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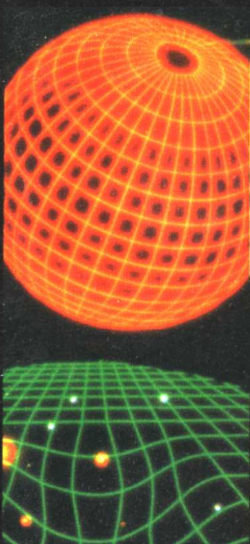
THE PENGUIN

DICTIONARY OF PHYSICS

EDITED BY VALERIE ILLINGWORTH



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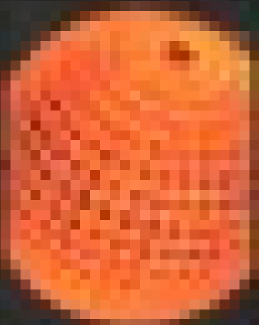
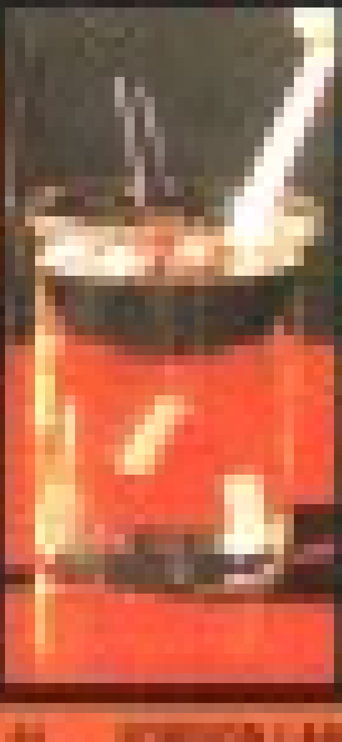
DICTIONARY OF PHYSICS





THE PENGUIN DICTIONARY

PHYSICS

EDITOR: VALERIE ILLINGWORTH

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瓦莱丽·伊美沃斯 编

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PREFACE

This dictionary is an abridged version of the recently revised *Dictionary of Physics* (Longman, 1991). Both books were prepared by Market House Books.

Although this dictionary is concerned primarily with the terminology of contemporary physics, words with a physical basis that are used in other scientific fields, such as physical chemistry, computing, astronomy, geophysics, medical physics, engineering subjects and music, have also been included. SI units are used throughout.

The dictionary should thus prove useful to students and teachers of physics and related subjects, to doctors and to scientists, technologists and technicians in research and industry. It contains many long entries in which a word of major importance is defined and discussed together with closely associated words. Shorter definitions supplement the longer entries.

The editor thanks Mr H. J. Gray and Dr Alan Isaacs, editors of the *Dictionary of Physics*, and also the contributors to the three editions of the Longman's dictionary, in particular Dr John Daintith, for entries that have passed into the *Penguin Dictionary of Physics*. The abridgements for this second edition of the *Penguin Dictionary of Physics* have been made by the editor without consulting the original contributors. Any changes of emphasis or style are therefore the responsibility of the editor.

VALERIE ILLINGWORTH, 1990

NOTES

An asterisk indicates a cross reference.

An entry having an initial capital letter is either a proper name or a trade name.

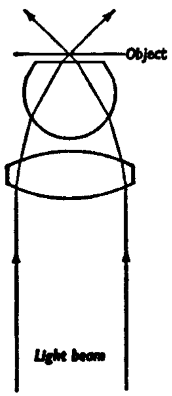
Syn. is an abbreviation for 'synonymous with'.

Symbols will be found in the Tables of SI units and the Table of Symbols for Physical Quantities (Appendix).

CONTENTS

A

Abbe condenser A simple two-lens *condenser that has good light-gathering



Abbe condenser

ability, the *numerical aperture being 1.25. It is therefore extensively used in general microscopy. Aberrations are not well corrected. A modified Abbe condenser called a *variable-focus condenser* is used to obtain a greater illuminated field area. The lower lens can be adjusted to bring light to a focus between the lenses. *See also* achromatic condenser.

Abbe criterion *See* resolving power.

Abbe number *Syn.* constringence; V-number. Symbol: V. The reciprocal of dispersive power. *See* dispersion.

aberration 1. A defect in the image formed by a lens or curved mirror, revealed as a blurring or distortion and possibly a false coloration. The four principal aberrations are *spherical aberration, *coma, and *astigmatism (which are due mainly to curvature of the optical surface) and *chromatic aberration (which occurs only with lenses and is due to *dispersion). *Curvature of field and *distortion are other aberrations.

Aberrations occur when light rays do not pass close to the optic axis of the system but make a considerable angle to it (so that it is no longer accurate to replace the sine of the angle involved by the angle itself (in radians)). Of the six aberrations, only spherical and chromatic aberrations are found in the images of axial points. The other four occur only when off-axis points are involved. *See also* Seidel aberrations.

2. Of light. The apparent displacement in the positions of stars, attributable to the finite speed of light and to the motion of the observer; the latter results mainly from the earth's orbital motion around the sun.

3. A defect in the image produced by an *electron lens system.

ablation The removal of material from the surface of a moving body by decomposition or vaporization resulting from friction with the atoms or molecules of the atmosphere.

absolute expansion *See* coefficient of expansion.

absolute humidity *See* humidity.

absolute magnitude *See* magnitude.

absolute temperature Former name for *thermodynamic temperature.

absolute unit If a quantity y is uniquely defined in terms of quantities $x_1, x_2, \ldots$ by

$$y = f(x_1, x_2, \ldots),$$

the unit U_y of y can be obtained from the units U_{x1}, U_{x2} of x_1, x_2 from the equation

$$U_y \propto f(U_{x1}, U_{x2}, \ldots).$$

In any given system an absolute unit is one for which the constant of proportionality is unity. All units of the *SI system are absolute.

absolute zero The unattainable lower limit to temperature. It is the zero of *thermodynamic temperature: 0 K = −273.15 °C = −459.67 °F.

According to thermodynamics, if an ideal heat engine working in a *Carnot cycle has its lower-temperature isothermal process at absolute zero, no heat will be discharged and the efficiency of the engine will be one.

The ideal-gas absolute scale can be shown to be equivalent to the thermodynamic scale. Temperature on this scale is defined to be proportional to the product of pressure and volume in the limit as pressure tends to zero and volume to infinity. Absolute zero is that temperature at which this product is zero.

In quantum theory, absolute zero is interpreted as the temperature at which all particles are in the lowest-energy quantum states available. Generally the available states do not have zero energy, so there is still molecular energy at absolute zero (the *zero-point energy*). The kinetic energies of the molecules of an ideal gas would be zero at 0 K, but not those of a real substance.

absorbance *See* internal transmission density.

absorbed dose *See* dose.

absorptance *Syn.* absorption factor. Symbol: α. A measure of the ability of a body or substance to absorb radiation as expressed by the ratio of the absorbed *radiant or *luminous flux to the incident radiant or luminous flux. For radiant heat the absorptance of a body, measured against a vacuum, depends on the thermodynamics temperature T of the body receiving the radiation and on the wavelength. The absorptance at a fixed frequency of radiation is called the *spectral absorptance*. *See also* internal absorptance.

absorption 1. Of radiation. Reduction in the flux of electromagnetic radiation, or other ionizing radiation, on passage through a medium. The energy of the radiation is converted into a different form. The nature of the absorbing process depends on the energy of the radiation and on the substance involved. The *internal energy of the absorbing medium will be increased by all these mechanisms. (*See also* photoelectric effect, photoionization, fluorescence, Compton effect, pair production.)

Reflection, transmission, and absorption of electromagnetic radiation can all occur when radiation passes from one medium to another. The extent to which they occur is given by the *reflectance, *transmittance, and *absorptance of the medium. The reduction in flux with distance traversed in a medium is given by the *linear absorption coefficient (for absorption alone) or by the *linear attenuation coefficient (when absorption and dispersion both occur).

2. Of sound. The reduction is *sound intensity when energy in the form of a sound wave passes from one medium to another. At the boundary of the media, part of the energy is reflected and part enters the second medium and may be regarded as being absorbed. The amount reflected is given by the *acoustic absorption coefficient.

The reduction in sound energy (and hence in sound intensity) is given by:

$$E = E_0 \exp(-\mu_a x),$$

where E_0 is the incident energy, E the energy after a distance x, and μ_a is a constant called the *linear absorption coefficient*.

The absorption of sound energy is caused principally by viscous forces opposing the relative motion of the particles as the sound passes (involving transformation of acoustic energy into internal energy) and by heat being conducted from the compressed particles to the (lower-temperature) rarified ones. Heat radiated from compressions to rarefactions also causes some energy dissipation at low frequencies. In general, absorption of sound by gases is basically due to viscosity, the conduction and radiation effects becoming more important for waves of larger amplitude. Water vapour content (humidity) also affects the absorption.

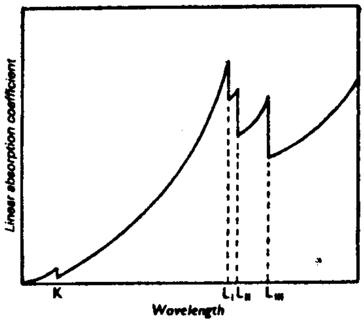
3. The process in which a gas or liquid is taken up by another substance, usually a solid. The absorbed material thus permeates into the bulk of the material. *Compare* adsorption.

absorption bands (and lines) Dark bands or lines present in a *spectrum as a result of absorption by some intervening medium. *See also* absorption spectrum.

absorption coefficient 1. Of electromagnetic radiation. *See* linear absorption coefficient.

2. Of sound. *See* acoustic absorption coefficient.

absorption edge (discontinuity or limit) An abrupt discontinuity in the graph relating the *linear absorption coefficient of X-rays in a given substance with the wavelength of the radiation. At certain critical absorption wavelengths the absorption shows a sudden decrease in value. This occurs when the quantum energy of the radiation becomes smaller than the work required to eject an electron from one or other of the quantum states in the absorbing atom, and the radiation thus ceases to be absorbed by that state. Thus, radiation of wavelength greater than the K absorption edge cannot eject electrons from the K states of the absorbing substance.



Absorption discontinuity

absorption factor *See* absorptance.

absorption hygrometer *See* chemical hygrometer.

absorption spectrum When light from a high-temperature source producing a continuous emission spectrum is passed through a medium into a spectroscope, the spectrum reveals dark regions where absorption has taken place (continuous, line, and band types). In general, the medium absorbs those wavelengths it would emit if its temperature were raised high enough. Solids and liquids show broad continuous absorption spectra; gases give more discontinuous types (line and band). *See* spectrum.

absorptivity 1. A measure of the ability of a substance to absorb radiation, as expressed by the *internal absorptance of a layer of substance when the path of the radiation is of unit length and the boundaries of the material have no influence.

2. Former name for *absorptance.

abundance Symbol: *C*. The number of atoms of a given isotope in a mixture of the isotopes of an element; usually expressed as a percentage of the total number of atoms of the element.

a.c. Abbreviation for alternating current.

acceleration 1. Linear acceleration. Symbol: *a*. The rate of change of velocity, expressed in metres per second per second (or similar units). This is a vector quantity.

2. Angular acceleration. Symbol: *α*. The rate of change of angular velocity, expressed in radians per second per second. This is a *pseudovector quantity having magnitude and the direction of orientation of an axis. In simple cases in which the axis of rotation is fixed, angular acceleration may be regarded as a scalar.

acceleration of free fall *See* free fall.

accelerator A machine for increasing the kinetic energy of charged particles or ions, such as protons or electrons, by accelerating them in an electric field. A magnetic field is used to maintain the particles in the desired direction. The particles can travel in a straight, spiral, or circular path. (*See* linear accelerator; cyclotron; synchrotron; proton synchrotron; synchrocyclotron; focusing.) At present, the highest energies are obtained in the proton synchrotron.

The Super Proton Synchroton at *CERN (Geneva) accelerates protons to 450 GeV. It can also cause proton–antiproton collisions with total kinetic energy (in centre-of-mass coordinates) of 620 GeV. In the USA the Fermi National Acceleration Laboratory proton synchrotron gives protons and antiprotons of 800 GeV, permitting collisions with total kinetic energy of 1600 GeV. The Large Electron Positron (LEP) system at CERN accelerates particles to 60 GeV.

All the aforementioned devices are designed to produce collisions between particles travelling in opposite directions. This gives effectively very much higher energies available for interaction than are possible when accelerated particles hit stationary targets. (*See also* intersecting storage ring.)

High-energy nuclear reactions occur when the particles (either moving or in a stationary target) collide. The particles created in these reactions are detected by sensitive equipment close to the collision site. New particles, including the tauon, W, and Z particles and requiring enormous energies for their creation, have been detected and their properties determined.

acceptor *See* semiconductor.

access time The mean time interval between demanding a particular piece of information from a computer *storage device and obtaining it.

accommodation The ability of the eye to alter its focal length and to produce clear images of objects at different distances. *See also* near point.

accumulator An electric cell that can be recharged after use. The common "lead" accumulator consists in principle of two plates coated with lead sulphate immersed in aqueous sulphuric acid. If connected to a suitable d.c. supply, current is sent through the cell and the anode is converted to lead(IV) oxide (lead peroxide) and the cathode reduced to metallic lead. If the two plates are then connected through an external circuit, the chemical action is reversed and current flows round the external circuit from the brown peroxide plate to the grey lead plate. The action may be summarized in the equation:

$$PbO_2 + Pb + 2H_2SO_4 \rightleftharpoons 2PbSO_4 + 2H_2O,$$

with the right-to-left reaction occurring on discharge and the left-to-right reaction occurring on charge.

An accumulator employing electrodes of nickel and iron (or cadmium) immersed in a 20% solution of potassium hydroxide is also employed for special purposes. (*See* Edison accumulator.)

achromat *See* achromatic lens.

achromatic colours Colours having no hue or saturation but only lightness. White, greys, and black are examples.

achromatic condenser A *condenser corrected for chromatic and spherical *aberrations, usually by having four elements, two of which are *achromatic lenses. It has a *numerical aperture of 1.4. It is used in *microscopes when high magnification is required. *See also* Abbe condenser.

achromatic lens *Syn.* achromat. A combination of two or more lenses using, if necessary, different kinds of glass, designed to remove the major part of *chromatic aberration. The elementary theory of simple achromatic doublets assumes two lenses of powers P_1 and P_2 placed in contact (with total power $P = P_1 + P_2$) made of glasses of *dispersive powers ω_1 and ω_2 so that the condition for achromatism ($\omega_1 P_1 + \omega_2 P_2 = 0$) is satisfied. To produce an achromatic converging lens, e.g. for telescope or photographic objectives, the dispersive power of the higher-power convergent lens must be less than that of the divergent lens of the combination. It is thus possible to bring two colours, say red and blue, to the same focus. There will still be some residual colour effects, known as a *secondary spectrum*. *See also* apochromatic lens.

achromatic prism A combination of two or more prisms that produces the same deviation of two or more colours so that objects viewed through them will not appear coloured (*see* chromatic aberration). As with thin lenses, "narrow angle" prisms are placed in contact in opposition, so that the *dispersive powers of the two glasses are inversely proportional to their angles of *deviation.

achromatism The removal of *chromatic aberration, or *chromatic differences of magnification, or both, arising from dispersion of light. Owing to nonlinearity of dispersion the correction is attempted for two colours in the first approximation, and for three colours in higher corrections. *See* achromatic lens; apochromatic lens.

acoustic absorption coefficient Symbol: α_a. The quantity $(1 - \rho)$, where ρ is the *reflection coefficient*, P_r/P_0; P_0 and P_r are the *sound power (or more generally the acoustic power) incident on and reflected from a body. *See also* absorption (2). The absorption and reflection coefficients both vary with frequency.

acoustic capacitance The imaginary component of acoustic *impedance due to the stiffness or elasticity (k) of the medium; it is equal to S^2/k, where S is the area in vibration.

acoustic delay line *See* delay line.

acoustic filters Systems using tubes and resonating boxes, in parallel and series, as acoustic *impedance elements to transmit high frequencies only (high-pass filter) or low frequency only (low-pass filter) or any given band of frequency (band-pass filter).

If any simple harmonic motion is impressed on equal impedances Z_1 connected in a conduit and separated by branches containing other equal impedances Z_2, it will not pass through unless the ratio Z_1/Z_2 for the frequency of this SHM lies between certain values; i.e. all other frequencies which do not satisfy this condition will be rapidly attenuated and only those covering this range will get through.

acoustic grating A series of objects, such as rods of equal size, placed in a row a fixed distance apart. An acoustic grating has similar properties to an optical *diffraction grating. When a sound wave is incident upon an acoustic grating, secondary waves are set up that reinforce each other or cancel out according to whether or not they are in phase. The result for a sinusoidal sound wave is a series of maxima and minima spaced round the grating. When the incident sound is normal to the grating, the condition for a maximum diffracted sound at an angle θ to the normal is: $\sin\theta = m\lambda/e$, where λ is the wavelength of the sound, e is the width of a rod plus the space between it and the next, and m is an integer. e must be greater than λ for a diffraction pattern to be formed and this condition necessitates very large gratings for low-frequency sounds.

acoustic impedance *See* impedance.

acoustic inertance The imaginary component of acoustic *impedance, due solely to inertia. It corresponds to inductance in electric circuits. In the case of a mass (m) of gas in a conduit of cross section S, the inertance (L) is equal to m/S^2.

acoustic levitation *See* levitation.

acoustic mass *See* reactance (acoustic).

acoustic power *See* sound-energy flux.

acoustic pressure *See* sound pressure.

acoustic reactance *See* reactance (acoustic).

acoustics 1. The science concerned with the production, properties, and propagation of sound waves.

2. The characteristics of a room, auditorium, etc., that determine the fidelity with which sound can be heard within it. For a room, etc., to have good acoustics there should be no noticeable echoes, the loudness should be adequate and uniform, the *reverberation time should be near the optimum for the room, resonance should be avoided, and the room should be sufficiently soundproof.

acoustic stiffness *See* reactance (acoustic).

acoustic wave *Syn.* sound wave. A wave that is transmitted through a solid, liquid, or gas as a result of mechanical vibrations of the particles in the medium. The direction of motion of the particles is parallel to the direction of propagation of the wave (i.e. it is a *longitudinal wave), and the wave therefore consists of compressions and rarefactions of the medium. The term sound wave is sometimes limited to those with a frequency to which the human ear is sensitive, i.e. about 20–20 000 Hz. A travelling acoustic wave in a solid can be produced by applying mechanical stress to a crystal or as a result of *magnetostriction or the *piezoelectric effect. *See also* ultrasonics.

acoustoelectronics The study and use of devices in which electrical signals are converted into acoustic waves by *transducers and the acoustic signals are propagated through a solid medium.

actinic Of radiation, such as light or ultraviolet. Able to produce a chemical change in exposed materials.

actinium series *See* radioactive series.

action 1. The product of a component of momentum, p_i, and the change in the corresponding positional coordinate, q_i;

or more precisely the integral $\int p_i \mathrm{d}q_i$. (*See* Hamiltonian function; quantum of action.)

2. Twice the time integral of the kinetic energy of a system, measured from an arbitrary zero time. (*See* least-action principle.)

activation analysis A sensitive analytical technique in which the sample is first activated by bombardment with slow neutrons, high-energy particles, or gamma rays and the subsequent decay of radioactive nuclei is then used to characterize the atoms present. For example, stable sodium nuclei can be activated by neutron capture:

$$^{23}\mathrm{Na} + n \rightarrow {}^{24}\mathrm{Na} + \gamma.$$

The ^{24}Na nuclei decay to give γ-rays, electrons, and neutrinos:

$$^{24}\mathrm{Na} \rightarrow {}^{24}\mathrm{Mg} + \gamma + e^- + \bar{\nu}.$$

The electrons have a characteristic energy spread and the γ-rays have energies of 2.75 and 1.37 MeV. Sodium can thus be detected by the presence of lines at these energies in the *gamma-ray spectrum of the irradiated material.

The usual method of irradiation is by neutron bombardment in a nuclear reactor. The technique is highly sensitive and can be used for a large number of elements. If the intensity of γ-ray emission is compared with that from a similarly treated standard, a quantitative analysis can be made.

activation cross section *See* cross section.

active aerial *See* directive aerial.

active component An electronic component such as a *transistor, that can be used to introduce *gain into a circuit. *Compare* passive component.

active current The component of an alternating current that is in *phase with the voltage, the current and voltage being regarded as vector quantities.

active voltage The component of an alternating voltage that is in *phase with the current, the voltage and current being regarded as vector quantities.

active volt-amperes The product of the current and the *active voltage or the product of the voltage and the *active current. It is equal to the power in watts.

activity 1. Symbol: *A*. The number of atoms of a radioactive substance that disintegrate per unit time ($-\mathrm{d}N/\mathrm{d}t$). It is measured in *becquerel, or, formerly, in *curie.

2. A quantity used mainly in chemical thermodynamics to express the effective concentration of a substance in a solution or mixture.

3. *See* optical activity.

ADC Abbreviation for *analogue/digital converter.

Adcock direction-finder *Syn.* Adcock antenna. A radio direction-finder employing a number of spaced vertical aerials. It is designed so that any horizontally polarized components of the received waves have the minimum effect upon the observed bearings.

A/D converter *See* analogue/digital converter.

additive process A process by which almost any colour can be produced or reproduced by mixing together lights of three colours, called *additive primary colours*, usually red, green, and blue, the proportions of which determine the colour obtained; white light is obtained from approximately equal proportions of red, green, and blue light; yellow from a mixture of red and green light. *Colour television uses an additive process for final colour production. *See also* chromaticity. *Compare* subtractive process.

adhesion The interaction between the surfaces of two closely adjacent bodies that causes them to cling together. *Compare* cohesion.

adiabatic demagnetization A process used for the production of temperatures near *absolute zero. A paramagnetic salt is placed between the poles of an electromagnet and the field switched on, the resulting heat being removed by a helium bath. The substance is then isolated thermally and on switching off the field the substance is demagnetized adiabatically and cools.

adiabatic process A process in which no heat enters or leaves a system. For example, if gas is compressed or expanded in a cylinder by a piston it undergoes an adiabatic change if the cylinder does not allow transfer of heat between the gas and the surroundings. An adiabatic expansion results in cooling of a gas whereas an adiabatic compression has the opposite effect. If an *ideal gas undergoes a reversible adiabatic change in volume, the pressure (p) is related to volume (V) by the equation: $pV^{\gamma} = K$, where K is a constant and γ is the ratio of the *heat capacities C_p/C_V of the gas. Any reversible adiabatic change (*see* reversible change) is *isentropic*, i.e. during the change the entropy of the system remains constant. *Compare* isothermal process.

adiathermic Not transparent to heat.

admittance Symbol: Y. The reciprocal of *impedance; it is related to *conductance (G) and *susceptance (B) by:

$$Y^2 = G^2 + B^2.$$

adsorption The formation of a layer of foreign substance on an impermeable surface. *Compare* absorption.

advanced gas-cooled reactor (AGR) *See* gas-cooled reactor.

advection A process of transfer of atmospheric properties by horizontal motion in the atmosphere, such as the movement of cold air from polar regions. Advection is concerned with large-scale motions in the atmosphere; vertical, locally induced motions are *convection processes. In oceanography, advection is the flow of sea water as a current.

aerial *Syn.* antenna. That part of a radio system from which energy is radiated into (*transmitting aerial*), or received from (*receiving aerial*) space. An aerial with its *feeders and all its supports is known as an *aerial system*. The most important types of aerial are the *dipole aerial and the *directive aerial.

Although the word aerial is in general use, as in TV aerial, the word antenna (originally a US term) is now usually preferred in UK scientific and technical literature.

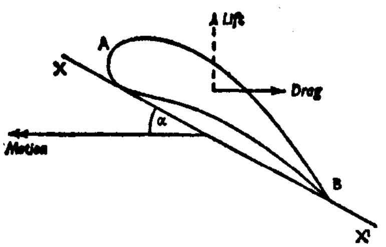
aerial array *Syn.* beam aerial. An arrangement of radiating or receiving elements so spaced and connected that directional effects are produced. With suitable design, very great directivity can be obtained and also, as a consequence, large *aerial gain. An array of elements along a horizontal line, which has marked directivity in the horizontal plane in a direction at right angles to the line of the array, is referred to as a *broadside array*. One that has directivity in the horizontal plane along the line of the array is called an *end-fire array* (or *staggered aerial*). Arrays are commonly designed for directivity in both horizontal and vertical planes. The horizontal directivity is influenced by the number of aerial elements that are arranged horizontally, whereas the vertical directivity depends upon the number of elements that are stacked in tiers (or stacks), one vertically above the other.

aerial gain The ratio of the signal power produced at the receiver input by the aerial to that which would be produced by a standard comparison aerial under similar conditions (i.e. similar receiving conditions and the same transmitted power). If the type of standard comparison aerial is not specified, a *half-wave dipole is implied.

aerial resistance The resistance that takes into account the energy consumed by an aerial system as a result of radiation and losses (e.g. I^2R losses in aerial wires, dielectric losses, earth losses, etc.). It is equal to the power supplied to the aerial divided by the square of the current at the aerial supply point.

aerial system *See* aerial.

aerodynamics The study of the motion of gases (particularly air) and the motion and control of solid bodies in air.



Aerofoil

aerofoil A body for which, when in relative motion with a fluid, the resistance to motion (drag) is many times less than the force perpendicular to motion (lift). The flight of aircraft depends on the use of aerofoils for wing and tail structure. The essential features of the aerofoil are the rounded leading edge A and the sharp trailing edge B (*see* diagram). The projection of the section on to the common tangent XX′ is called the *chord*; the angle α is the *angle of incidence* or *attack*.

Due to viscosity, the layers of fluid passing over the upper and lower surfaces of the aerofoil arrive at the trailing edge with different velocities. This leads to the production of an eddy or vortex at the trailing edge accompanied by a counter-circulation around the aerofoil. This circulation is essential for the production of the lift force.

afterglow *See* persistence.

age equation or theory *See* Fermi age theory.

age of the earth A time estimated as 4.6 × 10^9 years. The earth is believed to share a common origin with the rest of the solar system.

age of the universe A time of between 10 × 10^9 to 20 × 10^9 years as determined by the *Hubble constant. This value is clearly uncertain and depends on current theories of *cosmology. *See also* expanding universe.

AGR Abbreviation for advanced *gas-cooled reactor.

Aharonov–Casher effect An effect in which an electrically neutral particle with a magnetic moment is influenced by an electric field. It can be demonstrated by diffraction of neutrons by a line of electric charge. There is a magnetic field associated with a moving neutron in the vicinity of an electric field, and this affects the neutron's phase. A similar effect on electrically charged particles moving close to a magnetic field is called the *Aharonov–Bohm effect*.

air Normal dry air has the following composition by volume: