a *cyclotron. A full understanding of this type of maser requires the special theory of relativity. There are many practical applications of the device, including plasma heating in fusion research and telecommunications. This mechanism of maser emission may account for short intense pulses in solar microwave radiation and for certain ionospheric radio emissions.

electron-deficient compound A compound in which there are fewer electrons forming the chemical bonds than required in normal electron-pair bonds. Such compounds use *multicentre bonds. *See* BORANE.

electron diffraction *Diffraction of a beam of electrons by atoms or molecules. The fact that electrons can be diffracted in a similar way to light and X-rays shows that particles can act as waves (*see* DE BROGLIE WAVELENGTH). An electron (mass m, charge e) accelerated through a potential difference V acquires a kinetic energy $mv^2/2 = eV$, where v is the velocity of the electron. The (nonrelativistic) momentum (p) of the electron is $\sqrt{(2eVm)}$. The de Broglie wavelength (λ) of an electron is given by h/p, where h is the Planck constant, thus $\lambda = h/\sqrt{(2eVm)}$. For an accelerating voltage of 3600 V, the wavelength of the electron beam is 0.02 nanometre, some 3×10^4 times shorter than visible radiation.

Electrons then, like X-rays, show diffraction effects with molecules and crystals in which the interatomic spacing is comparable to the wavelength of the beam. They have the advantage that their wavelength can be set by adjusting the voltage. Unlike X-rays they have very low penetrating power. The first observation of electron diffraction was by George Thomson (1892–1975) in 1927, in an experiment in which he passed a beam of electrons in a vacuum through a very thin gold foil onto a photographic plate. Concentric circles were produced by diffraction of electrons by the lattice. The same year Clinton J. Davisson (1881–1958) and Lester Germer (1896–1971) performed a classic experiment in which they obtained diffraction patterns by glancing an electron beam off the surface of a nickel crystal. Both experiments were important verifications of de Broglie's theory and the new quantum theory.

Electron diffraction, because of the low penetration, cannot easily be used to investigate crystal structure. It is, however, employed to measure bond lengths and angles of molecules in gases. Moreover, it is extensively used in the study of solid surfaces and absorption. The main techniques are low-energy electron diffraction (**LEED**) in which the electron beam is reflected onto a fluorescent screen, and high-energy electron dif-

fraction (**HEED**) used either with reflection or transmission in investigating thin films.

electronegative Describing elements that tend to gain electrons and form negative ions. The halogens are typical electronegative elements. For example, in hydrogen chloride, the chlorine atom is more electronegative than the hydrogen and the molecule is polar, with negative charge on the chlorine atom. There are various ways of assigning values for the **electronegativity** of an element. **Mulliken electronegativities** are calculated from $E = (I + A)/2$, where I is ionization potential and A is electron affinity. More commonly, **Pauling electronegativities** are used. These are based on bond dissociation energies using a scale in which fluorine, the most electronegative element, has a value 4. Some other values on this scale are B 2, C 2.5, N 3.0, O 3.5, Si 1.8, P 2.1, S 2.5, Cl 3.0, Br 2.8.

electron flow The transfer of electrons along a series of carrier molecules in the *electron transport chain.

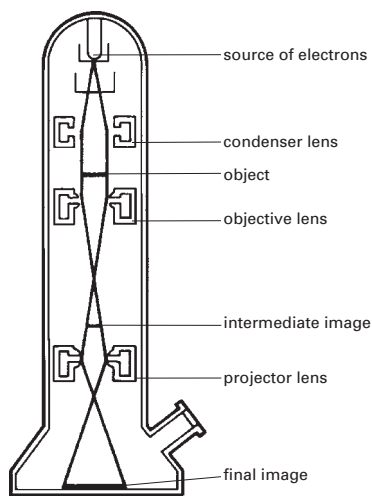
electron gun A device used in *cathode-ray tubes (including television tubes), electron microscopes, etc., to produce a steady narrow beam of electrons. It usually consists of a heated cathode, control grid, and two or more annular anodes inserted in an evacuated tube. The electrons emitted by the cathode are attracted to the final anode, through which they pass. The intensity of the beam is regulated by the control grid and potential differences between the anodes create electric fields that focus the diverging electrons into a narrow beam.

electronic mail (e-mail) Messages, documents, etc., sent between users of computer systems, the computer systems being used to transport and hold the e-mail. The service itself is also referred to as electronic mail. The sender and recipient(s) need not be at their computers at the same time to communicate, and the computer systems may be situated worldwide. The sender creates an e-mail by means of a mail-sending computer program, and a mail transport system then takes responsibility for delivering the e-mail to the indicated address(es).

electronics The study and design of control, communication, and computing devices that rely on the movement of electrons in circuits containing semiconductors, thermionic valves, resistors, capacitors, and inductors. See Chronology.

electron lens A device used to focus an electron beam. It is analogous to an optical lens but instead of using a refracting material, such as glass, it uses a coil or coils to produce a magnetic field or an arrangement of electrodes between which an electric field is created. Electron lenses are used in *electron microscopes and *cathode-ray tubes.

electron microscope A form of microscope that uses a beam of electrons instead of a beam of light (as in the optical microscope) to form a large image of a very small object. In optical microscopes the resolution is limited by the wavelength of the light. High-energy electrons, however, can be associated with a considerably shorter wavelength than light; for example, electrons accelerated to an energy of 10^5 electronvolts have a wavelength of 0.004 nanometre (*see* DE BROGLIE WAVELENGTH) enabling a resolution of 0.2–0.5 nm to be achieved. The **transmission electron microscope** (see illustration) has an electron beam, sharply focused by *electron lenses, passing through a very thin metallized specimen (less than 50 nanometres thick) onto a fluorescent screen, where a visual image is formed. This image can be photographed. The **scanning elec-**



Electron microscope. Principle of the transmission electron microscope.

ELECTRONICS

1887 Radio waves are discovered by Heinrich Hertz.

1894 Oliver Lodge invents the 'coherer' for detecting radio waves.
Marconi develops radio telegraphy.

1897 J. J. Thomson discovers the electron.

1902 US engineer Reginald Fessenden (1866–1932) develops radio telephony.

1903 Danish engineer Valdemar Poulsen (1869–1942) invents the arc transmitter for radio telegraphy.

1904 British engineer Ambrose Fleming (1849–1945) invents the diode thermionic valve.

1906 US engineer Lee De Forest (1873–1961) invents the triode thermionic valve.
US electrical engineer Greenleaf Pickard (1877–1956) patents the crystal detector for radios.
Fessenden introduces amplitude modulation in radio broadcasting.

1911 German physicist Karl Braun (1850–1918) invents cathode-ray tube scanning.

1912 Fessenden develops the heterodyne radio receiver.

1919 US electrical engineer Edwin Armstrong (1890–1954) develops the superheterodyne radio receiver.

1921 US physicist Albert Hull (1880–1966) invents the magnetron microwave-generating valve.

1923 Russian-born US engineer Vladimir Zworykin (1889–1982) invents the iconoscope television camera-tube.

1928 Scottish inventor John Logie Baird (1888–1946) and Vladimir Zworykin independently develop television.

1930 Swedish-born US electronics engineer Ernst Alexanderson (1878–1975) invents an all-electronic television system.

1933 US electrical engineer Edwin Armstrong (1890–1954) develops frequency modulation radio broadcasting.

1947 US physicists John Bardeen, Walter Brattain (1902–87), and William Shockley (1910–89) invent the point-contact transistor.

1950 US engineers develop the Videcon television camera tube.

1953 Chinese-born US computer engineer An Wang (1920–90) invents the magnetic core computer memory.

1954 US physicist Charles Townes (1915–) and Soviet physicists Nikolai Basov and Aleksandr Prokhorov (1916–2002) independently develop the maser.

1958 US electronics engineers Jack Kilby and Robert Noyce (1927–90) develop integrated circuits.

1960 US physicist Theodore Maiman (1927–2007) invents the ruby laser.

1961 US electronics engineer Steven Hofstein develops the field-effect transistor.

1971 US electronics engineer Marcian Edward Hoff (1937–) designs the first microprocessor (Intel 4004).

1977 US engineers transmit television signals along optical fibres.

tron microscope can be used with thicker specimens and forms a perspective image, although the resolution and magnification are lower. In this type of instrument a beam of primary electrons scans the specimen and those that are reflected, together with any secondary electrons emitted, are collected. This current is used to modulate a separate electron beam in a TV monitor, which scans the screen at the same frequency, consequently building up a picture of the specimen. The resolution is limited to about 10–20 nm. *See also* FIELD-EMISSION MICROSCOPE; FIELD-IONIZATION MICROSCOPE.

SEE WEB LINKS

- A tutorial featuring virtual scanning electron microscopy, created by the Optical Microscopy Division of the National High Magnetic Field Laboratory

electron–nuclear double resonance *See* ENDOR.

electron optics The study of the use of *electron lenses in the *electron microscope, *cathode-ray tubes, and other similar devices. The focusing of beams of positive or negative ions also relies on these methods.

electron paramagnetic resonance (EPR) A spectroscopic method of locating electrons within the molecules of a paramagnetic substance (*see* MAGNETISM) in order to provide information regarding its bonds and structure. The spin of an unpaired electron is associated with a *magnetic moment that is able to align itself in one of two ways with an applied external magnetic field. These two alignments correspond to different *energy levels, with a statistical probability, at normal temperatures, that there will be slightly more in the lower state than in the higher. By applying microwave radiation to the sample a transition to the higher state can be achieved. The precise energy difference between the two states of an electron depends on the surrounding electrons in the atom or molecule. In this way the position of unpaired electrons can be investigated. The technique is used particularly in studying free radicals and paramagnetic substances such as inorganic complexes. It is also called **electron-spin resonance** (**ESR**). *See also* NUCLEAR MAGNETIC RESONANCE.

electron probe microanalysis (EPM) A method of analysing a very small quantity of a substance (as little as 10^{-13} gram). The method consists of directing a very finely focused beam of electrons on to the sample to produce the characteristic X-ray spectrum of the elements present. It can be used quantitatively for elements with atomic numbers in excess of 11.

electron spectroscopy Any of a number of techniques in which information is obtained by analysing the energy spectrum of electrons. *Photoelectron spectroscopy is a typical example.

electron-spin resonance *See* ELECTRON PARAMAGNETIC RESONANCE.

electron-transfer reaction A chemical reaction that involves the transfer, addition, or removal of electrons. Electron-transfer reactions often involve complexes of transition metals. In such complexes one general mechanism for electron transfer is the **inner-sphere mechanism**, in which two complexes form an intermediate, with ligand bridges enabling electrons to be transferred from one complex to another complex. The other main mechanism is the **outer-sphere mechanism**, in which two complexes retain all their ligands, with electrons passing from one complex to the other. The rates of electron-transfer reactions vary enormously. These rates can be explained in terms of the way in which molecules of the solvent solvating the reactants rearrange so as to solvate the products in the case of the outer-sphere mechanism. In the case of the inner-sphere (ligand-bridged) reactions the rate of the reaction depends on the intermediate and the way in which the electron is transferred.

electron transport chain (electron transport system) A sequence of biochemical reduction–oxidation reactions that effects the transfer of electrons through a series of carriers. An electron transport chain, also known as the **respiratory chain**, forms the final stage of *aerobic respiration. It results in the transfer of electrons or hydrogen atoms derived from the *Krebs cycle to molecular oxygen, with the formation of water. At the same time it conserves energy from food or light in the form of *ATP. The chain comprises a series of *carrier molecules that undergo reversible reduction–oxidation reactions, accepting electrons and then donating them to the next carrier in the chain – a process known as **electron flow**. In the mitochondria, NADH and $FADH_2$, generated by the Krebs cycle, transfer their electrons to a

chain comprising flavin mononucleotide (FMN), *ubiquinone, and a series of *cytochromes. This process is coupled to the formation of ATP at three sites along the chain (*see* OXIDATIVE PHOSPHORYLATION). The ATP is then carried across the mitochondrial membrane in exchange for ADP. An electron transport chain also occurs in *photosynthesis.

electronvolt Symbol eV. A unit of energy equal to the work done on an electron in moving it through a potential difference of one volt. It is used as a measure of particle energies although it is not an *SI unit. 1 eV = 1.602×10^{-19} joule.

electroorganic reaction An organic reaction produced in an electrolytic cell. Electroorganic reactions are used to synthesize compounds that are difficult to produce by conventional techniques. An example of an electroorganic reaction is *Kolbe's method of synthesizing alkanes.

electroosmosis The movement of a polar liquid through a membrane under the influence of an applied electric field. The linear velocity of flow divided by the field strength is the **electroosmotic mobility**. Electroosmosis was formerly called **electroendosmosis**.

electroosmotic mobility *See* ELECTROOSMOSIS.

electropherogram *See* CAPILLARY ELECTROPHORESIS.

electrophile An ion or molecule that is electron deficient and can accept electrons. Electrophiles are often reducing agents and Lewis *acids. They are either positive ions (e.g. NO_2^+) or molecules that have a positive charge on a particular atom (e.g. SO_3, which has an electron-deficient sulphur atom). In organic reactions they tend to attack negatively charged parts of a molecule. *Compare* NUCLEOPHILE.

electrophilic addition An *addition reaction in which the first step is attack by an electrophile (e.g. a positive ion) on an electron-rich part of the molecule. An example is addition to the double bonds in alkenes.

electrophilic substitution A *substitution reaction in which the first step is attack by an electrophile. Electrophilic substitution is a feature of reactions of benzene (and its compounds) in which a positive ion approaches the delocalized pi electrons on the benzene ring.

electrophoresis (cataphoresis) A technique for the analysis and separation of colloids, based on the movement of charged colloidal particles in an electric field. There are various experimental methods. In the simplest, the sample is placed in a U-tube and a buffer solution added to each arm, so that there are sharp boundaries between buffer and sample. An electrode is placed in each arm, a voltage applied, and the motion of the boundaries under the influence of the field is observed. The rate of migration of the particles depends on the field, the charge on the particles, and on other factors, such as the size and shape of the particles. Electrophoresis can also be carried out using an adsorbent, such as a strip of filter paper, soaked in a buffer with two electrodes making contact. The sample is placed between the electrodes and a voltage applied. Different components of the mixture migrate at different rates, so the sample separates into zones. The components can be identified by the rate at which they move. In **gel electrophoresis** the medium is a gel, typically made of polyacrylamide, agarose, or starch. In modern automated DNA sequencers, electrophoresis is carried out in capillary tubes, less than 0.5mm in diameter and about 48cm long, containing the gel.

Electrophoresis, which has also been called **electrochromatography**, is used extensively in studying mixtures of proteins, nucleic acids, carbohydrates, enzymes, etc. In clinical medicine it is used for determining the protein content of body fluids.

electrophoretic deposition A technique for coating a material making it an electrode in a bath containing a colloidal suspension of charged particles. Under suitable conditions, the particles are attracted to, and deposited on, the electrode. Electrophoretic deposition is used extensively in industry; for example, in applying paint to metal components.

electrophoretic effect The effect in which the mobility of ions in solution moving under the influence of an applied electric field is affected by the flow of ions of opposite charge in the opposite direction.

electrophorus An early form of *electrostatic generator. It consists of a flat dielectric plate and a metal plate with an insulated handle. The dielectric plate is charged by

friction and the metal plate is placed on it and momentarily earthed, which leaves the metal plate with an induced charge of opposite polarity to that of the dielectric plate. The process can be repeated until all of the original charge has leaked away.

electroplating A method of plating one metal with another by *electrodeposition. The articles to be plated are made the cathode of an electrolytic cell and a rod or bar of the plating metal is made the anode. Electroplating is used for covering metal with a decorative, more expensive, or corrosion-resistant layer of another metal.

electropositive Describing elements that tend to lose electrons and form positive ions. The alkali metals are typical electropositive elements.

electroscope A device for detecting electric charge and for identifying its polarity. In the **gold-leaf electroscope** two rectangular gold leaves are attached to the end of a conducting rod held in an insulated frame. When a charge is applied to a plate attached to the other end of the conducting rod, the leaves move apart owing to the mutual repulsion of the like charges they have received.

electrospray ionization (ESI) A technique for producing ions for mass spectrometry, used especially for obtaining ions from large molecules. The sample is dissolved in a volatile solvent, which may also contain volatile acids or bases so that the sample exists in an ionic form. The solution is forced through a charged metal capillary tube and forms an aerosol. Evaporation of the solvent results in single ions of the sample, which are analysed by the mass spectrometer.

electrostatic field The *electric field that surrounds a stationary charged body.

electrostatic generator A device used to build up electric charge to an extreme potential usually for experimental purposes. The *electrophorus and the *Wimshurst machine were early examples; a more usual device now is the *Van de Graaff generator.

electrostatic precipitation A method of removing solid and liquid particles from suspension in a gas. The gas is exposed to an electric field so that the particles are attracted to and deposited on a suitably placed electrode. Electrostatic precipitation is widely used to remove dust and other pollutants from waste gases and from air. *See also* COTTRELL PRECIPITATOR.

electrostatics The study of electric charges at rest, the forces between them (*see* COULOMB'S LAW), and the electric fields associated with them. *Compare* ELECTRODYNAMICS.

electrostatic units (e.s.u.) A system of electrical units in the *c.g.s. system. The e.s.u. of electric charge is the **statcoulomb** (all e.s.u. have the prefix **stat-** attached to the names of practical units). The statcoulomb is the quantity of electric charge that will repel an equal quantity 1 centimetre distant with a force of 1 dyne. In e.s.u. the electric constant is of unit magnitude. The system has now been replaced for most purposes by *SI units. *Compare* ELECTROMAGNETIC UNITS; GAUSSIAN UNITS; HEAVISIDE–LORENTZ UNITS.

electrostriction A change in the dimensions of a body as a result of reorientation of its molecules when it is placed in an electric field. If the field is not homogeneous the body will tend to move; if its relative permittivity is higher than that of its surroundings it will tend to move into a region of higher field strength. *Compare* MAGNETOSTRICTION.

electrovalent bond *See* CHEMICAL BOND.

electroweak theory A *gauge theory (sometimes called **quantum flavourdynamics**, or **QFD**) that gives a unified description of the electromagnetic and weak interactions (*see* FUNDAMENTAL INTERACTIONS). A successful electroweak theory was proposed in 1967 by Steven Weinberg and Abdus Salam, known as the **Weinberg–Salam model** or **WS model**. Because early developments of these ideas were put forward by Sheldon Glashow, it is sometimes known as the **Glashow–Weinberg–Salam model** or **GWS model**. In this electroweak theory the gauge group is non-Abelian and the gauge symmetry is a *broken symmetry. The electroweak interaction is mediated by photons and by intermediate vector bosons, called the *W boson and the *Z boson. The observation of these particles in 1983–84, with their predicted energies, was a major success of the theory. The theory successfully accounts for existing data for electroweak processes and also predicts the existence of a heavy particle with spin 0, the *Higgs boson.

electrum **1.** An alloy of gold and silver containing 55–88% of gold. **2.** A *German sil-

ver alloy containing 52% copper, 26% nickel, and 22% zinc.

element A substance that cannot be decomposed into simpler substances. In an element, all the atoms have the same number of protons or electrons, although the number of neutrons may vary. There are 92 naturally occurring elements. *See also* PERIODIC TABLE; TRANSURANIC ELEMENTS; TRANSACTINIDE ELEMENTS.

elementary particles The fundamental constituents of all the matter in the universe. By the beginning of the 20th century, the electron and the proton had been discovered, but it was not until 1932 that the existence of the neutron was definitely established. Since 1932, it had been known that atomic nuclei consist of both protons and neutrons (except hydrogen, whose nucleus consists of a lone proton). Between 1900 and 1930, *quantum mechanics was also making progress in the understanding of physics on the atomic scale. Non-relativistic quantum theory was completed in an astonishingly brief period (1923–26), but it was the relativistic version that made the greatest impact on our understanding of elementary particles. Dirac's discovery in 1928 of the equation that bears his name led to the discovery of the positive electron or *positron. The mass of the positron is equal to that of the negative electron while its charge is equal in magnitude but opposite in sign. Pairs of particles related to each other in this way are said to be antiparticles of each other. Positrons have only a transitory existence; that is, they do not form part of ordinary matter. Positrons and electrons are produced simultaneously in high-energy collisions of charged particles or gamma rays with matter in a process called *pair production.

The union of *relativity and quantum mechanics therefore led to speculation as early as 1932 that there might also be antiprotons and antineutrons, bearing a similar relationship to their respective ordinary particles as the positron does to the electron. However, it was not until 1955 that particle beams were made sufficiently energetic to enable these antimatter particles to be observed. It is now understood that all known particles have antimatter equivalents, which are predicted by relativistic quantum equations.

By the mid-1930s the list of known and theoretically postulated particles was still small but steadily growing. At this time the Japanese physicist Hideki Yukawa (1907–81) was studying the possible *fundamental interactions that could hold the nucleus together. Since the nucleus is a closely packed collection of positively charged protons and neutral neutrons, clearly it could not be held together by an electromagnetic force; there had to be a different and very large force capable of holding proton charges together at such close proximity. This force would necessarily be restricted to the short range of nuclear dimensions, because evidence of its existence only arose after the discovery of the constituents of the atomic nucleus. Guided by the properties required of this new force, Yukawa proposed the existence of a particle called the *meson, which was responsible for transmitting nuclear forces. He suggested that protons and neutrons in the nucleus could interact by emitting and absorbing mesons. For this reason this new type of force was called an *exchange force. Yukawa was even able to predict the mass of his meson (meaning 'middle weight'), which turned out to be intermediate between the proton and the electron.

Only a year after Yukawa had made this suggestion, a particle of intermediate mass was discovered in *cosmic radiation. This particle was named the **μ-meson** or **muon**. The μ^- has a charge equal to the electron, and its antiparticle μ^+ has a positive charge of equal magnitude. However, physicists soon discovered that muons do not interact with nuclear particles sufficiently strongly to be Yukawa's meson. It was not until 1947 that a family of mesons with the appropriate properties was discovered. These were the **π-mesons** or **pions**, which occur in three types: positive, negative, and neutral. Pions, which interact strongly with nuclei, have in fact turned out to be the particles predicted by Yukawa in the 1930s. The nuclear force between protons and neutrons was given the name 'strong interaction' (*see* FUNDAMENTAL INTERACTIONS) and until the 1960s it was thought to be an exchange force as proposed by Yukawa.

A theory of the weak interaction was also in its infancy in the 1930s. The weak interaction is responsible for *beta decay, in which a radioactive nucleus is transformed into a slightly lighter nucleus with the emission of an electron. However, beta decays posed a problem because they appeared not to conserve energy and momentum. In 1931 *Pauli proposed the existence of a neutral particle that might be able to carry off the missing

energy and momentum in a beta decay and escape undetected. Three years later, *Fermi included Pauli's particle in a comprehensive theory of beta decay, which seemed to explain many experimentally observed results. Fermi called this new particle the *neutrino, the existence of which was finally established in the 1950s.

A plethora of experiments involving the neutrino revealed some remarkable properties for this new particle. The neutrino was found to have an intimate connection with the electron and muon, and indeed never appeared without the simultaneous appearance of one or other of these particles. A conservation law was postulated to explain this observation. Numbers were assigned to the electron, muon, and neutrino, so that during interactions these numbers were conserved; i.e. their algebraic sums before and after these interactions were equal. Since these particles were among the lightest known at the time, these assigned numbers became known as **lepton numbers** (lepton: 'light ones'). In order to make the assignments of lepton number agree with experiment, it is necessary to postulate the existence of two types of neutrino. Each of these types is associated with either the electron or muon; there are thus muon neutrinos and electron neutrinos. In 1978 the **tau particle** or **tauon** was discovered and was added to the list of particles with assigned lepton numbers. The conservation of lepton number in the various interactions involving the tau requires the existence of an equivalent tau neutrino. The six particles with assigned lepton numbers are now known as *leptons.

Neutrinos have zero charge and were originally thought to have zero rest mass, but there has been increasing indirect experimental evidence to the contrary. In 1985 a Soviet team reported a measurement, for the first time, of a non-zero neutrino mass. The mass measured was extremely small (10 000 times less than the mass of the electron), but subsequent attempts independently to reproduce these results did not succeed. More recently (1998–99), Japanese and US groups have put forward theories and corroborating experimental evidence to suggest, indirectly, that neutrinos do have mass. In these experiments neutrinos are found to apparently 'disappear'. Since it is unlikely that momentum and energy are actually vanishing from the universe, a more plausible explanation is that the types of neutrinos detected are changing into types that cannot be detected. Present theoretical considerations imply that the masses of neutrinos involved cannot be equal to one another, and therefore they cannot all be zero. This speculative work has not yet yielded estimates of the neutrino masses, which is indicated by the use of asterisks in the table.

In the 1960s, the development of high-energy accelerators and more sophisticated detection systems led to the discovery of many new and exotic particles. They were all unstable and existed for only small fractions of a second; nevertheless they set into motion a search for a theoretical description that could account for them all. The large number of these apparently fundamental particles suggested strongly that they do not, in fact, represent the most fundamental level of the structure of matter. Physicists found themselves in a position similar to Mendeleev when the *periodic table was being developed. Mendeleev realized that there had to be a level of structure below the elements themselves, which explained the chemical properties and the interrelations between elements.

Murray Gell-Mann and his collaborators proposed the particle-physics equivalent of the periodic table in 1961. In this structure, leptons were indeed regarded as fundamental particles, but the short-lived particles dis-

Name	Symbol	Charge (electron charges)	Rest mass (MeV/c^2)
electron	e^-	–1	0.511
electron neutrino	ν_e	0	*
muon	μ^-	–1	105.7
muon neutrino	ν_μ	0	*
tauon	τ^-	–1	1784
tau neutrino	ν_τ	0	*

Elementary particles. Table of leptons.

covered in the 1960s were not. These particles were found to undergo strong interactions, which did not seem to affect the leptons. Gell-Mann called these strongly interacting particles the *hadrons and proposed that they occurred in two different types: baryons and mesons. These two different types corresponded to the two different ways of constructing hadrons from constituent particles, which Gell-Mann called **quarks**. These quarks came in three **flavours**, up (u), down (d), and strange (s). These three quarks were thought to be the fundamental constituents of hadrons, i.e. matter that undergoes strong interactions: baryons are composed of three quarks (u, d, or s) or three antiquarks (ū, d̄, or s̄); mesons are composed of (u, d, or s) quark–antiquark pairs.

No other combinations seemed to be necessary to describe the full variation of the observed hadrons. This scheme even led to the prediction of other particles that were not known to exist in 1961. For example, in 1961 Gell-Mann not only predicted the Ω^- (omega-minus) particle, but more importantly told experimentalists exactly how to produce it. The Ω^- particle was finally discovered in 1964.

Gell-Mann called his scheme 'the eightfold way', after the similarly named Buddhist principle. The scheme requires that quarks have properties not previously allowed for fundamental particles. For example, quarks have fractional electric charges, i.e. charges of 1/3 and 2/3 of the electron charge. Quarks also have a strong affinity for each other through a new kind of charge known as **colour charge**. Thus colour charge is responsible for strong interactions, and the force is known as the colour force. This is a revision of Yukawa's proposal in 1930. Yukawa's strong force was mediated by π-mesons. The strong force is now thought to be mediated by exchange of particles carrying colour charge called **gluons**. The theory governing these colour charge combinations is modelled on *quantum electrodynamics and is known as *quantum chromodynamics.

In November 1974 the discovery of the ψ (psi) particle initiated what later came to be known as 'the November revolution'. At the time, any known hadron could be described as some combination of u, d, or s quarks. These hadrons were very short-lived with lifetimes of about 10^{-23} s. The ψ particle, however, had a lifetime of 10^{-20} s; i.e. a thousand times longer. This suggested a completely different species of particle. It is now universally accepted that the ψ represents a meson-bound state of a new fourth quark, the **charm** (c) quark and its antiquark. In 1977 the list of quarks once again increased with the discovery of a new even heavier meson, called the Y (**upsilon**) meson. This meson was found to have an even longer lifetime than the ψ, and was quickly identified as the carrier of a fifth quark, **bottom** (b).

Thus, by the end of 1977, five flavours of quark (u, d, s, c, b) were known to exist together with six flavours of lepton (e, μ, τ, ν_e, τ_μ, ν_τ). Assuming that quarks and leptons are the fundamental constituents of matter, many of the strong and weak interactions of hadrons and the weak interactions of leptons can be explained. However, anticipating a symmetry in nature's building blocks, it was expected that a sixth quark would eventually reveal itself. This quark, labelled **top** (t), would be the 2/3 electronic charge partner to the b quark (see table).

Quark symbol	Name	Charge
u	up	–2/3
d	down	–1/3
c	charm	–2/3
s	strange	–1/3
t	top	–2/3
b	bottom	–1/3

Elementary particles. Table of quarks (mass is not shown because quarks are never observed alone).

In 1998 the top quark was found at CERN in Geneva and the symmetry of six quarks with six leptons was finally verified.

In 1978 the **standard model** was proposed as the definitive theory of the fundamental constituents of matter. In the current view, all matter consists of three kinds of particles: leptons, quarks, and mediators (see table overleaf). The mediators are the particles by which the four fundamental interactions are mediated. In the standard model, each of these interactions has a particle mediator. For the electromagnetic reaction it is the *photon.

For weak interactions the force is mediated by three particles called W^+, W^-, and Z° *bosons; for the strong force it is the gluon. Current theories of quantum gravity propose the *graviton as the mediator for the gravitational interaction, but this work is highly

Interaction	Mediator (exchange particle)	Rest mass (GeV/c^2)	Charge
strong	gluon	0	0
electromagnetic	photon	0	0
weak	W^+, W^-, Z°	81,81,93	+1,–1,0
gravitational	graviton	0	0

Elementary particles. Table of mediators.

speculative and the graviton has never been detected.

elements of an orbit Six parameters used to define the path of a celestial body. The shape of the orbit is defined by its eccentricity (*see* CONIC) and semimajor axis. The orientation of the orbit is specified by the *inclination of the orbital plane to the reference plane (usually the *ecliptic) and by the longitude of the ascending *node (the angular distance from the vernal equinox to the ascending node). The position of the body in its orbit is defined by its eccentric *anomaly and the position as a function of time is calculated from the periapsis passage (*see* APSIDES).

elevation of boiling point An increase in the boiling point of a liquid when a solid is dissolved in it. The elevation is proportional to the number of particles dissolved (molecules or ions) and is given by $\Delta t = k_B C$, where C is the molal concentration of solute. The constant k_B is the **ebullioscopic constant** of the solvent and if this is known, the molecular weight of the solute can be calculated from the measured value of Δt. The elevation is measured by a Beckmann thermometer. *See also* COLLIGATIVE PROPERTIES.

elimination reaction A reaction in which one molecule decomposes into two, one much smaller than the other.

Elinvar Trade name for a nickel–chromium steel containing about 36% nickel, 12% chromium, and smaller proportions of tungsten and manganese. Its elasticity does not vary with temperature.

ELISA (enzyme-linked immunosorbent assay) A sensitive technique (*see* IMMUNOASSAY) for accurately determining the amount of protein or other antigen in a given sample by means of an enzyme-catalysed colour change. Antibody specific to the test protein is adsorbed onto a solid substrate, such as a PVC sheet, and a measured amount of the sample is added; all molecules of the test protein in the sample are bound by the antibody. A second antibody specific for a second site on the test protein is added; this is conjugated with an enzyme, which catalyses a colour change in the fourth reagent, added finally to the sheet. The colour change can be measured photometrically and compared against a standard curve to give the concentration of protein in the sample. ELISA is widely used for diagnostic and other purposes.

Ellingham diagram A diagram used to show the conditions under which a metal oxide can be reduced to a metal. The standard Gibbs free energy of formation of the oxide is considered, for example,

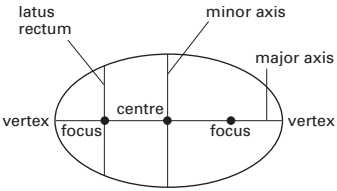
$$M + \tfrac{1}{2}O_2 \rightarrow MO$$

This value, $\Delta G^{\ominus}$, is plotted against temperature. In general, the result is a straight line. In some cases, there is an abrupt change in the line's slope at a point because of a phase change. The value of $\Delta G^{\ominus}$ for the reducing agent is also plotted. For example, if the reducing agent is carbon, forming carbon dioxide, it is $\Delta G^{\ominus}$ for the reaction

$$C + O_2 \rightarrow CO_2$$

Reduction can occur in the range of temperatures in which the carbon curve is lower than the metal curve. The diagram was devised by the physical chemist H. J. T. Ellingham.

ellipse A *conic formed by the intersection of a plane with a right circular cone, so that the plane is inclined to the axis of the cone at an angle in excess of half the apex angle of the cone. The ellipse has two vertices, which are joined by a line called the **major axis**. The centre of the ellipse falls on this line, midway between the vertices. The **minor axis** is the line perpendicular to the major axis that passes through the centre and joins two points on the ellipse. The **foci** of an el-



An ellipse.

lipse are two points on the major axis so placed that for any point on the ellipse the sum of the distances from that point to each focus is constant. (See illustration.) The area of an ellipse is πab, where a and b are half the major and minor axes, respectively. For an ellipse centred at the origin, the equation in Cartesian coordinates is $x^2/a^2 + y^2/b^2 = 1$. The foci are at $(ea, 0)$ and $(-ea, 0)$, where e is the eccentricity. Each of the two chords of the ellipse passing through a focus and parallel to the minor axis is called a **latus rectum** and has a length equal to $2b^2/a$.

ellipsoid A solid body formed when an *ellipse is rotated about an axis. If it is rotated about its major axis it is a **prolate ellipsoid**; if it is rotated about its minor axis it is an **oblate ellipsoid**. For an ellipsoid centred at the origin the equation in Cartesian coordinates is:

$$x^2/a^2 + y^2/b^2 + z^2/c^2 = 1.$$

elliptical galaxy *See* GALAXY.

elliptical polarization *See* POLARIZATION OF LIGHT.

El Niño A surge of warm ocean water (the Peru current) that occurs every 5 to 8 years off the eastern coast of South America. See Feature overleaf.

Elton, Charles Sutherland (1900–91) British zoologist and ecologist, who founded the Bureau of Animal Population at Oxford in 1932 and the same year became editor of the new *Journal of Animal Ecology*. The first zoologist to study animals in relation to their environment, he explored the nature of food chains and studied population fluctuations.

eluate *See* CHROMATOGRAPHY; ELUTION.

eluent *See* CHROMATOGRAPHY; ELUTION.

elution The process of removing an adsorbed material (**adsorbate**) from an adsorbent by washing it in a liquid (**eluent**). The solution consisting of the adsorbate dissolved in the eluent is the **eluate**. Elution is the process used to wash components of a mixture through a *chromatography column.

elutriation The process of suspending finely divided particles in an upward flowing stream of air or water to wash and separate them into sized fractions.

elytra The thickened horny forewings of the *Coleoptera (beetles), which cover and protect the membranous hindwings when the insect is at rest.

e-mail *See* ELECTRONIC MAIL.

emanation The former name for the gas radon, of which there are three isotopes: Rn–222 (radium emanation), Rn–220 (thoron emanation), and Rn–219 (actinium emanation).

emasculation The removal of the anthers of a flower in order to prevent self-pollination or the undesirable pollination of neighbouring plants.

EMBASE (Excerpta Medica Database) A bibliographic database containing citations, abstracts, indexing terms, and codes covering over 5000 biological and medical journals from more than 70 countries, especially Europe. It contains over 11 million records, with some half a million new ones added each year, and has a particular emphasis on drug-related fields.

Embden–Meyerhof pathway *See* GLYCOLYSIS.

embryo **1.** An animal in the earliest stages of its development, from the time when the fertilized ovum starts to divide (*see* CLEAVAGE), while it is contained within the egg or reproductive organs of the mother, until hatching or birth. A human embryo (see illustration p. 286) is called a *fetus after the first eight weeks of pregnancy. **2.** The structure in plants that develops from the zygote prior to germination. In seed plants the zygote is situated in the *embryo sac of the ovule. It divides by mitosis to form the embryonic cell and a structure called the **suspensor**, which embeds the embryo in the surrounding nutritive tissue. The embryonic cell divides continuously and eventually gives rise to the *radicle (young root), *plumule (young shoot), and one or two *cotyledons (seed leaves). Changes also take place in the surrounding tissues of the ovule,

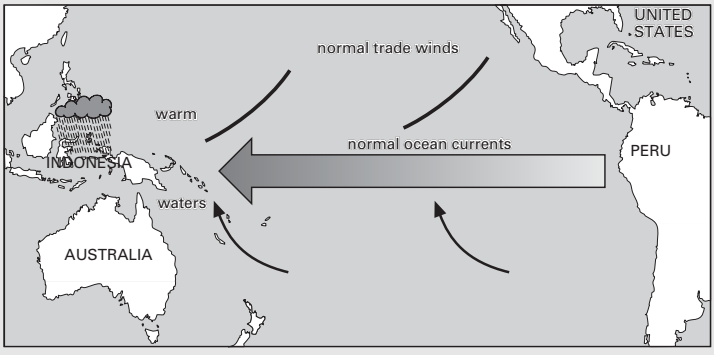
EL NIÑO

A phenomenon reoccurring every few years in the equatorial part of the Pacific ocean, characterized by movement of a mass of warm water eastward towards the west coast of South America. This change in ocean conditions has long been recognized in Peru, where sailors noticed that an unusual counter-current appeared in certain years around the area of the port of Paita. They named this current El Niño – 'the Christ Child' – because it usually appeared immediately after Christmas. It was also known that the appearance of this current coincided with different weather conditions, particularly increased rainfall and sometimes flooding.

The phenomenon has dramatic effects on the climate and ecology of this part of South America. In particular, it interrupts the Humbolf current, which is a cold ocean current carrying plankton from Arctic regions. El Niño occurs every 4–7 years and the effects last for about 8 months. In the 1960s interest developed in the phenomenon and it is now recognized that El Niño has effects on climate much wider than those observed on the west coast of South America. In extreme cases, as in 1986–87 and 1997–98, it can cause tropical cyclones over the whole Pacific area, drought in southeastern Asia and Australia, and increased rainfall and flooding in parts of North America.

The mechanism of El Niño

There is no definite agreement about what induces an El Niño event, but the physical mechanism of how it occurs is fairly well understood. The large-scale movement of water in the world's oceans is influenced by, and in turn influences, the prevailing wind patterns. In tropical regions there are persistent **trade winds** flowing from east to west. In the Pacific these push large amounts of water westward towards the coasts of Indonesia. This causes a significant difference in sea level between opposite sides of the Pacific. For instance, the sea level in the Philippines in the west is around 60 cm higher than that on the coast of Panama in the eastern Pacific. The water in the west is also much warmer. This mass of warm ocean in the western Pacific gives Indonesia its high rainfall under normal climatic conditions.



In normal years the trade winds blow from east to west across the Pacific. This causes a difference in sea level and a mass of warm water builds up in the western Pacific, creating a warm area of ocean off the east coast of Indonesia. This area has some of the highest rainfall in the world.

Every few years there is a significant change in the prevailing wind pattern, involving a fall in the intensity of the trade winds. In extreme cases, a reversal of direction of the winds may occur. As a result, the warm water that is piled up in the west flows back eastwards across the Pacific towards the west coast of South America. The event lasts until the normal conditions and wind patterns are re-established.

The Southern Oscillation and La Niña

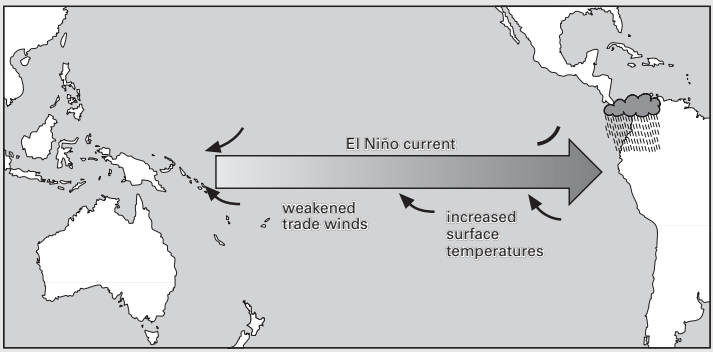
El Niño events are connected with another periodic phenomenon occurring not in the ocean but in the atmosphere. The meteorologist Sir Gilbert Walker noted in 1923 that when pressure was high in the Pacific it tends to be low in the Indian ocean, and vice versa. The extent of this is now measured by taking the difference between the surface atmospheric pressure at Darwin in Australia and at Tahiti in the south Pacific. A high pressure at one site is usually accompanied by a low pressure at the other and every few years the pattern reverses. There is a large mass of air slowly oscillating (with a period of a few years) across tropical regions. Walker called this the **Southern Oscillation**.

The Southern Oscillation is part of a large general cycle of coupled air and water flow known as the **El Niño–Southern Oscillation** (ENSO). El Niño is the warm phase of this cycle. In some years, as part of the ENSO cycle, a cold region develops in the eastern tropical Pacific. This is known as **La Niña** ('the little girl').

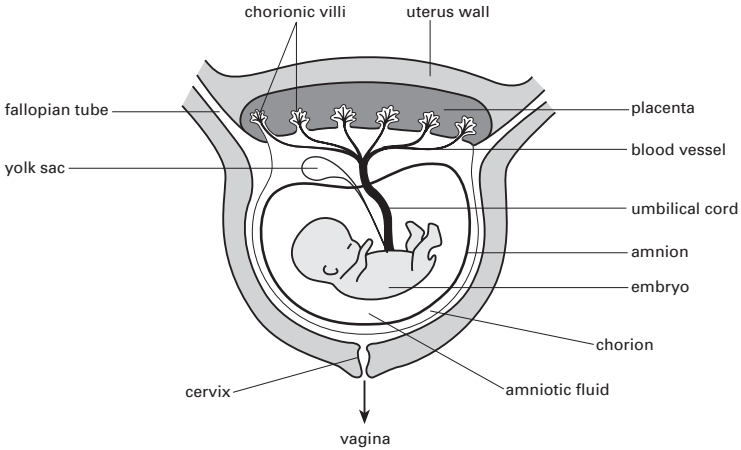
The Southern oscillation is not the only atmospheric oscillation that occurs. For example there is a **North Atlantic Oscillation** (NAO) measured by the pressure difference between Iceland and the Azores, which is thought to have a major influence on climatic conditions and on the ecosystems of this part of the globe. There is however no Atlantic analogue of El Niño.

The causes of El Niño

Although the flows of air and water are understood, there is no concensus about why an El Niño forms. Some workers have suggested that the frequency and intensities of El Niño events may be increasing because of global warming. However, there is no direct evidence for this .



In certain years there is a reduction in the intensity of the trade winds across the Pacific. This allows the mass of warm water in the west to flow across to the east, creating a warm area of ocean off the west coast of South America. This brings rain to Peru but causes drought in southeast Asia and Australia.



Embryo. A developing human embryo.

which becomes the *seed enclosing the embryo plant.

embryology The study of the development of animals from the fertilized egg to the new adult organism. It is sometimes limited to the period between fertilization of the egg and hatching or birth (*see* EMBRYO).

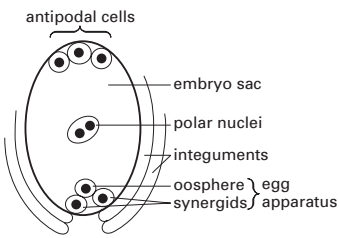
SEE WEB LINKS

- Hosted by the University of New South Wales, this dynamic site explores human embryology and development

embryonic stem cell *See* STEM CELL.

embryophyte A true plant, i.e. one that develops from an embryo and therefore is necessarily multicellular. The term underlines the distinction between plants and algae, which lack embryos.

embryo sac A large cell that develops in the *ovule of flowering plants. It is equivalent to the female *gametophyte of lower plants, although it is very much reduced. Typically, it contains eight nuclei formed by division of the original female gamete (see illustration). One forms the *oosphere (egg cell), which is fertilized by a male nucleus and becomes the *embryo. The two polar nuclei fuse with a second male nucleus to form a triploid nucleus that gives rise to the *endosperm. The three remaining nuclei form the antipodal cells.



Embryo sac.

emerald The green gem variety of *beryl: one of the most highly prized gemstones. The finest specimens occur in the Muzo mines, Colombia. Other occurrences include the Ural Mountains, the Transvaal in South Africa, and Kaligunan in India. Emeralds can also be successfully synthesized.

emergence A key concept in *complexity theory in which certain features of a complex system occur as a result of collective behaviour of the system. For example, in the kinetic theory of gases the concept of temperature emerges from the average kinetic energy of the very large number of particles in the system. It has been suggested that space and time in physics should ultimately be emergent quantities.

emergency action code *See* HAZCHEM CODE.

emery A rock composed of corundum

(natural aluminium oxide, Al_2O_3) with magnetite, haematite, or spinel. It occurs on the island of Naxos (Greece) and in Turkey. Emery is used as an abrasive and polishing material and in the manufacture of certain concrete floors.

e.m.f. *See* ELECTROMOTIVE FORCE.

emission spectrum *See* SPECTRUM.

emissivity Symbol ε. The ratio of the power per unit area radiated by a surface to that radiated by a *black body at the same temperature. A black body therefore has an emissivity of 1 and a perfect reflector has an emissivity of 0. The emissivity of a surface is equal to its *absorptance.

emittance *See* EXITANCE.

emitter *See* TRANSISTOR.

emitter-coupled logic (ECL) A set of integrated *logic circuits. The input part of an ECL consists of an emitter-coupled *transistor pair which is a very good differential amplifier. The output is through an *emitter follower. ECL circuits are very rapid logic circuits.

emitter follower An amplifying circuit using a bipolar junction *transistor with a *common-collector connection. The output is taken from the emitter.

empirical Denoting a result that is obtained by experiment or observation rather than from theory.

empirical formula *See* FORMULA.

emulsification (in digestion) The breakdown of fat globules in the duodenum into tiny droplets, which provides a larger surface area on which the enzyme pancreatic *lipase can act to digest the fats into fatty acids and glycerol. Emulsification is assisted by the action of the bile salts (*see* BILE).

emulsion A *colloid in which small particles of one liquid are dispersed in another liquid. Usually emulsions involve a dispersion of water in an oil or a dispersion of oil in water, and are stabilized by an **emulsifier**. Commonly emulsifiers are substances, such as *detergents, that have lyophobic and lyophilic parts in their molecules. Dietary fats are reduced to an emulsion in the duodenum to facilitate their subsequent digestion (*see* EMULSIFICATION).

en The symbol for ethylene diamine (1,2-diaminoethane) functioning as a bidentate ligand, used in formulae.

enamel The material that forms a covering over the crown of a *tooth (i.e. the part that projects above the gum). Enamel is smooth, white, and extremely hard, being rich in minerals containing calcium, especially *apatite. It is produced by certain cells (**ameloblasts**) of the oral epithelium and protects the underlying dentine of the tooth. Enamel may also be found in the placoid *scales of certain fish, which demonstrates the common developmental origin of scales and teeth.

enamine A type of compound with the general formula $R^1R^2C{=}C(R^3){-}NR^4R^5$, where R is a hydrocarbon group or hydrogen. Enamines can be produced by condensation of an aldehyde or ketone with a secondary amine.

enantiomers *See* OPTICAL ACTIVITY.

enantiomorphism *See* OPTICAL ACTIVITY.

enantiotropy *See* ALLOTROPY.

encephalin *See* ENKEPHALIN.

endangered species A plant or animal species defined by the IUCN (International Union for the Conservation of Nature and Natural Resources) as being in immediate danger of *extinction because its population numbers have reached a critical level or its habitats have been drastically reduced. If these causal factors continue the species is unlikely to survive. A list of endangered species is published by the IUCN, which also defines other categories of threatened species.

SEE WEB LINKS

- Official website of the IUCN

endemic **1.** Describing a plant or animal species that is restricted to one or a few localities in its distribution. Endemic species are usually confined to islands and are vulnerable to extinction. **2.** Describing a disease or a pest that is always present in an area. For example, malaria is endemic in parts of Africa.

endergonic reaction A chemical reaction in which energy is absorbed. *Compare* EXERGONIC REACTION.

endo- (in chemistry) Prefix used to designate a bridged ring molecule with a substituent on the ring that is on the same side

as the bridge. If the substituent is on the opposite side the compound is designated **exo-**.

endocannabinoids *See* CANNABINOIDS.

endocarp *See* PERICARP.

endocrine gland (ductless gland) Any gland in an animal that manufactures *hormones and secretes them directly into the bloodstream to act at distant sites in the body (known as **target organs** or **cells**). Endocrine glands tend to control slow long-term activities in the body, such as growth and sexual development. In mammals they include the *pituitary, *adrenal, *thyroid, and *parathyroid glands, the *ovary and *testis, the *placenta, and part of the pancreas (*see* ISLETS OF LANGERHANS). The activity of endocrine glands is controlled by negative feedback, i.e. a rise in output of hormone inhibits a further increase in its production, either directly or indirectly via the target organ or cell. *See also* NEUROENDOCRINE SYSTEM. *Compare* EXOCRINE GLAND.

endocrinology The study of the structure and functions of the *endocrine glands and of the *hormones they produce.

endocytosis The process by which materials enter a cell without passing through the plasma membrane. The membrane folds around material outside the cell, resulting in the formation of a saclike vesicle into which the material is incorporated. This vesicle is then pinched off from the cell surface so that it lies within the cell. Both *phagocytosis and *pinocytosis are forms of endocytosis. *Compare* EXOCYTOSIS.

endoderm (entoderm) The internal layer of cells of the *gastrula, which will develop into the alimentary canal (gut) and digestive glands of the adult. *See also* GERM LAYERS.

endodermis The innermost layer of the root *cortex of a plant, lying immediately outside the vascular tissue. Various modifications of the endodermal cell walls enable them to regulate the passage of materials both into and out of the vascular system. An endodermis may also be seen in the stems of some plants.

endoergic Denoting a nuclear process that absorbs energy. *Compare* EXOERGIC.

endogamy The fusion of reproductive cells from closely related parents, i.e. *inbreeding. *Compare* EXOGAMY.

endogenous Describing a substance, stimulus, organ, etc., that originates from within an organism. For example, growth rhythms not directed by environmental stimuli are termed endogenous rhythms. Lateral roots, which always grow from inside the main root rather than from its surface, are said to arise endogenously. *Compare* EXOGENOUS.

endolymph The fluid that fills the membranous labyrinth of the vertebrate *inner ear. *See* COCHLEA; SEMICIRCULAR CANALS. *Compare* PERILYMPH.

endometrium The mucous membrane that lines the *uterus of mammals. It is comprised of an upper mucus-secreting layer, which is shed during menstruation, and a basal layer, which proliferates to form the upper layer. *See also* MENSTRUAL CYCLE.

endonuclease An enzyme that catalyses the internal cleavage of nucleic acids. *See also* RESTRICTION ENZYME. *Compare* EXONUCLEASE.

endoparasite A parasite that lives inside its host's body. *See* PARASITISM.

endopeptidase A protein-digesting enzyme that cleaves a polypeptide chain at specific sites between amino acids. For example, *chymotrypsin cleaves the chain next to aromatic amino acids, such as phenylalanine; *trypsin cleaves the chain next to basic amino acids, such as lysine or arginine; and *pepsin cleaves the chain next to tyrosine and phenylalanine. *Compare* EXOPEPTIDASE.

endoplasm *See* CYTOPLASM.

endoplasmic reticulum (ER) A system of membranes within the cytoplasm of plant and animal *cells. It forms a link between the plasma and nuclear membranes and is the site of protein synthesis. It is also concerned with the transport of proteins and lipids within the cell. **Rough ER** has *ribosomes attached to its surface; proteins synthesized on the ribosomes are enclosed in vesicles and transported to the *Golgi apparatus. **Smooth ER** lacks ribosomes; it is the site of important metabolic reactions, including phospholipid and fatty-acid synthesis.

ENDOR Electron–nuclear double resonance. A magnetic resonance technique involving exitation of both electron spins and nuclear spins. Two sources of radiation are used. One is a fixed source at microwave frequency, which partially saturates the elec-

tron spins. The other is a variable radiofrequency source, which excites the atomic nuclear spins. Excitation of the nuclear spins affects the electron spins by hyperfire coupling, increasing the relaxation time of the excited electron spins and increasing the signal strength. The technique, which is usually done at low temperatures, is used to investigate paramagnetic molecules. *See also* ELECTRON PARAMAGNETIC RESONANCE.

end organ The structure at the end of a peripheral nerve. Examples of end organs are the muscle *end plate at the end of a motor neuron and the *receptor at the end of a sensory neuron.

endorphin Any of a class of three endogenous *opioids – α-, β-, and γ- endorphins – found naturally in brain and other tissues that have pain-relieving effects similar to those of morphine. They are all peptides or polypeptides derived from the precursor pro-opiomelanocortin; for example, β-endorphin is a 31-amino-acid peptide. The endorphins mediate their analgesic effects by binding to opioid receptors. *See also* ENKEPHALIN.

endoskeleton A supporting framework that lies entirely within the body of an animal, such as the bony *skeleton of vertebrates or the spicules of a sponge. The function of an endoskeleton is to support the body and in vertebrates it also protects the organs and provides a system of levers on which the muscles can act to produce movement. *Compare* EXOSKELETON.

endosperm A nutritive tissue, characteristic of flowering plants, that surrounds the developing embryo in a seed. It develops from nuclei in the *embryo sac and its cells are triploid. In **endospermic** seeds it remains and increases in size; in **nonendospermic** seeds it disappears as the food is absorbed by the embryo, particularly the *cotyledons. Many plants with endospermic seeds, such as cereals and oil crops, are cultivated for the rich food reserves in the endosperm.

endospore The resting stage of certain bacteria, formed in response to adverse conditions. The bacterial cell becomes enclosed in a tough resistant protein coat. On return to favourable conditions the spore germinates and reverts to the normal vegetative form of the organism. Endospores can remain viable for long periods, perhaps several thousands of years.

endosymbiont theory A theory, devised principally by US biologist Lynn Margulis (1938–), that eukaryotic organisms evolved from symbiotic associations between prokaryotic ancestors. Free-living aerobic bacteria and chloroxybacteria (*see* CYANOBACTERIA) became incorporated inside larger nucleated prokaryotic cells, where they acted as forerunners of the mitochondria and chloroplasts seen in modern eukaryotes. Such events are held to have occurred on several occasions, producing various lineages of both heterotrophic and phototrophic protoctists, from which evolved ancestors of animals, plants, and fungi. There is strong evidence for the theory, particularly the finding that mitochondria and chloroplasts have DNA similar in form to that of eubacteria, and that they contain prokaryotic-type ribosomes.

endothelium A single layer of thin platelike cells that line the inner surfaces of blood and lymph vessels and the heart. Endothelium is derived from the *mesoderm. *Compare* EPITHELIUM; MESOTHELIUM.

endotherm (homoiotherm) An animal that can generate and maintain heat within its body independently of the environmental temperature. Mammals and birds are endotherms; they are often described as being **warm-blooded**. *See* HOMOIOTHERMY. *Compare* ECTOTHERM.

endothermic Denoting a chemical reaction that takes heat from its surroundings. *Compare* EXOTHERMIC.

endotoxin *See* TOXIN.

end plate The area of the plasma membrane of a muscle cell that lies immediately beneath a motor nerve ending at a *neuromuscular junction. Release of a *neurotransmitter at the end plate induces contraction of the muscle fibre.

end point The point in a titration at which reaction is complete as shown by the *indicator.

energy A measure of a system's ability to do work. Like work itself, it is measured in joules. Energy is conveniently classified into two forms: **potential energy** is the energy stored in a body or system as a consequence of its position, shape, or state (this includes gravitational energy, electrical energy, nuclear energy, and chemical energy); **kinetic energy** is energy of motion and is usually

defined as the work that will be done by the body possessing the energy when it is brought to rest. For a body of mass m having a speed v, the kinetic energy is $mv^2/2$ (classical) or $(m - m_0)c^2$ (relativistic). The rotational kinetic energy of a body having an angular velocity ω is $I\omega^2/2$, where I is its moment of inertia.

The *internal energy of a body is the sum of the potential energy and the kinetic energy of its component atoms and molecules.

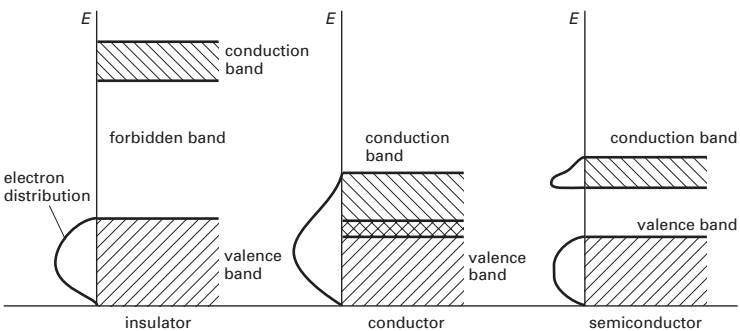
energy bands Ranges of energies that electrons can have in a solid. In a single atom, electrons exist in discrete *energy levels. In a crystal, in which large numbers of atoms are held closely together in a lattice, electrons are influenced by a number of adjacent nuclei and the sharply defined levels of the atoms become bands of allowed energy (see illustration); this approach to energy levels in solids is often known as the **band theory**. Each band represents a large number of allowed quantum states. Between the bands are **forbidden bands**. The outermost electrons of the atoms (i.e. the ones responsible for chemical bonding) form the **valence band** of the solid. This is the band, of those occupied, that has the highest energy.

The band structure of solids accounts for their electrical properties. In order to move through the solid, the electrons have to change from one quantum state to another. This can only occur if there are empty quantum states with the same energy. In general, if the valence band is full, electrons cannot change to new quantum states in the same band. For conduction to occur, the electrons have to be in an unfilled band – the **conduction band**. Metals are good conductors either because the valence band and the conduction band are only half-filled or because the conduction band overlaps with the valence band; in either case vacant states are available. In insulators the conduction band and valence band are separated by a wide forbidden band and electrons do not have enough energy to 'jump' from one to the other.

In intrinsic *semiconductors the forbidden gap is narrow and, at normal temperatures, electrons at the top of the valence band can move by thermal agitation into the conduction band (at absolute zero, a semiconductor would act as an insulator). Doped semiconductors have extra bands in the forbidden gap.

energy flow (in ecology) The flow of energy that occurs along a *food chain. Energy enters the food chain at the level of the *producers (usually plants) in the form of solar energy. The plants convert solar energy into chemical energy in the process of *photosynthesis. Chemical energy is passed from one trophic level to the next through feeding. Since a large proportion of energy is lost at each trophic level, mostly in the form of heat energy due to respiration, a food chain does not normally consist of more than five trophic levels: the fifth trophic level does not contain enough energy to support further levels. Energy is also lost from the food chain in excretory products and the remains of dead organisms; this is converted into heat energy by the action of *decomposers. *See also* PRODUCTIVITY; PYRAMID OF ENERGY.

energy landscape A multidimensional surface in which the energy of a system is



Energy bands.

plotted against parameters characterizing that system. For example, in molecular spectroscopy the parameters are the distances between atoms in the molecule. The concept of energy landscape is very useful in many topics in physics and chemistry, including nuclear fission and protein folding. *See also* STRING LANDSCAPE.

energy level A definite fixed energy that a system described by *quantum mechanics, such as a molecule, atom, electron, or nucleus, can have. In an atom, for example, the atom has a fixed energy corresponding to the *orbitals in which its electrons move around the nucleus. The atom can accept a quantum of energy to become an excited atom (*see* EXCITATION) if that extra energy will raise an electron to a permitted orbital. Between the **ground state**, which is the lowest possible energy level for a particular system, and the first excited state there are no permissible energy levels. According to the *quantum theory, only certain energy levels are possible. An atom passes from one energy level to the next without passing through fractions of that energy transition. These levels are usually described by the energies associated with the individual electrons in the atoms, which are always lower than an arbitrary level for a free electron. The energy levels of molecules also involve quantized vibrational and rotational motion.

Engel's salt *See* POTASSIUM CARBONATE.

engine Any device for converting some forms of energy into mechanical work. *See* HEAT ENGINE; CARNOT CYCLE; INTERNAL-COMBUSTION ENGINE; STEAM ENGINE.

enkephalin (encephalin) Any of a class of endogenous *opioids consisting of five amino acids and found principally in the central nervous system. They bind to opioid receptors, chiefly in the brain, and their release controls levels of pain and other sensations. *See also* ENDORPHIN.

enols Compounds containing the group –CH=C(OH)– in their molecules. *See also* KETO–ENOL TAUTOMERISM.

enrichment The process of increasing the abundance of a specified isotope in a mixture of isotopes. It is usually applied to an increase in the proportion of U–235, or the addition of Pu–239 to natural uranium for use in a nuclear reactor or weapon.

Ensembl A joint venture between the European Molecular Biology Laboratory (EMBL), the European Bioinformatics Institute (EBI), and the Wellcome Trust's Sanger Institute that provides both sequence data from various eukaryotic genomes and open-source (free) software for researchers handling the data.

ensemble A set of systems of particles used in *statistical mechanics to describe a single system. The concept of an ensemble was put forward by the US scientist Josiah Willard Gibbs (1839–1903) in 1902 as a way of calculating the time average of the single system, by averaging over the systems in the ensemble at a fixed time. An ensemble of systems is constructed from knowledge of the single system and can be represented as a set of points in *phase space with each system of the ensemble represented by a point. Ensembles can be constructed both for isolated systems and for open systems.

entanglement *See* QUANTUM ENTANGLEMENT.

enterokinase (enteropeptidase) An enzyme in the small intestine that activates trypsinogen to *trypsin.

enteron (coelenteron; **gastrovascular cavity)** The body cavity of the coelenterates, which has one opening functioning both as mouth and anus. *See* CNIDARIA.

enthalpy Symbol H. A thermodynamic property of a system defined by $H = U + pV$, where H is the enthalpy, U is the internal energy of the system, p its pressure, and V its volume. In a chemical reaction carried out in the atmosphere the pressure remains constant and the enthalpy of reaction, ΔH, is equal to $\Delta U + p\Delta V$. For an exothermic reaction ΔH is taken to be negative.

entoderm *See* ENDODERM.

entomology The study of insects.

entomophily Pollination of a flower in which the pollen is carried on an insect. Entomophilous flowers are usually brightly coloured and scented and often secrete nectar. In some species (e.g. primulas) there are structural differences between the flowers to ensure that cross-pollination occurs. Other examples of entomophilous flowers are orchids and antirrhinums. *Compare* ANEMOPHILY; HYDROPHILY.

Entrez An information retrieval service, or browser, provided by the National Center for

Biotechnology Information (NCBI), a division of the US National Library of Medicine. It gives access to a collection of NCBI databases, both bibliographic and biomolecular, including PubMed, *MEDLINE, and OMIM (Online Mendelian Inheritance in Man).

entropy Symbol *S*. A measure of the unavailability of a system's energy to do work; in a closed system an increase in entropy is accompanied by a decrease in energy availability. When a system undergoes a reversible change the entropy (*S*) changes by an amount equal to the energy (*Q*) transferred to the system by heat divided by the thermodynamic temperature (*T*) at which this occurs, i.e. $\Delta S = \Delta Q/T$. However, all real processes are to a certain extent irreversible changes and in any closed system an irreversible change is always accompanied by an increase in entropy.

In a wider sense entropy can be interpreted as a measure of disorder; the higher the entropy the greater the disorder (*see* BOLTZMANN FORMULA). As any real change to a closed system tends towards higher entropy, and therefore higher disorder, it follows that the entropy of the universe (if it can be considered a closed system) is increasing and its available energy is decreasing (*see* HEAT DEATH OF THE UNIVERSE). This increase in the entropy of the universe is one way of stating the second law of *thermodynamics.

SEE WEB LINKS

- Translations of papers by Clausius on entropy (1850) and the second law (1865), published in *Annalen der Physik und Chemie*

environment (in ecology) The physical, chemical, and biological conditions of the region in which an organism lives. *See also* ECOLOGY; ECOSYSTEM.

environmental resistance The sum total of the factors that prevent populations from continually growing and therefore tend to keep populations at constant levels. These factors include predators, disease, and a shortage of any of the various requirements for survival, such as food, water, shelter, and light (which is particularly important for plants). *See also* POPULATION GROWTH.

enyl complex A type of complex in which there is a link between the metal atom or ion and the pi electrons of a double bond. *Zeise's salt was the first known example.

enzyme A protein that acts as a *catalyst in biochemical reactions. Each enzyme is specific to a particular reaction or group of similar reactions. Many require the association of certain nonprotein *cofactors in order to function. The molecule undergoing reaction (the **substrate**) binds to a specific *active site on the enzyme molecule to form a short-lived intermediate (*see* ENZYME–SUBSTRATE COMPLEX): this greatly increases (by a factor of up to 10^{20}) the rate at which the reaction proceeds to form the product. Enzyme activity is influenced by substrate concentration and by temperature and pH, which must lie within a certain range. Other molecules may compete for the active site, causing *inhibition of the enzyme or even irreversible destruction of its catalytic properties.

Enzyme production is governed by a cell's genes. Enzyme activity is further controlled by pH changes, alterations in the concentrations of essential cofactors, feedback inhibition by the products of the reaction, and activation by another enzyme, either from a less active form or an inactive precursor (*zymogen). Such changes may themselves be under the control of hormones or the nervous system. *See also* ENZYME KINETICS.

Enzymes are classified into six major groups, according to the type of reaction they catalyse: (1) *oxidoreductases; (2) *transferases; (3) *hydrolases; (4) *lyases; (5) *isomerases; (6) *ligases. The names of most individual enzymes also end in *-ase*, which is added to the names of the substrates on which they act. Thus *lactase is the enzyme that acts to break down lactose; it is classified as a hydrolase.

SEE WEB LINKS

- Information about IUPAC nomenclature

enzyme inhibition *See* INHIBITION.

enzyme kinetics The study of the rates of enzyme-catalysed reactions. Rates of reaction are usually measured by using the purified enzyme *in vitro* with the substrate and then observing the formation of the product or disappearance of the substrate. As the concentration of the substrate is increased the rate of reaction increases proportionally up to a certain point, after which any further increase in substrate concentration no longer increases the reaction rate (*see* MICHAELIS–MENTEN CURVE). At this point, all active sites of the enzyme are saturated with substrate; any further increase in the rate of reaction will occur only if more

enzyme is added. Reaction rates are also affected by the presence of inhibitors (*see* INHIBITION), temperature, and pH (*see* ENZYME).

enzyme-linked immunosorbent assay *See* ELISA.

enzyme–substrate complex The intermediate formed when a substrate molecule interacts with the *active site of an enzyme. Following the formation of an enzyme–substrate complex, the substrate molecule undergoes a chemical reaction and is converted into a new product. Various mechanisms for the formation of enzyme–substrate complexes have been suggested, including the *lock-and-key mechanism.

Eocene The second geological epoch of the *Palaeogene period. It extended from the end of the Palaeocene epoch, about 55 million years ago, to the beginning of the Oligocene epoch, about 34 million years ago. The term was first proposed by Sir Charles Lyell in 1833. Mammals were dominant in the Eocene: rodents, artiodactyls, carnivores, perissodactyls (including early horses), and whales were among the groups to make their first appearance.

eosin One of a series of acidic dyes, used in optical microscopy, that colours cytoplasm pink and cellulose red. It is frequently used as a counterstain with *haematoxylin for colouring tissue smears and sections of animal tissue.

ephedrine An alkaloid, $C_6H_5CH(OH)CH(CH_3)NHCH_3$, found in plants of the genus *Ephedra*, once used as a bronchodilator in the treatment of asthma. It is also used as a stimulant and appetite suppressant. Structurally, it is a phenylethylamine and is similar to amphetamines, although less active. It is, however, widely used in the illegal synthesis of methamphetamine. The molecule has two chiral centres. If the stereochemical conformations are opposite (i.e. 1*R*,2*S* or 1*S*,1*R*) the name ephedrine is used. If the conformations are the same (1*R*,2*R* or 1*S*,2*S*) then the compound is called **pseudoephedrine**.

ephemeral **1.** (in botany) An *annual plant that completes its life cycle in considerably less than one growing season. A number of generations can therefore occur in one year. Many troublesome weeds, such as groundsel and willowherb, are ephemerals. Certain desert plants are also ephemerals, completing their life cycles in a short period following rain. **2.** (in zoology) A short-lived animal, such as a mayfly.

ephemeris A tabulation showing the calculated future positions of the sun, moon, and planets, together with other useful information for astronomers and navigators. It is published at regular intervals.

ephemeris time (ET) A time system that has a constant uniform rate as opposed to other systems that depend on the earth's rate of rotation, which has inherent irregularities. It is reckoned from an instant in 1900 (Jan 0d 12h) when the sun's mean longitude was 279.696 677 8°. The unit by which ephemeris time is measured is the tropical year, which contains 31 556 925.9747 **ephemeris seconds**. This fundamental definition of the *second was replaced in 1964 by the caesium second of atomic time.

epicalyx A ring of bracts below a flower that resembles a calyx. It is seen, for example, in the strawberry flower.

epicarp *See* PERICARP.

epicentre The point on the surface of the earth directly above the focus of an earthquake or directly above or below a nuclear explosion.

epicotyl The region of a seedling stem above the stalks of the seed leaves (*cotyledons) of an embryo plant. It grows rapidly in seeds showing *hypogeal germination and lifts the stem above the soil surface. *Compare* HYPOCOTYL.

epicycle A small circle whose centre rolls around the circumference of a larger fixed circle. The curve traced out by a point on the epicycle is called an **epicycloid**.

epidemiology The study of diseases that affect large numbers of people. Traditionally, epidemiologists have been concerned primarily with infectious diseases, such as typhoid and influenza, that arise and spread rapidly among the population as epidemics. However, today the discipline also covers noninfectious disorders, such as diabetes, heart disease, and back pain. Typically the distribution of a disease is charted in order to discover patterns that might yield clues about its mode of transmission or the susceptibility of certain groups of people. This in turn may reveal insights about the causes of the disease and possible preventive measures.

epidermis **1.** (in zoology) The outermost layer of cells of the body of an animal. In invertebrates the epidermis is normally only one cell thick and is covered by an impermeable *cuticle. In vertebrates the epidermis is the thinner of the two layers of *skin (*compare* DERMIS). It consists of a basal layer of actively dividing cells (*see* MALPIGHIAN LAYER), covered by layers of cells that become impregnated with keratin (*see* KERATINIZATION). The outermost layers of epidermal cells (the *stratum corneum) form a water-resistant protective layer. The epidermis may bear a variety of specialized structures (e.g. *feathers, *hairs). **2.** (in botany) The outermost layer of cells covering a plant. It is overlaid by a *cuticle and its functions are principally to protect the plant from injury and to reduce water loss. Some epidermal cells are modified to form guard cells (*see* STOMA) or hairs of various types (*see* PILIFEROUS LAYER). In woody plants the functions of the shoot epidermis are taken over by the periderm tissues (*see* CORK CAMBIUM) and in mature roots the epidermis is sloughed off and replaced by the *hypodermis.

epidiascope An optical instrument used by lecturers, etc., for projecting an enlarged image of either a translucent object (such as a slide or transparency) or an opaque object (such as a diagram or printed page) onto a screen.

epididymis A long coiled tube in which spermatozoa are stored in vertebrates. In reptiles, birds, and mammals it is attached at one end to the *testis and opens into the sperm duct (*vas deferens) at the other.

epigamic Serving to attract a mate. Epigamic characters include the bright plumage of some male birds.

epigeal Describing seed germination in which the seed leaves (cotyledons) emerge from the ground and function as true leaves. Examples of epigeal germination are seen in sycamore and sunflower. *Compare* HYPOGEAL.

epiglottis A flexible flap of cartilage in mammals that is attached to the wall of the pharynx near the base of the tongue. During swallowing (*see* DEGLUTITION) it covers the *glottis (the opening to the respiratory tract) and helps to prevent food from entering the trachea (windpipe), although it is not essential for this purpose.

epilimnion The upper layer of water in a lake. *Compare* HYPOLIMNION. *See* THERMOCLINE.

epimerism A type of optical isomerism in which a molecule has two chiral centres; two optical isomers (**epimers**) differ in the arrangement about one of these centres. *See also* OPTICAL ACTIVITY.

epinephrine *See* ADRENALINE.

epiphysis The terminal section of a growing bone (especially a long limb bone) in mammals. It is separated from the bone shaft (**diaphysis**) by cartilage. New bone is produced on the side of the cartilage facing the diaphysis, while new cartilage is produced on the other side of the cartilage disc. When the bone reaches adult length the epiphysis merges with the diaphysis.

epiphyte A plant that grows upon another plant but is neither parasitic on it nor rooted in the ground. Epiphytes include many mosses and lichens and some tropical orchids.

episome A genetic element that can exist and replicate either independently of its host cell's chromosomes or as an integrated part of the chromosomes. Examples include certain bacterial *plasmids.

epistasis A gene interaction in which one gene suppresses the effect of another gene that is situated at a different *locus on the chromosome. For example, in guinea pigs the gene that controls the production of melanin is epistatic to the gene that regulates the deposition of melanin. A dominant allele (C) is responsible for the production of melanin, while the amount of melanin deposited is controlled by a second gene, which determines whether the coat colour is black or brown. If an animal is homozygous recessive (cc) for melanin production, the coat colour will be white regardless of the alleles that produce black or brown coloration.

epitaxy (epitaxial growth) Growth of a layer of one substance on a single crystal of another, such that the crystal structure in the layer is the same as that in the substrate. It is used in making semiconductor devices.

epithelium A tissue in vertebrates consisting of closely packed cells in a sheet with little intercellular material. It covers the outer surfaces of the body and the walls of the internal cavities (coeloms). It also forms glands

and parts of sense organs. Its functions are protective, absorptive, secretory, and sensory. The types of cell vary, giving rise to **squamous**, **cuboidal**, **columnar**, and **ciliated epithelia**. **Stratified epithelium** (e.g. in the skin) is made up of several layers of cells. Epithelium is derived from *ectoderm and *endoderm. *Compare* ENDOTHELIUM; MESOTHELIUM.

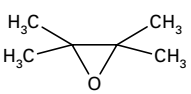
epithermal neutron A neutron with an energy in excess of that associated with a thermal neutron (*see* MODERATOR) but less than that of a *fast neutron, i.e. a neutron having an energy in the range 0.1 to 100 eV.

EPM *See* ELECTRON PROBE MICROANALYSIS.

epoch **1.** (in astronomy) An arbitrary date used as a fixed reference point, especially for the celestial coordinates of a star or deep-sky object or the orbital elements of a planet. Because the coordinates *right ascension and *declination change over time, the position of an astronomical object given in a catalogue must always be referred to a particular epoch, e.g. the date and time that an observation was made, the start of a year. **2.** The starting date of a calendar or chronological era. **3.** A unit of geological time in which a series of rocks is formed.

epoetin (EPO) A drug used medically to treat anaemia, and also used illegally by athletes participating in endurance events. It is a genetically engineered form of the hormone erythropoietin, which regulates the production of red blood cells.

epoxides Compounds that contain oxygen atoms in their molecules as part of a three-membered ring (see formula). Epoxides are thus **cyclic ethers**.



Epoxides. The functional group in epoxides.

epoxyethane (ethylene oxide) A colourless flammable gas, C_2H_4O; m.p. –111°C; b.p. 13.5°C. It is a cyclic ether (*see* EPOXIDES) that is made by the catalytic oxidation of ethene. It can be hydrolysed to ethane-1,2-diol and also polymerizes to:

… –O–C_2H_4–O–C_2H_4–…,

which is used for lowering the viscosity of water (e.g. in fire fighting).

epoxy resins Synthetic resins produced by copolymerizing epoxide compounds with phenols. They contain –O– linkages and epoxide groups and are usually viscous liquids. They can be hardened by addition of agents, such as polyamines, that form cross-linkages. Alternatively, catalysts may be used to induce further polymerization of the resin. Epoxy resins are used in electrical equipment and in the chemical industry (because of resistance to chemical attack). They are also used as adhesives.

EPR *See* ELECTRON PARAMAGNETIC RESONANCE.

epsomite A mineral form of *magnesium sulphate heptahydrate, $MgSO_4$. $7H_2O$.

Epsom salt *See* MAGNESIUM SULPHATE.

Epstein–Barr virus *See* HERPESVIRUS.

equation of motion (kinematic equation) Any of four equations that apply to bodies moving linearly with uniform acceleration (a). The equations, which relate distance covered (s) to the time taken (t), are:

$v = u + at$

$s = (u + v)t/2$

$s = ut + at^2/2$

$v^2 = u^2 + 2as$,

where u is the initial velocity of the body and v is its final velocity.

equation of state An equation that relates the pressure p, volume V, and thermodynamic temperature T of an amount of substance n. The simplest is the ideal *gas law:

$pV = nRT$,

where R is the universal gas constant. Applying only to ideal gases, this equation takes no account of the volume occupied by the gas molecules (according to this law if the pressure is infinitely great the volume becomes zero), nor does it take into account any forces between molecules. A more accurate equation of state would therefore be

$(p + k)(V - nb) = nRT$,

where k is a factor that reflects the decreased pressure on the walls of the container as a result of the attractive forces between particles, and nb is the volume occupied by the particles themselves when the pressure is infinitely high. In the **van der Waals equa-**

tion of state, proposed by the Dutch physicist J. D. van der Waals (1837–1923),

$k = n^2a/V^2$,

where a is a constant. This equation more accurately reflects the behaviour of real gases; several others have done better but are more complicated.

equation of time The length of time that must be added to the mean solar time, as shown on a clock, to give the apparent solar time, as shown by a sundial. The amount varies during the year, being a minimum of –14.2 minutes in February and a maximum of +16.4 minutes in October. It is zero on four days (April 15/16, June 14/15, Sept. 1/2, Dec. 25/26). The difference arises as a result of two factors: the eccentricity of the earth's orbit and the inclination of the ecliptic to the celestial equator.

equator **1.** The great circle around the earth that lies in a plane perpendicular to the earth's axis. It is equidistant from the two geographical poles. **2.** The **magnetic equator** is a line of zero magnetic dip (*see* GEOMAGNETISM) that is close to the geographical equator but lies north of it in Africa and south of it in America. **3.** The **celestial equator** is the circle formed on the *celestial sphere by the extension of the earth's equatorial plane. **4.** (in cell biology) *See* SPINDLE.

equilibrium A state in which a system has its energy distributed in the statistically most probable manner; a state of a system in which forces, influences, reactions, etc., balance each other out so that there is no net change.

A body is in **static equilibrium** if the resultants of all forces and all couples acting on it are both zero; it may be at rest and will certainly not be accelerated. Such a body at rest is in **stable equilibrium** if after a slight displacement it returns to its original position – for a body whose weight is the only downward force this will be the case if the vertical line through its centre of gravity always passes through its base. If a slight displacement causes the body to move to a new position, then the body is in **unstable equilibrium**.

A body is said to be in **thermal equilibrium** if no net heat exchange is taking place within it or between it and its surroundings. A system is in *chemical equilibrium when a reaction and its reverse are proceeding at equal rates (*see also* EQUILIBRIUM CONSTANT). These are examples of **dynamic equilibrium**, in which activity in one sense or direction is in aggregate balanced by comparable reverse activity.

equilibrium constant For a reversible reaction of the type

$xA + yB \rightleftharpoons zC + wD$

chemical equilibrium occurs when the rate of the forward reaction equals the rate of the back reaction, so that the concentrations of products and reactants reach steady-state values. It can be shown that at equilibrium the ratio of concentrations

$[C]^z[D]^w/[A]^x[B]^y$

is a constant for a given reaction and fixed temperature, called the equilibrium constant K_c (where the c indicates concentrations have been used). Note that, by convention, the products on the right-hand side of the reaction are used on the top line of the expression for equilibrium constant. This form of the equilibrium constant was originally introduced in 1863 by C. M. Guldberg and P. Waage using the law of *mass action. They derived the expression by taking the rate of the forward reaction

$k_f[A]^x[B]^y$

and that of the back reaction

$k_b[C]^z[D]^w$

Since the two rates are equal at equilibrium, the equilibrium constant K_c is the ratio of the rate constants k_f/k_b. The principle that the expression is a constant is known as the **equilibrium law** or **law of chemical equilibrium**.

The equilibrium constant shows the **position** of equilibrium. A low value of K_c indicates that [C] and [D] are small compared to [A] and [B]; i.e. that the back reaction predominates. It also indicates how the equilibrium shifts if concentration changes. For example, if [A] is increased (by adding A) the equilibrium shifts towards the right so that [C] and [D] increase, and K_c remains constant.

For gas reactions, partial pressures are used rather than concentrations. The symbol K_p is then used. Thus, in the example above

$K_p = p_C{}^z p_D{}^w/p_A{}^x p_B{}^y$

It can be shown that, for a given reaction $K_p = K_c(RT)^{\Delta\nu}$, where $\Delta\nu$ is the difference in stoichiometric coefficients for the reaction (i.e. $z + w - x - y$). Note that the units of K_p and K_c depend on the numbers of molecules appearing in the stoichiometric equation. The value of the equilibrium constant depends

on the temperature. If the forward reaction is exothermic, the equilibrium constant decreases as the temperature rises; if endothermic it increases (*see also* VAN'T HOFF'S ISOCHORE).

The expression for the equilibrium constant can also be obtained by thermodynamics; it can be shown that the standard equilibrium constant $K^{\ominus}$ is given by $\exp(-\Delta G^{\ominus}/RT)$, where $\Delta G^{\ominus}$ is the standard Gibbs free energy change for the complete reaction. Strictly, the expressions above for equilibrium constants are true only for ideal gases (pressure) or infinite dilution (concentration). For accurate work *activities are used.

equilibrium law *See* EQUILIBRIUM CONSTANT.

equinox **1.** Either of the two points on the *celestial sphere at which the *ecliptic intersects the celestial equator. The sun appears to cross the celestial equator from south to north at the **vernal equinox** and from north to south at the **autumnal equinox**. **2.** Either of the two instants at which the centre of the sun appears to cross the celestial equator. In the northern hemisphere the vernal equinox occurs on or about March 21 and the autumnal equinox on or about Sept. 23. In the southern hemisphere the dates are reversed. *See* PRECESSION OF THE EQUINOXES.

equipartition of energy The theory, proposed by Ludwig Boltzmann and given some theoretical support by James Clerk Maxwell, that the energy of gas molecules in a large sample under thermal *equilibrium is equally divided among their available *degrees of freedom, the average energy for each degree of freedom being $kT/2$, where k is the *Boltzmann constant and T is the thermodynamic temperature. The proposition is not generally true if *quantum considerations are important, but is frequently a good approximation.

equivalence point The point in a titration at which reaction is complete. *See* INDICATOR.

equivalent proportions *See* CHEMICAL COMBINATION.

equivalent weight The mass of an element or compound that could combine with or displace one gram of hydrogen (or eight grams of oxygen or 35.5 grams of chlorine) in a chemical reaction. The equivalent weight represents the 'combining power' of the substance. For an element it is the relative atomic mass divided by the valency. For a compound it depends on the reaction considered.

erbium Symbol Er. A soft silvery metallic element belonging to the *lanthanoids; a.n. 68; r.a.m. 167.26; r.d. 9.006 (20°C); m.p. 1529°C; b.p. 2863°C. It occurs in apatite, gadolinite, and xenotine from certain sources. There are six natural isotopes, which are stable, and twelve artificial isotopes are known. It has been used in alloys for nuclear technology as it is a neutron absorber; it is being investigated for other potential uses. It was discovered by Carl Mosander (1797–1858) in 1843.

SEE WEB LINKS

- Information from the WebElements site

erecting prism A glass prism used in optical instruments to convert an inverted image into an erect image, as in prismatic binoculars.

erg A unit of work or energy used in the c.g.s. system and defined as the work done by a force of 1 dyne when it acts through a distance of 1 centimetre. 1 erg = 10^{-7} joule.

ergocalciferol *See* VITAMIN D.

ergonomics The study of the engineering aspects of the relationship between workers and their working environment.

ergosphere The region immediately around a *black hole. The hole's rotation drags the space–time continuum round with it, so that frames of reference are not stationary with reference to the remainder of the universe. The ergosphere's outer boundary is called the stationary limit.

ergosterol A *sterol occurring in fungi, bacteria, algae, and plants. It is converted into vitamin D_2 by the action of ultraviolet light.

Eris A *small solar system body made of rock and ice that is the largest *dwarf planet so far known and the ninth largest body orbiting the sun. At an estimated 2400 km or more in diameter, it is at least 5% larger than *Pluto and 27% more massive. Eris was discovered in January 2005 by a team at Mount Palomar led by Michael E. Brown (1965–). It is a *scattered disc object, orbiting the sun once every 557.43 years at a mean distance of 10.12×10^9 km. The eccentricity of its orbit is about 0.44 and when at its farthest point

from the sun (14.6×10^9 km), it is three times as far away as Neptune. One natural satellite, Dysnomia, orbits Eris at an estimated distance of nearly 37 400 km in a period of 15.77 days.

Erlangen Programme The view, put forward by the German mathematician Felix Klein (1849–1925) in 1872 when he became a faculty member of the University of Erlangen, that each type of geometry can be characterized by a group of transformations. There are many physical examples of this, including the Lorentz group of Minkowski space–time and the space groups of crystals. However, not all types of geometry fit into this view readily; in particular, Riemannian geometry, and hence curved space–time, do not fit unless the Erlangen Programme is given a wider interpretation. It has been suggested that such a broader interpretation might lead to important insights into the foundations of fundamental physics.

erosion The wearing away of the land surface by natural agents that involves the transport of rock debris. These natural agents include moving waters (e.g. rivers, ocean waves), ice (e.g. glaciers), wind, organisms, and gravity. *See also* SOIL EROSION.

erratic A fragment of rock, often unlike the rocks around it, that has been displaced from its original location by the action of a glacier or, more rarely, an iceberg. Erratics may have been moved as little as several metres to more than 800 km. They vary in size from small pebbles to massive boulders, and may be found on the surface or embedded in *boulder clay. They provide geologists with information about the movement of ice sheets.

erythroblast Any of the cells in the *myeloid tissue of red bone marrow that develop into erythrocytes (red blood cells). Erythroblasts have a nucleus and are at first colourless, but fill with *haemoglobin as they develop. In mammals the nucleus disappears.

erythrocyte (red blood cell) The most numerous type of blood cell, which contains the red pigment *haemoglobin and is responsible for oxygen transport. Mammalian erythrocytes are disc-shaped and lack a nucleus; those of other vertebrates are oval and nucleated. In man the number of erythrocytes in the blood varies between 4.5 and 5.5 million per cubic millimetre. They survive for about four months and are then destroyed in the spleen and liver. *See also* ERYTHROBLAST. *Compare* LEUCOCYTE.

Esaki diode *See* TUNNEL DIODE.

ESCA *See* PHOTOELECTRON SPECTROSCOPY.

escapement A device in a clock or watch that controls the transmission of power from the spring or falling weight to the hands. It is usually based on a balance wheel or pendulum. It thus allows energy to enter the mechanism in order to move the hands round the face, overcome friction in the gear trains, and maintain the balance wheel or pendulum in continuous motion.

escape velocity The minimum speed needed by a space vehicle, rocket, etc., to escape from the gravitational field of the earth, moon, or other celestial body. The gravitational force between a rocket of mass m and a celestial body of mass M and radius r is MmG/r^2 (*see* NEWTON'S LAW OF GRAVITATION). Therefore the gravitational potential energy of the rocket with respect to its possible position very far from the celestial body on which it is resting can be shown to be $-GmM/r$, assuming (by convention) that the potential energy is zero at an infinite distance from the celestial body. If the rocket is to escape from the gravitational field it must have a kinetic energy that exceeds this potential energy, i.e. the kinetic energy $mv^2/2$ must be greater than MmG/r, or $v > \sqrt{(2MG/r)}$. This is the value of the escape velocity. Inserting numerical values for the earth and moon into this relationship gives an escape velocity from the earth of 11 200 m s^{-1} and from the moon of 2370 m s^{-1}.

***Escherichia coli* (*E. coli*)** A species of Gram-negative aerobic bacteria that is found in the intestine and is also widely used in microbiological and genetics research. The motile rod-shaped cells ferment lactose and are usually harmless commensals, although certain strains are pathogenic and can cause a severe form of food poisoning. Studies of *E. coli* laboratory cultures have revealed much about the genetics of prokaryotes; the species is also frequently used in genetic engineering, particularly as a host for *gene cloning and the expression of recombinant foreign genes in culture.

ESI *See* ELECTROSPRAY IONIZATION.

esker An elongated, steep-sided ridge of debris left behind by meltwater streams

flowing in or under a slow-moving glacier. The ridge may be straight or, more often, sinuous in shape. It may be up to 50 m high and 700 m wide. In very cold regions, some eskers have ice cores. The debris is stratified in layers and generally consists of rounded particles of gravel and sand, with some fine-grain deposits. *See also* KAME.

ESR *See* ELECTRON-PARAMAGNETIC RESONANCE.

essential amino acid An *amino acid that an organism is unable to synthesize in sufficient quantities. It must therefore be present in the diet. In humans the essential amino acids are histidine, lysine, threonine, methionine, isoleucine, leucine, valine, phenylalanine, and tryptophan. These are required for protein synthesis and deficiency leads to retarded growth and other symptoms. Most of the amino acids required by man are also essential for all other multicellular animals and for most protozoans.

essential element Any of a number of elements required by living organisms to ensure normal growth, development, and maintenance. Apart from the elements found in organic compounds (i.e. carbon, hydrogen, oxygen, and nitrogen), plants, animals, and microorganisms all require a range of elements in inorganic forms in varying amounts, depending on the type of organism. The **major elements**, present in tissues in relatively large amounts (greater than 0.005%), are calcium, phosphorus, potassium, sodium, chlorine, sulphur, and magnesium (*see also* MACRONUTRIENT). The **trace elements** occur at much lower concentrations and thus requirements are much less. The most important are iron, manganese, zinc, copper, iodine, cobalt, selenium, molybdenum, chromium, and silicon (*see also* MICRONUTRIENT). Each element may fulfil one or more of a variety of metabolic roles. Sodium, potassium, and chloride ions are the chief electrolytic components of cells and body fluids and thus determine their electrical and osmotic status. Calcium, phosphorus, and magnesium are all present in bone. Calcium is also essential to nerve and muscle activity, while phosphorus is a key constituent of the chemical energy carriers (e.g. *ATP) and the nucleic acids. Sulphur is needed primarily for amino acid synthesis (in plants and microorganisms). The trace elements may serve as *cofactors or as constituents of complex molecules, e.g. iron in haem and cobalt in vitamin B_{12}. *See also* MINERAL DEFICIENCY.

essential fatty acids (omega fatty acids) *Fatty acids that must normally be present in the diet of certain animals, including humans. Essential fatty acids belong to the *n*-3 (or omega-3) and *n*-6 (or omega-6) classes of polyunsaturated fatty acids and include *arachidonic (omega-6), *linoleic (omega-6), and *linolenic (omega-3) acids; all possess double bonds at the same two positions along their hydrocarbon chain and so can act as precursors of *prostaglandins. Deficiency can cause dermatosis, weight loss, irregular oestrus, etc. Both omega-3 and omega-6 acids should be consumed in the diet, ideally in roughly the same amounts.

essential oil A natural oil with a distinctive scent secreted by the glands of certain aromatic plants. *Terpenes are the main constituents. Essential oils are extracted from plants by steam distillation, extraction with cold neutral fats or solvents (e.g. alcohol), or pressing and used in perfumes, flavourings, and medicine. Examples are citrus oils, flower oils (e.g. rose, jasmine), and oil of cloves.

esterification A reaction of an alcohol with an acid to produce an ester and water; e.g.

$$CH_3OH + C_6H_5COOH \rightleftharpoons CH_3OOCC_6H_5 + H_2O$$

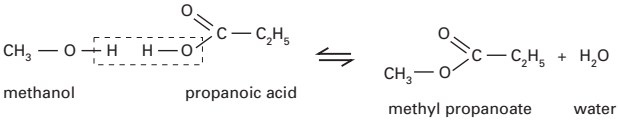
The reaction is an equilibrium and is normally slow, but can be speeded up by addition of a strong acid catalyst. The ester can often be distilled off so that the reaction can proceed to completion. The reverse reaction is ester hydrolysis or *saponification. *See also* LABELLING.

esters Organic compounds formed by reaction between alcohols and acids (see illustration overleaf). Esters formed from carboxylic acids have the general formula RCOOR′. Examples are ethyl ethanoate, $CH_3COOC_2H_5$, and methyl propanoate, $C_2H_5COOCH_3$. Esters containing simple hydrocarbon groups are volatile fragrant substances used as flavourings in the food industry. Triesters, molecules containing three ester groups, occur in nature as oils and fats. *See also* GLYCERIDE.

SEE WEB LINKS

- Information about IUPAC nomenclature

etaerio A cluster of fruits formed from the



Ester formation.

unfused carpels of a single flower. For example, the anemone has an etaerio of *achenes, larkspur an etaerio of *follicles, and blackberry an etaerio of *drupes.

ethanal (acetaldehyde) A colourless highly flammable liquid aldehyde, CH_3CHO; r.d. 0.78; m.p. –121°C; b.p. 20.8°C. It is made from ethene by the *Wacker process and used as a starting material for making many organic compounds. The compound polymerizes if dilute acid is added to give **ethanal trimer** (or **paraldehyde**), which contains a six-membered ring of alternating carbon and oxygen atoms with a hydrogen atom and a methyl group attached to each carbon atom. It is used as a drug for inducing sleep. Addition of dilute acid below 0°C gives **ethanal tetramer** (or **metaldehyde**), which has a similar structure to the trimer but with an eight-membered ring. It is used as a solid fuel in portable stoves and in slug pellets.

ethanamide (acetamide) A colourless solid crystallizing in the form of long white crystals with a characteristic smell of mice, CH_3CONH_2; r.d. 1.159; m.p. 82.3°C; b.p. 221.25°C. It is made by the dehydration of ammonium ethanoate or by the action of ammonia on ethanoyl chloride, ethanoic anhydride, or ethyl ethanoate.

ethane A colourless flammable gaseous hydrocarbon, C_2H_6; m.p. –183°C; b.p. –89°C. It is the second member of the *alkane series of hydrocarbons and occurs in natural gas.

ethanedioic acid *See* OXALIC ACID.

ethane-1,2-diol (ethylene glycol; glycol) A colourless viscous hygroscopic liquid, CH_2OHCH_2OH; m.p. –11.5°C; b.p. 198°C. It is made by hydrolysis of epoxyethane (from ethene) and used as an antifreeze and a raw material for making *polyesters (e.g. Terylene).

ethanoate (acetate) A salt or ester of ethanoic acid (acetic acid).

ethanoic acid (acetic acid) A clear viscous liquid or glassy solid *carboxylic acid, CH_3COOH, with a characteristically sharp odour of vinegar; r.d. 1.049; m.p. 16.6°C; b.p. 117.9°C. The pure compound is called **glacial ethanoic acid**. It is manufactured by the oxidation of ethanol or by the oxidation of butane in the presence of dissolved manganese(II) or cobalt(II) ethanoates at 200°C, and is used in making ethanoic anhydride for producing cellulose ethanoates. It is also used in making ethenyl ethanoate (for polyvinylacetate). The compound is formed by the fermentation of alcohol and is present in vinegar, which is made by fermenting beer or wine. 'Vinegar' made from ethanoic acid with added colouring matter is called 'non-brewed condiment'. In living organisms it combines with *coenzyme A to form acetyl coenzyme A, which plays a crucial role in energy metabolism.

ethanoic anhydride (acetic anhydride) A pungent-smelling colourless liquid, $(CH_3CO)_2O$, b.p. 139.5°C. It is used in organic synthesis as an *ethanoylating agent (attacking an –OH or –NH group) and in the manufacture of aspirin and cellulose plastics. It hydrolyses in water to give ethanoic acid.

ethanol (ethyl alcohol) A colourless water-soluble *alcohol, C_2H_5OH; r.d. 0.789 (0°C); m.p. –117.3°C; b.p. –78.3°C. It is the active principle in intoxicating drinks, in which it is produced by fermentation of sugar using yeast

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

The ethanol produced kills the yeast and fermentation alone cannot produce ethanol solutions containing more than 15% ethanol by volume. Distillation can produce a constant-boiling mixture containing 95.6% ethanol and 4.4% water. Pure ethanol (**absolute alcohol**) is made by removing this water by means of drying agents.

The main industrial use of ethanol is as a solvent although at one time it was a major starting point for making other chemicals. For this it was produced by fermentation of

molasses. Now ethene has replaced ethanol as a raw material and industrial ethanol is made by hydrolysis of ethene.

ethanoylating agent (acetylating agent) A chemical reagent used to introduce an ethanoyl group (–$COCH_3$) instead of hydrogen in an organic compound. Examples include *ethanoic anhydride and ethanoyl chloride (acetyl chloride, CH_3COCl).

ethanoyl chloride (acetyl chloride) A colourless liquid acyl chloride (*see* ACYL HALIDES), CH_3COCl, with a pungent smell; r.d. 1.105; m.p. –112.15°C; b.p. 50.9°C. It is made by reacting ethanoic acid with a halogenating agent such as phosphorus(III) chloride, phosphorus(V) chloride, or sulphur dichloride oxide and is used to introduce ethanoyl groups into organic compounds containing –OH, $–NH_2$, and –SH groups. *See* ACYLATION.

ethanoyl group (acetyl group) The organic group $CH_3CO–$.

ethene (ethylene) A colourless flammable gaseous hydrocarbon, C_2H_4; m.p. –169°C; b.p. –103.7°C. It is the first member of the *alkene series of hydrocarbons. It is made by cracking hydrocarbons from petroleum and is now a major raw material for making other organic chemicals (e.g. ethanal, ethanol, ethane-1,2-diol). It can be polymerized to *polyethene. It occurs naturally in plants, in which it acts as a growth substance (*see* PLANT HORMONE): its best-known effect is the stimulation of fruit ripening.

ethenone *See* KETENE.

ethenyl ethanoate (vinyl acetate) An unsaturated organic ester, CH_2:$CHOOCCH_3$; r.d. 0.9; m.p. –100°C; b.p. 73°C. It is made by catalytic reaction of ethanoic acid and ethene and used to make polyvinylacetate.

ether 1. (aether) A hypothetical medium once believed to be necessary to support the propagation of electromagnetic radiation. It is now regarded as unnecessary and in modern theory electromagnetic radiation can be propagated through empty space. The existence of the ether was first called into question as a result of the *Michelson–Morley experiment. **2.** *See* ETHOXYETHANE; ETHERS.

ethers Organic compounds containing the group –O– in their molecules. Examples are dimethyl ether, CH_3OCH_3, and diethyl ether, $C_2H_5OC_2H_5$ (*see* ETHOXYETHANE). They are volatile highly flammable compounds made by dehydrating alcohols using sulphuric acid.

SEE WEB LINKS

- Information about IUPAC nomenclature

ethology The study of the biology of *animal behaviour. Central to the ethologist's approach is the principle that animal behaviour (like physical characteristics) is subject to evolution through natural selection. Ethologists therefore seek to explain how the behaviour of animals, both as individuals and social groups, in their natural environment may contribute to the survival of the maximum number of its relatives and offspring. This involves recognizing the stimuli that are important in nature (*see* SIGN STIMULUS) and how innate predispositions interact with *learning in the development of behaviour (*see* INSTINCT). Studies of this sort were pioneered by Konrad Lorenz and Niko Tinbergen and have led to the modern disciplines of sociobiology and behavioural ecology.

ethoxyethane (diethyl ether; ether) A colourless flammable volatile *ether, $C_2H_5OC_2H_5$; r.d. 0.71; m.p. –116°C; b.p. 34.5°C. It can be made by *Williamson's synthesis. It is an anaesthetic and useful organic solvent.

ethyl 3-oxobutanoate (ethyl acetoacetonate) A colourless liquid ester with a pleasant odour, $CH_3COCH_2COOC_2H_5$; r.d. 1.03; m.p. <–80°C; b.p. 180.4°C. It can be prepared by reacting ethyl ethanoate ($CH_3COOC_2H_5$) with sodium or sodium ethoxide. The compound shows keto–enol *tautomerism and contains about 7% of the enol form, $CH_3C(OH)$:$CHCOOC_2H_5$, under normal conditions. Sometimes known as **acetoacetic ester**, it is used in organic synthesis.

ethyl acetate *See* ETHYL ETHANOATE.

ethyl acetoacetonate *See* ETHYL 3-OXOBUTANOATE.

ethyl alcohol *See* ETHANOL.

ethylamine A colourless flammable volatile liquid, $C_2H_5NH_2$; r.d. 0.69; m.p. –81°C; b.p. 16.6°C. It is a primary amine made by reacting chloroethane with ammonia and used in making dyes.

ethylbenzene A colourless flammable liquid, $C_6H_5C_2H_5$; r.d. 0.867; m.p. –95°C; b.p.

136°C. It is made from ethene and ethybenzene by a *Friedel–Crafts reaction and is used in making phenylethene (for polystyrene).

ethyl bromide *See* BROMOETHANE.

ethylene *See* ETHENE.

ethylene glycol *See* ETHANE-1,2-DIOL.

ethylene oxide *See* EPOXYETHANE.

ethyl ethanoate (ethyl acetate) A colourless flammable liquid ester, $C_2H_5OOCCH_3$; r.d. 0.9; m.p. –83.6°C; b.p. 77.06°C. It is used as a solvent and in flavourings and perfumery.

ethyl group The organic group CH_3CH_2–.

ethyl iodide *See* IODOETHANE.

ethyne (acetylene) A colourless unstable gas, C_2H_2, with a characteristic sweet odour; r.d. 0.618; m.p. –80.8°C; b.p. –84.0°C. It is the simplest member of the *alkyne series of unsaturated hydrocarbons, and is prepared by the action of water on calcium dicarbide or by adding alcoholic potassium hydroxide to 1,2-dibromoethane. It can be manufactured by heating methane to 1500°C in the presence of a catalyst. It is used in oxyacetylene welding and in the manufacture of ethanal and ethanoic acid. Ethyne can be polymerized easily at high temperatures to give a range of products. The inorganic saltlike dicarbides contain the ion C_2^{2-}, although ethyne itself is a neutral compound (i.e. not a protonic acid).

etiolation The abnormal form of growth observed when plants grow in darkness or severely reduced light. Such plants characteristically have blanched leaves and shoots, excessively long shoots, and reduced leaves and root systems.

Eubacteria *See* BACTERIA.

eucaryote *See* EUKARYOTE.

euchromatin *See* CHROMATIN.

Euclid (*c.* 330–*c.* 260 BC) Greek mathematician, who worked at the academy in Alexandria. He is best known for his 13-volume work the *Elements*, which deals mainly with geometry and established the axiomatic method of reasoning.

Euclidean geometry The form of geometry set forth in the 13 volumes, called the *Elements*, by Euclid. It is based on a series of axioms and applies to plane figures. *Compare* NON-EUCLIDEAN GEOMETRY.

eudicot Any dicotyledonous flowering plant whose pollen has three apertures (i.e. **triaperturate pollen**), through one of which the pollen tube emerges during pollination. Eudicots contrast with the so-called 'primitive' dicots, such as the magnolia family, which have **uniaperturate pollen** (i.e. with a single aperture). The eudicots form a large clade, but their phylogenetic relationships to other dicots and to monocots remain unclear.

eudiometer An apparatus for measuring changes in volume of gases during chemical reactions. A simple example is a graduated glass tube sealed at one end and inverted in mercury. Wires passing into the tube allow the gas mixture to be sparked to initiate the reaction between gases in the tube.

eugenics The study of methods of improving the quality of human populations by the application of genetic principles. **Positive eugenics** would seek to do this by selective breeding programmes. **Negative eugenics** aims to eliminate harmful genes (e.g. those causing haemophilia and colour blindness) by counselling any prospective parents who are likely to be *carriers.

Euglenida A class of mostly unicellular protists (including *Euglena*) that move by means of undulipodia (flagella). Most euglenids are photosynthetic and inhabit fresh water, and in some earlier classification systems were regarded as green algae (phylum Chlorophyta). However, they lack a cell wall, being covered with a proteinaceous *pellicle, and some forms are colourless and thus ingest food, since they cannot photosynthesize. Euglenids are sometimes classified as a phylum, Euglenophyta, but they are now more usually included in a larger phylum, Discomitochondria, together with three other groups of organisms, on the basis of a common mitochondrial structure (characterized by disc-shaped cristae) and the absence of sexual reproduction.

Eukarya *See* DOMAIN; EUKARYOTE.

eukaryote (eucaryote) An organism consisting of cells in which the genetic material is contained within a distinct nucleus. All organisms except bacteria are eukaryotes, which are classified in the **Eukarya**, one of the three *domains of life. *See* CELL. *Compare* PROKARYOTE.

Eulerian fluid dynamics A formulation of fluid mechanics in which the velocity of the fluid at fixed postions is analysed, i.e. a formulation that describes changes at fixed positions in the fluid, in contrast to *Lagrangian fluid dynamics. It is named after the Swiss mathematician and physicist Leonhard Euler (1707–83).

Eumetazoa *See* METAZOA.

euphotic zone (epipelagic zone; photic zone) The topmost layer of a lake or sea in which there is sufficient light for net primary production, i.e. where the energy fixed by photosynthesis exceeds that lost by respiration. The depth varies, depending on such factors as turbidity, supply of nutrients in the water, tidal turbulence, and temperature. It typically ranges from 1 m to about 30 m in lakes and coastal waters, and rarely reaches depths of more than 200 m in the open ocean. *Compare* APHOTIC ZONE.

europium Symbol Eu. A soft silvery metallic element belonging to the *lanthanoids; a.n. 63; r.a.m. 151.96; r.d. 5.245 (20°C); m.p. 822°C; b.p. 1597°C. It occurs in small quantities in bastanite and monazite. Two stable isotopes occur naturally: europium–151 and europium–153, both of which are neutron absorbers. Experimental europium alloys have been tried for nuclear-reactor parts but until recently the metal has not been available in sufficient quantities. It is widely used in the form of the oxide in phosphors for television screens. It was discovered by Sir William Crookes in 1889.

SEE WEB LINKS

- Information from the WebElements site

Eustachian tube The tube that connects the *middle ear to the back of the throat (pharynx) in vertebrates. It is normally closed, but during swallowing it opens to allow air into the middle ear, which equalizes the pressure on each side of the *tympanum (eardrum). It was named after the Italian anatomist Bartolomeo Eustachio (?1520–74).

eustasy Fluctuations in sea level on a global scale. One cause is the growth and decay of ice masses, such as glaciers and ice sheets (**glacio-eustasy**); since the last ice age sea levels have gradually risen. Tectonic movements can also change the volume of ocean basins (e.g. through sea-floor spreading). Global average sea level rose between 0.1 and 0.2 m during the 20th century.

eutectic mixture A solid solution consisting of two or more substances and having the lowest freezing point of any possible mixture of these components. The minimum freezing point for a set of components is called the **eutectic point**. Low-melting-point alloys are usually eutectic mixtures.

euthanasia The act of ending the life of a person or animal in order to prevent further suffering, e.g. from an incurable and painful disease. This can be achieved by administering a lethal drug or by withholding vital treatment. In human medicine euthanasia is fraught with ethical and legal problems, and is illegal in most countries. Where it is practised, strict safeguards are enforced to ensure that the patient's wishes are determined and adhered to. Euthanasia is widely performed in veterinary medicine.

Eutheria (Placentalia) An infraclass of mammals in which the embryos are retained in a uterus in the mother's body and nourished by a *placenta. The young are thus fully protected during their embryonic development and kept at a constant temperature. Placental mammals evolved during the Cretaceous period (about 125 million years ago). Modern placentals are a highly diverse group that occupy all types of habitat in all parts of the world. They include the orders *Artiodactyla, *Carnivora, *Cetacea, *Chiroptera, *Insectivora, *Perissodactyla, *Primates, *Proboscidea, and *Rodentia. *Compare* METATHERIA; PROTOTHERIA.

eutrophic Describing a body of water (e.g. a lake) with an abundant supply of nutrients and a high rate of formation of organic matter by photosynthesis. Pollution of a lake by *sewage or *fertilizers renders it eutrophic (a process called **eutrophication**). This stimulates excessive growth of algae (*see* ALGAL BLOOM); the death and subsequent decomposition of these increases the *biochemical oxygen demand and thus depletes the oxygen content of the lake, resulting in the death of the lake's fish and other animals. *Compare* DYSTROPHIC; OLIGOTROPHIC.

Evans balance *See* GOUY BALANCE.

evaporation The change of state of a liquid into a vapour at a temperature below the boiling point of the liquid. Evaporation occurs at the surface of a liquid, some of those molecules with the highest kinetic energies escaping into the gas phase. The result is a fall in the average kinetic energy of the mol-

ecules of the liquid and consequently a fall in its temperature.

evaporative cooling Cooling of a substance as a result of evaporation. *See also* LASER COOLING.

even–even nucleus An atomic nucleus containing an even number of protons and an even number of neutrons. Such nuclei are very common because they are very stable.

even–odd nucleus An atomic nucleus containing an even number of protons and an odd number of neutrons.

event horizon *See* BLACK HOLE.

evergreen (Describing) a plant that bears leaves throughout the year, each leaf being shed independently of the others after two or three years. The leaves of evergreens are often reduced or adapted in some way to prevent excessive water loss; examples are the needles of conifers and the leathery waxy leaves of holly. *Compare* DECIDUOUS.

evocation The ability of experimental stimuli (e.g. chemicals or tissue implants) to cause unspecialized embryonic tissue to develop into specialized tissue.

evo-devo Short for evolution of development – a field of study concerned with the interplay of developmental genetics and evolution. Advances in molecular biology and genetics have revealed how evolution of diversity in form and function can arise from mutations that alter the course or timing of development. One is alteration of the modular organization of body plans, such as repeated limbs or body segments. Duplication of such a module may lead to its further adaptation into a novel structure, such as pincers or mouthparts. Another area involves changes in the timing, location, or level of gene expression or alterations in the relative growth rates of different parts of the body. In this way relatively few mutations affecting development can have profound effects on the morphology of the mature organism.

evolute The locus of the centres of curvature of all the points on a given curve (called the **involute**).

evolution The gradual process by which the present diversity of plant and animal life arose from the earliest and most primitive organisms, which is believed to have been continuing for at least the past 3000 million years. Until the middle of the 18th century it was generally believed that each species was divinely created and fixed in its form throughout its existence (*see* SPECIAL CREATION). Lamarck was the first biologist to publish a theory to explain how one species could have evolved into another (*see* LAMARCKISM), but it was not until the publication of Darwin's *On the Origin of Species* in 1859 that special creation was seriously challenged. Unlike Lamarck, Darwin proposed a feasible mechanism for evolution and backed it up with evidence from the fossil record and studies of comparative anatomy and embryology (*see* DARWINISM; NATURAL SELECTION). The modern version of Darwinism, which incorporates discoveries in genetics made since Darwin's time, remains the most acceptable theory of species evolution (*see also* PUNCTUATED EQUILIBRIUM). More controversial, however, and still to be firmly clarified, are the relationships and evolution of groups above the species level.

SEE WEB LINKS

- Understanding Evolution, created by the University of California Museum of Paleontology, covers the evidence for and mechanisms of evolution

exa- Symbol E. A prefix used in the metric system to denote 10^{18} times. For example, 10^{18} metres = 1 exametre (Em).

exbi- *See* BINARY PREFIXES.

excess electron An electron in a *semiconductor that is not required in the bonding system of the crystal lattice and has been donated by an impurity atom. It is available for conduction (**excess conduction**).

exchange force **1.** A force resulting from the continued interchange of particles in a manner that bonds their hosts together. Examples are the covalent bond involving electrons, and the strong interaction (*see* FUNDAMENTAL INTERACTIONS) in which mesons are exchanged between nucleons or gluons are exchanged between quarks (*see* ELEMENTARY PARTICLES). **2.** *See* MAGNETISM.

excimer *See* EXCIPLEX.

exciplex A combination of two different atoms that exists only in an excited state. When an exciplex emits a photon of electromagnetic radiation, it immediately dissociates into the atoms, rather than reverting to the ground state. A similar transient excited association of two atoms of the same kind is

an **excimer**. An example of an exciplex is the species $XeCl^*$ (the asterisk indicates an excited state), which can be formed by an electric discharge in xenon and chlorine. This is used in the **exciplex laser**, in which a population inversion is produced by an electrical discharge.

excitation **1.** A process in which a nucleus, electron, atom, ion, or molecule acquires energy that raises it to a quantum state (**excited state**) higher than that of its *ground state. The difference between the energy in the ground state and that in the excited state is called the **excitation energy**. *See* COLLECTIVE EXCITATION; ENERGY LEVEL; QUASIPARTICLE. **2.** The process of applying current to the winding of an electromagnet, as in an electric motor. **3.** The process of applying a signal to the base of a transistor or the control electrode of a thermionic valve.

excitatory postsynaptic potential (EPSP) The electric potential that is generated in a postsynaptic neuron during the transmission of a nerve impulse (*see* SYNAPSE). It is caused by *depolarization of the postsynaptic membrane when a *neurotransmitter (such as acetylcholine), released from the presynaptic membrane, binds to the postsynaptic membrane. This will induce an *action potential in the receiving neuron if the EPSP is large enough. *Compare* INHIBITORY POSTSYNAPTIC POTENTIAL.

exciton An electron–hole pair in a crystal that is bound in a manner analogous to the electron and proton of a hydrogen atom. It behaves like an atomic excitation that passes from one atom to another and may be long-lived. Exciton behaviour in *semiconductors is important.

exclusion principle *See* PAULI EXCLUSION PRINCIPLE.

excretion The elimination by an organism of the waste products that arise as a result of metabolic activity. These products include water, carbon dioxide, and nitrogenous compounds. Excretion plays an important role in maintaining the constancy of an organism's *internal environment (*see* HOMEOSTASIS). In plants and simple animals waste products are excreted by simple diffusion from the body, but higher animals have specialized organs and organ systems devoted to this function. Examples of excretory organs in vertebrates are the lungs (for carbon dioxide and water), and the *kidneys (for nitrogenous compounds (urea) and water). In addition, mammals excrete small amounts of urea, salts, and water from the skin in sweat.

exercise Increased muscular activity, which results in an increase in metabolic rate, heart rate, and oxygen uptake. Exercise also causes an increase in *anaerobic respiration in order to compensate for the *oxygen debt, which results in a build-up of lactic acid in the tissues.

exergonic reaction A chemical reaction in which energy is released (*compare* ENDERGONIC REACTION). An *exothermic reaction is an exergonic reaction in which energy is released in the form of heat.

exfoliation A type of rock erosion that results from weathering. Layers or shells of rock are gradually removed from a massive outcrop, causing so-called onion-skin weathering. Commonly affecting basalt and granite, it is thought to be caused mainly by variations in temperature between day and night. Pressure changes in newly exposed rocks may also cause large-scale exfoliation.

exhalation *See* EXPIRATION.

exitance Symbol *M*. The radiant or luminous flux emitted per unit area of a surface. The **radiant exitance** (M_e) is measured in watts per square metre (W m^{-2}), while the **luminous exitance** (M_v) is measured in lumens per square metre (lm m^{-2}). Exitance was formerly called **emittance**.

exo- *See* ENDO-.

exocarp *See* PERICARP.

exocrine gland A gland that discharges its secretion into a body cavity (such as the gut) or onto the body surface. Examples are the *sebaceous and *sweat glands, the *mammary glands, and part of the pancreas. Exocrine glands are formed in the embryo from the invagination of epithelial cells. Their secretions pass initially into a cavity (an **alveolus** or **acinus**) and then out through a duct or duct network, along which the secretion may become modified by exchange with the blood across the duct epithelium.

exocytosis The passage of material from the inside of the cell to the cell surface within membrane-bound vesicles. The membranes of the vesicles fuse with the plasma membrane, releasing their contents to the exterior. Exocytosis is used both for the removal

of waste material from the cell and for secretion; for example of mucus by *goblet cells. *Compare* ENDOCYTOSIS.

exodermis *See* HYPODERMIS.

exoergic Denoting a nuclear process that gives out energy. *Compare* ENDOERGIC.

exogamy The fusion of reproductive cells from distantly related or unrelated organisms, i.e. *outbreeding. *Compare* ENDOGAMY.

exogenous Describing substances, stimuli, etc., that originate outside an organism. For example, vitamins that cannot be synthesized by an animal are said to be supplied exogenously in the diet. *Compare* ENDOGENOUS.

exon A nucleotide sequence in a gene that codes for part or all of the gene product and is therefore expressed in mature messenger RNA, ribosomal RNA, or transfer RNA. In eukaryotes, exons are separated by noncoding sequences called *introns.

exonuclease An enzyme that catalyses the cleavage of nucleotides from the end of a nucleic acid molecule. *Compare* ENDONUCLEASE.

exopeptidase A protein-digesting enzyme that cleaves amino acids from the ends of a polypeptide chain. *Carboxypeptidase, which breaks down proteins in the small intestine, is an example of an exopeptidase. *Compare* ENDOPEPTIDASE.

exoplanet *See* EXTRASOLAR PLANET.

exoskeleton A rigid external covering for the body in certain animals, such as the hard chitinous cuticle of arthropods. An exoskeleton protects and supports the body and provides points of attachment for muscles. The cuticle of arthropods must be shed at intervals to allow growth to occur (*see* ECDYSIS). Other examples of exoskeletons are the shells of molluscs and the bony plates of tortoises and armadillos. *Compare* ENDOSKELETON.

exosphere *See* EARTH'S ATMOSPHERE.

exothermic Denoting a chemical reaction that releases heat into its surroundings. *Compare* ENDOTHERMIC.

exotic atom **1.** An atom in which an electron has been replaced by another negatively charged particle, such as a muon or *meson. In this case the negative particle eventually collides with the nucleus with the emission of X-ray photons. **2.** A system in which the nucleus of an atom has been replaced by a positively charged meson. Such exotic atoms have to be created artifically and are unstable.

exotoxin *See* TOXIN.

expanded plastic (cellular plastic) A plastic in the form of a rigid solid foam. Polystyrene, used as a packing material, is a common example.

expansion The writing of a function or quantity as a *series of terms. The series may be finite or infinite. *See* BINOMIAL THEOREM; TAYLOR SERIES.

expansion of the universe The hypothesis, based on the evidence of the *redshift, that the distance between the galaxies is continuously increasing. The original theory, which was proposed in 1929 by Edwin Hubble, assumes that the galaxies are flying apart as a consequence of the big bang with which the universe originated. Several variants have since been proposed. *See also* BIG-BANG THEORY; HUBBLE CONSTANT.

expansivity (thermal expansion) **1. Linear expansivity** is the fractional increase in length of a specimen of a solid, per unit rise in temperature. If a specimen increases in length from l_1 to l_2 when its temperature is raised θ°, then the expansivity (α) is given by:

$$l_2 = l_1(1 + \alpha\theta).$$

This relationship assumes that α is independent of temperature. This is not, in general, the case and a more accurate relationship is:

$$l_2 = l_1(1 + a\theta + b\theta^2 + c\theta^3\ldots),$$

where *a*, *b*, and *c* are constants. **2. Superficial expansivity** is the fractional increase in area of a solid surface caused by unit rise in temperature, i.e.

$$A_2 = A_1(1 + \beta\theta),$$

where β is the superficial expansivity. To a good approximation $\beta = 2\alpha$. **3. Volume expansivity** is the fractional increase in volume of a solid, liquid, or gas per unit rise in temperature, i.e.

$$V_2 = V_1(1 + \gamma\theta),$$

where γ is the cubic expansivity and $\gamma = 3\alpha$. For liquids, the expansivity observed directly is called the **apparent expansivity** as the container will also have expanded with the rise in temperature. The **absolute expansivity** is the apparent expansivity plus the vol-

ume expansivity of the container. For the expansion of gases, *see* CHARLES' LAW.

SEE WEB LINKS

- Values of the expansivity of selected liquids and solids at the NPL website

experiment A process or trial designed to test a scientific theory.

expert system A computer program that, using stored data, can reach conclusions in a particular field of knowledge; in effect, it makes decisions. Thus unlike a *database, it processes the data before presenting the result. The user can usually question the system's reasoning, often via a language processor. Such systems are used for troubleshooting in industry, for diagnosing medical disorders, for determining the structures of molecules, etc.

expiration (exhalation) The process by which gas is expelled from the lungs (*see* RESPIRATORY MOVEMENT). In mammals, the volume of the thoracic cavity is reduced by contraction of the internal *intercostal muscles and relaxation of the muscles of the diaphragm, assisted by upward pressure of the abdominal organs. As a result, pressure in the lungs exceeds atmospheric pressure and gas flows out of the lungs, allowing the pressures to equalize. *Compare* INSPIRATION.

expiratory centre *See* VENTILATION CENTRE.

explantation The removal of cells, tissues, or organs of animals and plants for observation of their growth and development in appropriate culture media. *See also* TISSUE CULTURE; ORGAN CULTURE.

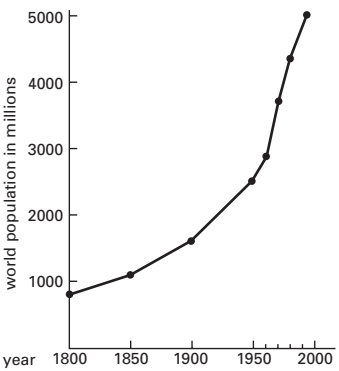
explosive A compound or mixture that, when ignited or detonated, undergoes a rapid violent chemical reaction that produces large amounts of gas and heat, accompanied by light, sound and a high-pressure shock wave. **Low explosives** burn comparatively slowly when ignited, and are employed as propellants in firearms and guns; they are also used in blasting. Examples include *gunpowder and various smokeless propellants, such as *cordite. **High explosives** decompose very rapidly to produce an uncontrollable blast. Examples of this type include *dynamite, *nitroglycerine, and *trinitrotoluene (TNT); they are exploded using a detonator. Other high-power explosives include pentaerythritol tetranitrate (PETN) and ammonium nitride/fuel oil mixture (ANFO). Cyclonite (RDX) is a military high explosive; mixed with oils and waxes, it forms a plastic explosive (such as Semtex). See also Chronology.

exponent A number or symbol that indicates the power to which another number or expression is raised. For example, $(x + y)^n$ indicates that the expression $(x + y)$ is raised to the nth power; n is the exponent. Any number or expression in which the exponent is zero is equal to 1, i.e. $x^0 = 1$.

exponential A function that varies as the power of another quantity. If $y = a^x$, y varies exponentially with x. The function e^x, also written as $\exp(x)$, is called the **exponential function** (*see* E). It is equal to the sum of the **exponential series**, i.e.

$$e^x = 1 + x + x^2/2! + x^3/3! + \ldots + x^n/n! + \ldots$$

exponential growth A form of *population growth in which the rate of growth is related to the number of individuals present. Increase is slow when numbers are low but rises sharply as numbers increase. If population number is plotted against time on a graph a characteristic J-shaped curve results (see graph). In animal and plant populations, such factors as overcrowding, lack of nutrients, and disease limit population increase beyond a certain point and the J-shaped exponential curve tails off giving an S-shaped (sigmoid) curve.



Exponential growth. Graph showing exponential growth of the human population.

exposure meter A photocell that operates a meter to indicate the correct exposure for a specified film in photography. It en-

EXPLOSIVES

900–1000	Gunpowder developed in China.
1242	English monk Roger Bacon (1220–92) describes the preparation of gunpowder.
c.1250	German alchemist Berthold Schwarz claims to have reinvented gunpowder.
1771	French chemist Pierre Woulfe discovers picric acid (originally used as a yellow dye).
1807	Scottish cleric Alexander Forsyth (1767–1843) discovers mercury fulminate.
1833	French chemist Henri Braconnot (1781–1855) nitrates starch, making a highly flammable compound (crude nitrocellulose).
1838	French chemist Théophile Pelouze (1807–67) nitrates paper, making crude nitrocellulose.
1845	German chemist Christian Schönbein (1799–1868) nitrates cotton, making nitrocellulose.
1846	Italian chemist Ascania Sobrero (1812–88) discovers nitroglycerine.
1863	Swedish chemist J. Wilbrand discovers trinitrotoluene (TNT). Swedish chemist Alfred Nobel (1833–96) invents a detonating cap based on mercury fulminate.
1867	Alfred Nobel invents dynamite by mixing nitroglycerine and kieselguhr.
1871	German chemist Hermann Sprengel shows that picric acid can be used as an explosive.
1875	Alfred Nobel invents blasting gelatin (nitroglycerine mixed with nitrocellulose).
1885	French chemist Eugène Turpin discovers ammonium picrate (Mélinite).
1888	Alfred Nobel invents a propellant from nitroglycerine and nitrocellulose (Ballistite).
1889	British scientists Frederick Abel (1826–1902) and James Dewar invent a propellant (Cordite) similar to Ballistite.
1891	German chemist Bernhard Tollens (1841–1918) discovers pentaerythritol tetranitrate (PETN).
1899	Henning discovers cyclotrimethylenetrinitramine (RDX or cyclonite).
1905	US army officer B. W. Dunn (1860–1936) invents ammonium picrate explosive (Dunnite).
1915	British scientists invent amatol (TNT + ammonium nitrate).
1955	US scientists develop ammonium nitrate–fuel oil mixtures (ANFO) as industrial explosives.

ables the correct shutter speed and aperture to be chosen for any photographic circumstances. Some cameras have a built-in exposure meter that automatically sets the aperture according to the amount of light available and the chosen shutter speed.

extended ASCII A set of characters with *ASCII values between 128 and 255. These characters may include special symbols, graphics characters, and accented characters. The assignment of extended ASCII characters is not standard. It depends on the

particular computer system and may also depend on the font being used.

extended phenotype The concept, advanced by British biologist Richard Dawkins in his 1982 book of the same title, that the phenotype of an organism extends beyond its body to encompass the organism's behaviour and the consequences of that behaviour. Dawkins cites a beaver's lake as an example. This manifestation of the beaver's instinctive dam-building activities is, he argues, an evolutionary adaptation just as much as, say, the beaver's coat, and is likewise subject to natural selection. Other instances include birds' nests, termite mounds, and spiders' webs.

extender An inert substance added to a product (paint, rubber, washing powder, etc.) to dilute it (for economy) or to modify its physical properties.

extensive variable A quantity in a *macroscopic system that is proportional to the size of the system. Examples of extensive variables include the volume, mass, and total energy. If an extensive variable is divided by an arbitrary extensive variable, such as the volume, an *intensive variable results. A macroscopic system can be described by one extensive variable and a set of intensive variables.

extensometer Any device for measuring the extension of a specimen of a material under longitudinal stress. A common method is to make the specimen form part of a capacitor, the capacitance of which will change with a change in the specimen's dimensions.

extensor Any muscle that causes a limb to extend. *See* VOLUNTARY MUSCLE. *Compare* FLEXOR.

external conversion A process in which molecules in electronically excited states pass to a lower electronic state (which is frequently the ground state) by colliding with other molecules. In this process the electronic energy is eventually converted into heat. Since this process involves collisions, the rate at which it occurs depends on how frequently collisons occur. As a result, this process occurs much faster in liquids than in gases. It is sometimes called **collision quenching**.

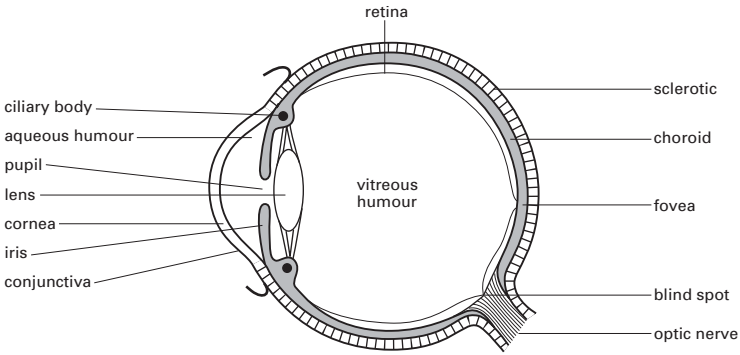
exteroceptor Any *receptor that detects external stimuli. Examples of exteroceptors are the thermoreceptors in the skin, which monitor the temperature of the external environment. *Compare* INTEROCEPTOR.

extinction **1.** (in biology) The irreversible condition of a species or other group of organisms of having no living representatives in the wild, which follows the death of the last surviving individual of that species or group. Extinction may occur on a local or global level; it can result from various human activities, including the destruction of habitats or the overexploitation of species that are hunted or harvested as a resource. Species at the top of a *food chain (e.g. large birds of prey) will be more prone to extinction since they exist in relatively small numbers and will be affected by a deleterious change at any of the levels in the food chain. *See also* MASS EXTINCTION. **2.** (in behaviour) The termination of a behaviour pattern that is no longer appropriate. For example, dogs can be conditioned to salivate when they hear a bell ring in the absence of a food stimulus (*see* CONDITIONING). However, if the bell continues to be rung in the absence of food the dogs will gradually stop salivating on hearing the bell. **3.** (in physics) A reduction in the intensity of radiation as a result of absorption or scattering as it passes through matter.

extinction coefficient A measure of the extent by which the intensity of a beam of light is reduced by passing through a distance d of a solution having a molar concentration c of the dissolved substance. If the intensity of the light is reduced from I_1 to I_2, the extinction coefficient is $[\log(I_1/I_2)]/cd$.

extracellular Located or occurring outside the cell. *Cuticularization is an example of an extracellular process.

extracellular matrix (ECM) The viscous watery fluid that surrounds cells in animal tissues. Secreted by the cells themselves, it is the medium through which they receive materials (e.g. nutrients, hormones) from elsewhere in the body and via which they communicate with other cells. The ECM is the environment in which cells migrate during tissue development and it contains constituents that bind cells together to maintain tissue integrity. It consists of glycoproteins, *collagens, and other structural components. The ECM is especially prominent in connective tissues, such as bone, cartilage, and adipose tissue, in which it is sometimes called **ground substance**.



Eye. Structure of the vertebrate eye.

extraction **1.** The process of obtaining a metal from its ore. **2.** The separation of a component from a mixture by selective solubility. *See* PARTITION.

extractive distillation A distillation technique in which a solvent is added to the mixture in order to separate two closely boiling components. The added solvent is usually nonvolatile and is selected for its ability to have different effects on the volatilities of the components.

extraembryonic membranes (embryonic membranes) The tissues produced by an animal *embryo for protection and nutrition but otherwise taking no part in its development. The four membranes, which are called **fetal membranes** in man, are the *chorion, *amnion, *allantois, and *yolk sac.

extraordinary ray *See* DOUBLE REFRACTION.

extrapolation An *approximation technique for finding the value of a function or measurement beyond the values already known. If the values $f(x_0)$, $f(x_1)$,…,$f(x_n)$ of a function of a variable x are known in the interval $[x_0,x_n]$, the value of $f(x)$ for a value of x outside the interval $[x_0,x_n]$ can be found by extrapolation. The techniques used in extrapolation are usually not as good as those used in *interpolation.

extrasolar planet (exoplanet) A planet in a solar system beyond our own. As of mid-2009, over 350 extrasolar planets had been discovered since the first confirmed observations were made in the early 1990s. Most extrasolar planets have been detected through their effects on the stars that they orbit. The majority of those found so far have been giants, typically much larger than Jupiter. Many occupy orbits very close to their parent star and have been dubbed 'hot Jupiters'.

extremely high frequency (EHF) A radio frequency between 30 000 megahertz and 300 gigahertz.

extremophile A bacterium that thrives under extreme conditions, e.g. at very high or very low temperatures, or in very salty or acidic environments. For example, certain archaebacteria (*see* ARCHAEA), termed **hyperthermophiles**, live in hot springs at temperatures near or even above 100°C. The enzymes of such organisms exhibit great stability and have been extracted for use in laboratory and commercial processes.

extrinsic semiconductor *See* SEMICONDUCTOR.

eye The organ of sight. The most primitive eyes are the *eyespots of some unicellular organisms. More advanced eyes are the *ocelli and *compound eyes of arthropods (e.g. insects). The cephalopod molluscs (e.g. the octopus and squid) and vertebrates possess the most highly developed eyes (see illustration). These normally occur in pairs, are nearly spherical, and filled with fluid. Light is refracted by the *cornea through the pupil in the *iris and onto the *lens, which focuses images onto the retina. These images are received by light-sensitive cells in

the retina (*see* CONE; ROD), which transmit impulses to the brain via the optic nerve.

SEE WEB LINKS

- Gross anatomy of the eye; prepared by members of the John Moran Eye Center, University of Utah

eyepiece (ocular) The lens or system of lenses in an optical instrument that is nearest to the eye. It usually produces a magnified image of the previous image formed by the instrument.

eyespot (stigma) **1.** A structure found in some free-swimming unicellular algae and in plant reproductive cells that contains orange or red pigments (carotenoids) and is sensitive to light. It enables the cell to move in relation to a light source (*see* PHOTOTAXIS). **2.** A spot of pigment found in some lower animals, e.g. jellyfish.

eye tooth A *canine tooth in the upper jaw.

***E–Z* convention** A convention for the description of a molecule showing cis–trans isomerism (*see* ISOMERISM). In a molecule ABC=CDE, where A, B, D, and E are substituent groups, the sequence rule (*see* CIP SYSTEM) is applied to the pair A and B to find which has priority and similarly to the pair C and D. If the two groups of highest priority are on the same side of the bond then the isomer is designated *Z* (from German *zusammen*, together). If they are on opposite sides the isomer is designated *E* (German *entgegen*, opposite). The letters are used in the names of compounds; for example (*E*)-butenedioic acid (fumaric acid) and (*Z*)-butenedioic acid (maleic acid). In compounds containing two (or more) double bonds numbers are used to designate the bonds (e.g. (2*E*, 4*Z*)-2,4-hexadienoic acid). The system is less ambiguous than the cis/trans system of describing isomers.