

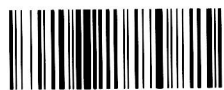
Dictionary of Physics



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Dictionary of Physics

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| Volume 1 | a – Dysprosium |
| Volume 2 | e – Ives–Stillwell experiment |
| Volume 3 | J – Pythagoras |
| Volume 4 | Q band – ZZ Ceti star |



E200401087



The *Dictionary of Physics* is an updated translation of the *Lexicon der Physik*, published in German by Spektrum Akademischer Verlag.

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Published by Macmillan Publishers Ltd, The Macmillan Building, 4 Crinan Street, London N1 9XW, UK

345 Park Avenue South, New York, NY 10010, USA

Associated companies and representatives throughout the world

ISBN: 0-333-91236-5

British Library Cataloguing in Publication Data

A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data

A catalog record for this book is available from the Library of Congress

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Typeset by Macmillan India

Printed and bound in the UK by Antony Rowe Ltd, Chippenham

Dictionary of Physics

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A

a, 1) symbol for the unit of area, \triangleright are.

2) abbreviation for the prefix \triangleright atto (equivalent to 10^{-18}).

3) symbol for \triangleright ab- system.

A, symbol for the unit of electric current, \triangleright ampere.

Å, symbol for the unit of length, \triangleright Ångström.

A4, V_2 , abbreviation for \triangleright Aggregate 4.

AA chain, a special case of the \triangleright AB-chain (\triangleright linear chain). In an AA chain the infinitely long linear chain consists of atoms of equal mass, m . The unit cell basis vector is $\mathbf{a} = 2\mathbf{d}$, where \mathbf{d} is the \triangleright interatomic distance. The \triangleright dispersion relation yields two branches for the vibrational frequency ω :

$$\omega_{\pm}^2(k) = \frac{2q}{m}(1 \pm \cos qd)$$

(where k is the spring constant and q is the wave vector). The two branches are coupled at a frequency of $\omega(\pi/a) = \sqrt{2d/m}$ at the edge of the \triangleright Brillouin zone ($-\pi < ka = 2kd \leq \pi$). An AA chain is physically equivalent to an \triangleright A chain.

ab-, symbol a, prefix largely used in the USA to identify units in the \triangleright electromagnetic CGS system. It is derived from the "technical units" by multiplying by an appropriate power of ten. For example: 1 abampere = 1 aA = 10 A; 1 abcoulomb = 1 aC = 10 C; 1 abfarad = 1 aF = 10^9 F; 1 abhenry = 1 aH = 10^{-9} H; 1 abmho = $1((FU)) = 10^9$ S; 1 abohm = 1 aΩ = 10^{-9} Ω; 1 abvolt = 1 aV = 10^{-8} V. The ab-units are related to the stat-units via the factor $\mu\epsilon = 1/c^2$ where c is the speed of light.

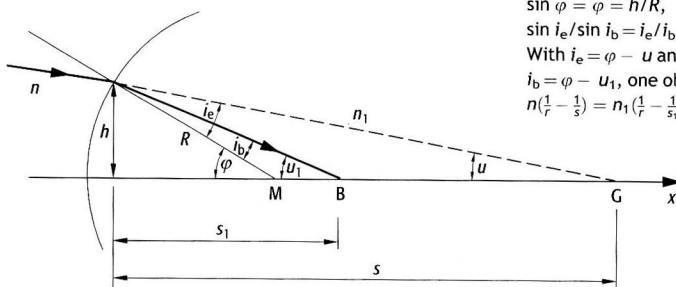
Abbe, *Ernst*, German physicist, b. 23 January 1840 Eisenach, d. 14 January 1905 Jena. Professor (1870–96) and director (1878–91) of the Observatory in Jena. From 1889 sole owner of the firm of Carl Zeiss; created the Carl Zeiss Foundation in 1891 using company assets. Played a decisive role in the foundation in 1884 of the glass works Schott Jena. In 1866 developed the apochromatic objective; from 1867 onwards constructed various optical measuring devices, including refractometers, focimeters, spectrometers and comparators, for checking optical lenses. Fundamental work in optical imaging and the theory of optical instruments; published \triangleright Abbe's theory (1873);

developed the photographic objective, the telescope, optical measuring devices and glasses (giving his name to the \triangleright Abbe number); invented the microscopic substage illuminator (*Abbe illuminator*).

Abbe's invariant, *refractive invariant*, *null invariant*, *invariant method*, a linear relationship between the \triangleright refractive indices n and n_1 in the object space and image space, the radius of curvature r of the refractive surface (\triangleright refraction; \triangleright lens) and the focal intercepts s and s_1 on the object and image sides in the case of \triangleright optical mapping (see Figure):

$$Q = n\left(\frac{1}{r} - \frac{1}{s}\right) = n_1\left(\frac{1}{r} - \frac{1}{s_1}\right)$$

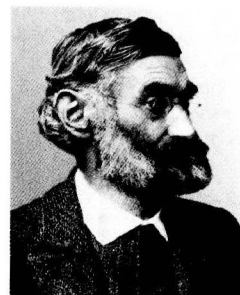
The variable Q is invariant with respect to the refraction in the paraxial region.



Abbe's invariant: The following holds for rays close to the optical axis: $\tan u = h/s$, $\tan u_1 = u_1 = h/s_1$, $\sin \varphi = \varphi = h/R$, $\sin i_e/\sin i_b = i_e/i_b = n_1 n$. With $i_e = \varphi - u$ and $i_b = \varphi - u_1$, one obtains $n(\frac{1}{r} - \frac{1}{s}) = n_1(\frac{1}{r} - \frac{1}{s_1})$.

Abbe's number, a variable $v_D = (n_D - 1)/(n_F - n_C)$ introduced by \triangleright Abbe to indicate the \triangleright dispersion of an optical medium, where n_D , n_F and n_C are the \triangleright refractive indices of the medium on the Fraunhofer lines D, F and C. D is the average value of the \triangleright sodium-D lines $\lambda_1 = 589.6$ nm and $\lambda_2 = 589.0$ nm; F is the \triangleright hydrogen line with $\lambda = 486.1$ nm; and C is the hydrogen line with $\lambda = 656.3$ nm. Of late, use has been made of a \triangleright mercury line with $\lambda = 546.1$ nm and \triangleright cadmium lines with $\lambda = 643.8$ nm and $\lambda = 480.0$ nm. A large Abbe's number indicates a low dispersion. *Relative dispersion* is used to designate the reciprocal value of Abbe's number.

Abbe's prism, a \triangleright prism, named after \triangleright Abbe, that offers different possibilities of application in accordance with the number of individual prisms involved: as a \triangleright dispersion prism, composed of two half-prisms and one reflection

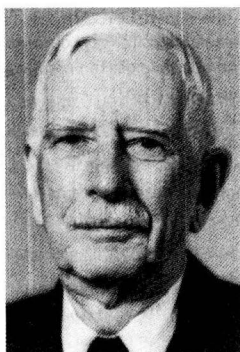


Abbe, Ernst

prism; as a reflection prism, with a ridged surface that is used as a direct-vision inverting prism and that serves for complete image inversion; and as a polarization prism, consisting of one double-refractive, equilateral calcite prism (\triangleright calcite structure) and two rectangular \triangleright glass prisms.

Abbe's resolving capacity, a theory on the \triangleright resolving capacity of non-luminescent objects (\triangleright luminescence), published in 1873 by \triangleright Abbe.

Abbe's theory, a theory of microscopic mapping developed by \triangleright Abbe, according to which image formation—following correction of \triangleright image distortion—is decisively influenced by the \triangleright diffraction of the \triangleright light on the \triangleright object, and in which the \triangleright resolving capacity is limited by the \triangleright wavelength of the impinging light. The type of illumination—for example, vertical or non-vertical incidence of light—also plays a role in the resolution of the object structures: If the direct light is stopped down in the plane of the objective \triangleright focus and only the diffracted light (\triangleright diffraction) is allowed to act, then the contours of the object appear light against a dark background (dark-field illumination).

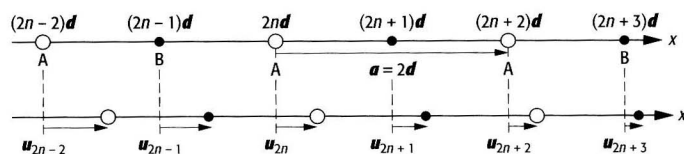


Abbot, Charles Greeley

Abbot, Charles Greeley, American astrophysicist and meteorologist, b. 31 May 1872 Wilton (NH), d. 17 December 1973 Riverdale (MD). Director (1907–44) of the Smithsonian Astrophysical Observatory in Washington DC. Worked on radiation from the stars and the Sun and is regarded as one of the co-founders of solar physics; best known for his extremely precise determination of the solar constants by means of a \triangleright pyrheliometer, which he constructed in 1909. Among the first to suggest that solar radiation varies with time; demonstrated in 1953 that these variations influence the weather.

AB chain, a one-dimensional crystal model developed by \triangleright Born and von \triangleright Kármán. An AB chain develops out of an infinitely long linear chain in which atoms of species *A* (with mass m_A) and species *B* (with mass m_B) are separated by equal distances d . The chain also consists of cells with a \triangleright basis vector $a = 2d$ and with two atoms per \triangleright unit cell. The coordinate origin lies at the equilibrium position of an *A* atom, so that the equilibrium positions of all the *A* atoms are given by $x_A = 2nd = na$ ($n = 0, \pm 1, \pm 2$, etc.) and those of the *B* atoms by $x_B = x_A \pm d = (2n \pm 1)d = (n \pm 1/2)a$. Here a linear force law is assumed and only longitudinal waves are considered; furthermore, each atom

AB chain: An infinite AB chain in its equilibrium state (top) and during a longitudinal wave (bottom). The hollow circles (even subscripts) denote *A* atoms and the solid circles (odd subscripts), *B* atoms.



should only be subject to forces from its nearest neighbors. Hence a restorative force acts only when the distances from the neighbors to the right and left are of different magnitudes and this force is proportional to the difference between the distances to the two neighbors. The atoms can oscillate about their equilibrium positions, with the deviation of the *i*-th atom from its equilibrium position denoted by u_i . For an *A* atom (even subscript) the distances from the $2n$ -th atoms of its neighbors to the right and left are given by $d_+ = d + u_{2n+1} - u_{2n}$ and $d_- = d + u_{2n} - u_{2n-1}$, $n = 0, \pm 1$, etc. The equations of motion of the *A* atoms, therefore, are given by

$$m_A u_{2n} = \alpha(d_+ - d_-) = \alpha(u_{2n+1} + u_{2n-1} - 2u_{2n})$$

and, similarly, those of the *B* atoms (odd subscripts), by

$$m_B u_{2n+1} = \alpha(u_{2n+2} + u_{2n} - 2u_{2n+1}).$$

The \triangleright spring constant α is naturally the same for both types of atoms since the restorative force is determined by the mutual coupling between the *A* and *B* atoms. The solutions of the equations of motion are harmonic waves (eigenmodes) with angular frequencies ω and complex amplitudes that are to be determined. A \triangleright dispersion relation, which specifies the relationship between the frequency and wave vector $k = (k_x, 0, 0)$, where $k = 2\pi/\lambda = \omega/v$ (where λ is the wavelength and v the \triangleright phase velocity of the waves) follows from this. Its solutions yield two branches of the dispersion curve,

$$\omega_{\pm}^2(k) = \frac{\alpha}{m_A m_B} \left(m_A + m_B \pm \sqrt{m_B^2 + m_A^2 + 2m_A m_B \cos ka} \right),$$

which are periodic in ka with period 2π . In this way all the allowed eigenmodes lying within the wave numbers interval $-\pi < ka \leq \pi$ or wave vector interval $-g/2 < k \leq g/2$ can be determined. All of the eigenmodes lie within the first \triangleright Brillouin zone. Its width,

$$g = \frac{2\pi}{a} \cdot \frac{a}{a},$$

is equal to the length of the basis vector of the corresponding reciprocal chain.

Abegg, Richard, German chemist, b. 9 January 1869 Danzig, d. 3 April 1910 Tessin. In 1900 became professor of inorganic chemistry in Breslau. Work in physical chemistry, valence theory and electrochemistry, particularly on the position and modification of chemical equilibria; in 1904 proposed the theory of electron affinity (*Abegg's valence rule*), according to which the sum of the maximum valencies of an element with respect to oxygen and hydrogen is 8 (which corresponds to the maximum number of outer electrons).

Abel, Niels Henrik, Norwegian mathematician, b. 5 August 1802 Finnoy, near Stavanger, d. 6 April 1829 Froland, near Arendal. Appointed, two days after his death, to a professorship in Berlin. Founder of modern algebra; important work in, among other things, the theory of elliptical functions (independently of Carl \triangleright Jacobi) and the solvability of algebraic equations; the *Abelian set* and *Abelian groups* were named after him.

Abel group, a group in which a *commutative law* applies. The groups of translations and of rotations in a plane are, for example, Abel groups, although the group of space rotations is not.

Abelian anomaly, \triangleright anomaly.

Abel inversion, reconstruction of a function which, in cylindrical geometry, is dependent only on the coordinates of the radius, from linearly integrated measurements of this function along a number of collimating rays perpendicular to the axis of the cylinder. Abel inversion plays an important role in \triangleright plasma diagnostics.

Abelson, Philip Hauge, American physicist and chemist, b. 27 April 1913 Tacoma (WA). Professor in Washington (DC); worked at the Carnegie Institute there from 1946 onwards. Developed the thermodiffusion process for the separation of uranium isotopes 235 and 238 (starting with uranium hexafluoride); in 1940, with \triangleright McMillan, discovered the first transuranic element, \triangleright neptunium; also conducted biophysical research, developing the tracer method using radionuclides. Editor (1962–84) of the journal *Science*.

Abel transform, \triangleright Abel inversion.

aberration, 1) In *astronomy*, a small, apparent shift in the position of a \triangleright star in the sky caused by the motion of the observer and the finite speed of propagation of light. The light impinging from a star S on the center O of the \triangleright objective of a \triangleright telescope needs a certain amount of time to reach the center M of the \triangleright eyepiece (see Figure). If, during this period, the telescope moves by a distance MM' as a result of the motion of the \triangleright Earth, the light no longer impinges on point M but on point M'. For the observer, the light of the star thus appears to originate from direction S'. In order to compensate for this, the telescope needs to be rotated by an angle α toward the direction of rotation of the Earth. The *angle of aberration* α depends on the ratio between the \triangleright velocity v of the telescope and the speed of light c , as well as the angle between the incident light beam and the direction of movement of the telescope. Its value is largest when the direction to a star is vertical with respect to the direction of rotation of the earth ($\alpha_{\max} = 20.5''$).

There are four different aberration effects. *Daily aberration* is caused by the rotation of the Earth. The aberration angle α as a function of the geographical width φ of the site of observation is determined with the equation $\alpha = 0.32'' \cos \varphi$. Its value is largest at the \triangleright equator of the Earth (rotational velocity $v = 465 \text{ m/s}$), with $\alpha = 0.32''$, and approaches zero at the poles. When passing through the \triangleright meridian, for example, in the northern hemisphere, the star appears shifted eastward by this small angle. *Annual aberration*, caused by the elliptical \triangleright orbit of the Earth around the \triangleright Sun, makes itself apparent by a star following an elliptical, circular or straight trajectory with respect to its actual position in the course of a year, depending on its position in the \triangleright celestial sphere. A star at the \triangleright pole of the \triangleright ecliptic follows a circular trajectory with a radius $\alpha = v/c = 20.48''$, while a star in the ecliptic follows a straight trajectory with a maximum deflection of $\pm \alpha$. Third, *secular aberration* is caused by the motion of the Sun in the \triangleright Milky Way and does not play any role in practical astronomy, as it does not have any influence on the mutual positions of the heavenly bodies. Fourth and finally, *planetary aberration* is the change in the position of a \triangleright planet during the time taken by light to travel from the planet to the Earth (known as the *aberration time*). It needs to be taken into consideration during the orbital tracking of these bodies.

Annual aberration was discovered by \triangleright Bradley in 1728 during a measurement of trigonometric parallaxes. These latter are tiny, annual shifts in the positions of neighboring stars with respect to more distant background stars, caused by a shift in the position of the observer resulting from the annual motion of the Earth. However, these shifts are independent of the aberration.

2) In *optics*, \triangleright image distortion.

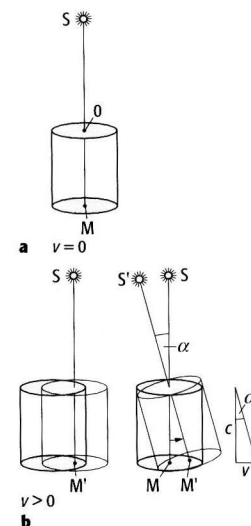
Abetti, Giorgio, Italian solar physicist, b. 5 October 1882 Padua, d. 24 August 1982 Florence. Director (1921–52) of the Arcetri Observatory of the University of Florence. Conducted important research into the structure of the chromosphere and the flow of gas masses in \triangleright sunspots (*Evershed–Abetti effect*); also wrote on the history of astronomy.

ab-initio calculation, \triangleright ab-initio methods.

ab-initio methods, a term originating from \triangleright quantum chemistry that is used there mainly as a synonym for *Hartree-Fock methods*. In solid state theory, the more usual term is “methods from first principles”. Generally speaking, *ab-initio* methods are all the procedures of electron theory of atoms, molecules and solids that do not use any parameters that have been adjusted to experimental data. All methods in



Abel, Niels Henrik



Aberration: (a) For an observer at rest, the star S always appears in the middle of the visual field. (b) For an observer moving with velocity v , the star moves to the right in the visual field. The observer must rotate the telescope by the aberration angle α to compensate. For $v/c \ll 1$ we have $\tan \alpha \approx v/c$.



Abetti, Giorgio

which either all single-electron and double-electron integrals are calculated explicitly (within the ▷Hartree–Fock approximation) or in which theoretically proven exchange correlation functions are used (within the ▷density-functional theory) are parameter-free in this sense. Therefore, the attribute *ab-initio* (Latin, meaning “from the beginning”) does not mean that such methods are free from approximations. Practically all *ab-initio* methods are based on the ▷Born–Oppenheimer approximation. Most methods neglect relativistic effects or only take them into account through perturbative calculation. For heavy atoms (usually starting with sodium $Z=11$), pseudo-potentials are usually used, and almost all calculations are based on finite ▷basis sets.

ab-initio protein structure prediction, prediction of the tertiary structure of a ▷protein from the amino acid sequence alone and by using fundamental physical laws. *Ab-initio* prediction is one of the approaches to the theoretical computation of the protein structure, along with more empirical techniques such as *homology modeling* or *threading*. It is based on the assumption that the native space structure of the protein corresponds to the global minimum of the free energy of the “protein-solvent” system and that all information for the correct folding is contained in the amino acid sequence alone. This postulate is supported by ▷denaturing–renaturing experiments on small proteins. *Ab-initio* prediction requires both a small energy function of the atomic coordinates (which distinguishes between conformations of high and low energy, and which has the global minimum at the native structure) and an optimization method which can accurately find the global minimum within an energy range having many minima (“multiminima problem”). The energy function must be capable of simple determination by calculation, since the complicated structure of the energy range requires analysis of many million conformations even in the case of *oligopeptides*. While a solution seems to be emerging in the field of optimization, due to improved computer technology and especially due to algorithmic advances (efficient stochastic search methods), crucial steps in formulating the energy function are still lacking. Solvent effects in particular have not yet been adequately described.

ablation cooling, a technology used for protecting ▷space vehicles before or during their entry into an ▷atmosphere against high ▷temperatures caused by ▷friction there. Similar to the ▷Leidenfrost phenomenon, the frictional ▷heat on the exposed ▷surface of a spacecraft results in the formation of a ▷melting and vaporization layer, which protects the spacecraft until its ▷velocities and external temperature have dropped to harmless values. To protect

the shell of a spacecraft against damage, ablation materials with a high ▷melting point and high vaporization heat but low ▷thermal conductivity are applied to the areas of the spacecraft that are particularly exposed during re-entry. An underlying, metallic honeycomb structure increases the mechanical strength. For example, the atmospheric capsule of the Galileo space probe had a velocity of $50\text{--}60\text{ km s}^{-1}$ during its entry into the atmosphere of ▷Jupiter, in which process the protective layer was heated to a temperature of $8500\text{ }^{\circ}\text{C}$. The 10-cm-thick carbon-reinforced ▷heat shield required for such temperatures constituted roughly half the total weight of the re-entry vehicle. In contrast, heat protection on the American ▷space shuttle is provided by more than 30 000 ▷ceramic tiles, which consist of a composite structure of ▷carbon fibers in a ▷matrix comprising carbon and silicon carbide, and which can be easily replaced when required. Through optimization of the re-entry trajectory, the temperatures here are reduced to just $1600\text{ }^{\circ}\text{C}$.

ablation layer, in ▷laser fusion, the outer layer of the pellet, which flows outwards at supersonic speed after irradiation by the laser, and whose recoil concentrates the remaining material in the center of the pellet.

ablator, that part of the *pellets* (small hollow spheres) which explodes outwards during the bombardment of the pellet with heavy ions in inertial confinement fusion (ICF). The other part implodes towards the center, where it induces nuclear fusion to occur and generate energy.

Abney, *Sir William de Wiveleslie*, British chemist, b. 24 July 1843 Derby, d. 3 December 1920 Folkestone. Elected to the Royal Society in 1876. Worked on the basic chemical principles of photography, particularly color photography; contributions to multicolor printing, to the theory of colors (Abney law), and to color vision (the *Bezold–Abney phenomenon* in the psychology of perception carries his name and that of ▷Bezold); also worked in astrophotography and astrophotometry. Developed emulsions for instant and infrared photography (1878–79) and in 1880 discovered that hydroquinones are well suited as developing agents.

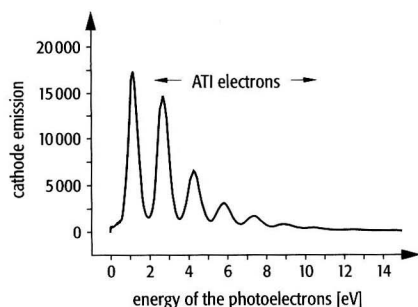
Abney’s law, a finding, attributed to ▷Abney but already known before him, where the ▷luminance of individual components are added to form the total luminance during additive ▷color mixing.

abnormal dispersion, ▷dispersion.

A bomb, ▷atom bomb.

above-threshold ionization, *ATI*, a special form of ▷photoionization where the atom

absorbs more photons than are necessary to reach the ionization threshold. This effect is mainly observed for atoms in strong, pulsed laser fields (especially for pulse lengths in the ps and fs range) because of the high photon flux densities that can occur here. In the energy spectrum of photoelectrons, we therefore find not only photoelectrons of the first order, which only absorb the photons necessary for ionization, but also electrons with energies that are higher than those of the first-order electrons by a multiple of the photon energy. The reason for this is that the energy of the excess photons is transformed directly into the kinetic energy of the photoelectrons. If E_B is the binding energy of an emitted electron, then its kinetic energy is: $E_{\text{kin}} = N \times h\nu - E_B$, where $h\nu$ is the energy of a photon, and N is the number of absorbed photons. N has to be at least big enough so that $Nh\nu > E_B$. Such an energy spectrum for xenon atoms that were ionized with a fs-titanium-sapphire laser is shown in the Figure.



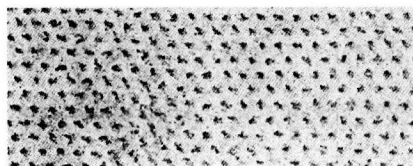
Above-threshold ionization: Photoelectron spectrum of xenon ionized by a pulsed titanium-sapphire laser. The first peak is generated by electrons that absorb the minimum number of photons necessary for ionization. Further peaks are made up of electrons generated by above-threshold ionization. The energy difference of these peaks is exactly the photon energy $E=1.55$ eV of the laser.

abrasion working, from the Latin *abrasio*, procedures for the preliminary working of surfaces and cutting of materials. Usually liquid or air mixtures with abrasive materials (sand, chips) are sprayed onto the work piece at high pressure (up to 800 MPa). The polyphase stream gradually removes the surface layer of the material as a result of its high kinetic energy or cuts through the work piece. Examples include equipment for *jet-cutting*, *sand-stream working* and *high-pressure cleaning*.

Abrikosov, Alexey Alexeevich, Russian physicist, b. 25 June 1928 Moscow. Appointed professor in Moscow in 1965. Studies in \triangleright plasma physics and \triangleright quantum field theory, with special reference to its application in \triangleright statistical physics. Important research in solid state physics, particularly on type II \triangleright superconductors. In 1957 developed a considerably expanded version of the Ginzburg-Landau theory, a phenomenological theory of superconduction

originally proposed in 1950 by \triangleright Ginzburg and \triangleright Landau, which, after additional contributions in 1959 by Gorkov, was renamed the \triangleright GLAG theory, the acronym being derived from the initial letters of the surnames of the four researchers.

Abrikosov lattice, the periodic ordering of \triangleright flux tubes as triangular \triangleright lattices in the mixed state of type II superconductors. The Abrikosov lattice was predicted theoretically by \triangleright Abrikosov in 1957 in terms of the \triangleright GLAG theory and was first made visible by Essmann and Träuble using a tracer of cobalt iron. As it leads to enhanced \triangleright flux anchoring, it is of some practical relevance.



Abrikosov lattice: An electron microscope picture of an Abrikosov lattice in a superconducting lead-indium alloy.

absolute dating, \triangleright dating.

absolute electrical units, old name for the electromagnetic units in the \triangleright CGS or MKSA (i.e. the \triangleright SI) system (in contrast to \triangleright international electrical units).

absolute magnitude, the \triangleright apparent magnitude that a celestial body would have if it were at the fiducial distance of 10 pc (\triangleright parsec). It is measured in \triangleright magnitudes and is generally denoted by the symbol M . It is a measure for the radiation power of a cosmic object and can be calculated from the \triangleright distance modulus: if the apparent magnitude m and the distance from the Earth r are known and if one takes into account that the flux S decreases with $1/r^2$, then:

$$S/S_{10\text{pc}} = 10^2/r^2$$

$$m - M = -2.5 \log(S/S_{10\text{pc}}) = 5 \log r - 5$$

$$M = m + 5 - 5 \log r$$

If the apparent magnitude of an object is decreased by the amount A due to interstellar extinction, then $M = m + 5 - 5 \log r - A$. The Sun, for example, has an apparent magnitude of -26.86 mag while its absolute magnitude is only $+4.73$. If the expression is used for objects within the solar system—for example, planets—then the fiducial distance is one \triangleright astronomical unit (AU). For meteors a distance of 100 km is used.

absolute measurement, the measurement of the total value of a physical variable with reference to basic physical units such as length, mass, time, current intensity and temperature, on the basis of explicit, exact, natural relationships and

known, natural constants. For example, absolute measurements of gravity are today performed in free-fall experiments using the falling distance and falling times as parameters, while absolute measurements of magnetic field intensity involve a determination of the precession frequency of protons or electrons given a known gyromagnetic relationship (▷magnetometer).

Absolute measurements of a higher precision can prove to be very elaborate. In contrast, *relative* measurements only require a high time constancy and an independence of the measuring system from external influences, but no explicit knowledge of the relationships with basic variables. Relative measurements often comprise differential measurements of values. Usually, they can be performed much more easily and quickly than absolute measurements. Examples here include measurements of gravity using a spring ▷gravimeter and temperature measurements using a ▷mercury ▷thermometer.

absolute simultaneity, simultaneity concept of pre-relativistic physics. The general acceptance of the ▷special theory of relativity meant that the idea of absolute simultaneity had to be abandoned, because two events that are simultaneous for one observer take place in succession for another observer moving relative to the first. This is true even when the light propagation time is taken into consideration in the synchronization of clocks. This implies in particular that there is no ▷absolute time as postulated by ▷Newton.

absolute space, ▷absolute time.

absolute system of measurement, general description for metric systems of units which connect mechanical units with electromagnetic units; specifically the ▷CGS system.

absolute temperature, *Kelvin temperature*, *temperature on the Kelvin scale*, *thermodynamic temperature*, temperature parameter that starts at ▷absolute zero. It is therefore independent of an arbitrary ▷thermometer scale. The statistical definition of the absolute temperature T is

$$\frac{1}{k_B T} = \frac{\partial \ln \Omega(E)}{\partial E},$$

where k_B is the ▷Boltzmann constant, E is the ▷energy and $\Omega(E)$ is the number of states of the observed system in the energy interval from E to $E + \delta E$. Since $\Omega(E)$ is a rapidly growing function of the energy (approximately $\Omega \propto E^f$, where f is the number of degrees of freedom), usually $T > 0$. The temperature $T = 0$ is reached when the system is at its energy minimum, its quantum-mechanical ground-state energy. However, this state is rarely reached. The absolute temperature is given in ▷Kelvin (K). Its value is fixed

so that the temperature of the triple point of water is exactly $T_t = 273.160$ K.

Absolute temperature is positive definite for all common systems in which the kinetic energy of the particles is taken into account, because such systems always have a lower limit, but not an upper limit, for their possible energy. Pure spin systems, however, have an upper limit of energy that is reached, for example, when all the spins are antiparallel to an external field. In such a system, $\Omega(E)$ decreases with increasing energy after reaching its maximum, and the absolute temperature becomes negative.

From the view of phenomenological thermodynamics, the absolute temperature can be defined by the efficiency of the ▷Carnot working cycle, equivalent to the definition above. According to this theory, the ratio of the heat quantities, Q_1 and Q_2 , equals the ratio of the absolute temperatures of the reservoirs: $Q_1/Q_2 = T_1/T_2$. This definition therefore reduces the measurement of temperature ratios to the measurement of heat quantities, i.e. energies. This is expressed more generally by the succinct ▷Sommerfeld statement of the ▷second law of thermodynamics: "Every thermodynamic system has an extensive thermodynamic property S , the ▷entropy. Its increase during reversible changes of state is the quotient of the heat input and the absolute temperature, which shall be defined at this opportunity."

With this definition, the absolute temperature creates a temperature parameter that is completely independent of the nature of the thermometer that is used to determine the temperature. The absolute temperature is a parameter of fundamental significance that is used in many thermodynamic equations. In principle, any one of these theoretical equations can be used to determine the temperature. The simplest and easiest method of temperature measurement is based on the ideal gas equation $pV = Nk_B T$. With its help, the absolute temperature can be determined by measuring the pressure p , the volume V and the amount of a substance N . (▷thermometer)

absolute time, concept of time in classical, pre-relativistic physics. In 1686, ▷Newton postulated in his *Principia* that space and time were absolute. ▷Einstein's ▷special theory of relativity, however, showed that space and time are quantities that depend on the observer's reference system. In particular, the principles of ▷absolute simultaneity and *absolute velocity* have to be abandoned. (▷proper time)

absolute zero, *absolute zero of temperature*, *zero absolute*, the zero of absolute temperature that no temperature can (usually) fall below (▷absolute temperature). At absolute zero, all physical systems are in their state of minimum energy, the quantum-mechanical

▷ground state. However, absolute zero can practically never be reached (▷third law of thermodynamics). Absolute zero is the zero on the ▷Kelvin scale.

absorber, saturable, optically nonlinear material (▷nonlinear optics) with an ▷absorption coefficient which decreases with increasing incident intensity and which becomes optically transmittive at a specific intensity, the *saturation intensity*. Saturable absorbers are used as components in ▷laser resonators to produce very short laser pulses via passive ▷mode locking or Q switching. Due to the nonlinear saturation of the absorbing medium the most intense portion of the radiation field experiences the lowest absorption and thus the greatest amplification within the ▷resonator. When the ▷relaxation time of the absorber is short compared to the *resonator roundtrip time*, it is possible to selectively amplify a pulse.

absorber rod, ▷control rod.

absorbing agent, the absorbing substance (solid or liquid) in the ▷absorption of gases or other substances.

absorbing foil, *absorber foil*, a foil, usually of a synthetic material, used to select particles in ▷accelerators. Heavy particles (e.g. neon) will be completely stopped in an absorbing foil owing to their large ▷stopping cross section, or their kinetic energy will be reduced so much that they produce no perturbation in the measurement spectrum. As light particles pass through an absorber foil, their kinetic energy is reduced and the energy spread of the particle beam is increased (energy broadening). As an example, mylar ($C_{10}H_8O_4$) foils, with a density of $\rho = 1.39 \text{ g cm}^{-3}$, are used for this purpose.

absorptance, the fraction of radiation intensity that falls on a body and is not reflected, but rather penetrates the body and is completely absorbed. The absorptance, a dimensionless value smaller than one, depends on the incident angle of the radiation falling on the body. (▷Kirchhoff's law of emission)

absorption, 1) *atomic physics*, the infiltration of a gas or vapor into a liquid or a solid. The gas forms a ▷solution with the atoms or molecules of the liquid or solid. The absorbing medium is called the ▷absorbing agent. The process is only called absorption if no chemical transformation takes place. Infiltration of gases accompanied by a chemical transformation is called chemisorption. The amount of gas dissolved during the absorption is proportional to the ▷vapor pressure of the gas in the absorbing agent i.e. $n_{\text{sol}} = \alpha \cdot p$, where n_{sol} is the concentration of the dissolved substance, p is the partial pressure, and α is a proportionality constant. This is the *Henry–Dalton absorption law*.

2) *oscillations and waves*, weakening of electromagnetic or particle radiation during its passage through a medium. The energy is lost due to ▷radiation excitation or collision excitation of the absorbing medium, which is transferred to a state of higher energy due to the absorption of radiation energy. Ohmic dissipation is particularly important for electromagnetic waves. For the decrease in radiation intensity in a medium, the ▷Lambert–Beer law applies.

Absorption and ▷adsorption should never be confused.

absorption coefficient, constant α for the reduction in intensity of radiation during the absorption of radiation according to the ▷Lambert–Beer law. The absorption coefficient determines after what path length the radiation intensity decreases to $1/e$ during passage through an absorbing medium. The coefficient has the units $1/\text{m}$. In an atomic system of ground state $|g\rangle$ and excited state $|e\rangle$, the frequency dependent absorption coefficient $\alpha(\nu)$ is given by

$$\alpha(\nu) = [N_g - (g_g/g_e)N_e]\sigma(\nu),$$

where N_g and N_e are the population densities of the ground and excited states (i.e. the number densities of the atoms in the states), g_g and g_e are the statistical weights of the states (i.e. the number of substates with the same energy as the respective state) and $\sigma(\nu)$ is the frequency-dependent absorption cross section.

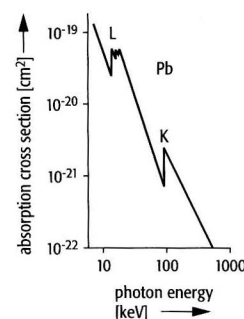
absorption cross section, total effective cross section for the absorption of radiation passing through matter. The absorption cross section is mainly applied to the absorption of electromagnetic radiation. For an ▷absorption coefficient α given by the ▷Lambert–Beer law with population densities of the ground and excited states N_g and N_e , statistical weights g_g and g_e and a frequency-dependent absorption cross section $\sigma(\nu)$,

$$\alpha(\nu) = [N_g - (g_g/g_e)N_e]\sigma(\nu),$$

where $\sigma(\nu)$ has the units m^2 and describes an area associated with a particle within which the incident radiation is absorbed.

absorption dose, ▷dose.

absorption edge, the frequency of a sudden rise in the absorption ▷spectrum of an element or compound which sets in when the incident energy corresponds directly to that required for excitation or ionization, ΔE ; that is, $h\nu \geq \Delta E$. For ▷semiconductors, radiation in the optical range is sufficient to raise electrons out of the ▷valence band into the ▷conduction band, and in this way, the energy ▷band gaps of semiconductors can be measured. If x rays are used, electrons will be removed from the inner shells of an element and the energies of the K and L shells can be determined.



Absorption edge: The energies of the electron shells of elements can be determined from sudden changes in the absorption cross section at particular energies.

absorption filter, a \triangleright filter that only transmits frequencies outside a certain frequency range. An absorption filter is thus the opposite of a bandpass filter.

absorption grating for neutrons, a neutron-optical component that is similar to the light-optical \triangleright amplitude grating and is used for the \triangleright diffraction of \triangleright neutrons based on their properties as matter \triangleright waves. Typical absorption gratings for neutrons are made, for example, of \triangleright nickel and have a grating constant of between 10 μm and 50 μm , given neutron wavelengths ranging from less than 0.2 nm (*thermal neutrons*) to more than 100 nm (*ultra-cold neutrons*). (\triangleright neutron diffraction, \triangleright neutron spectrometry)

absorption heat pump, a \triangleright heat pump where the coolant circuit is sealed with the aid of a third temperature level, without the use of a compressor. The principle behind it is exactly the same as that of an \triangleright absorption refrigerator, except that the heat source and heat sink are reversed.

absorption length, the path length x_{abs} that radiation has to transverse during \triangleright absorption in a medium for its intensity to decrease to the fraction $1/e$ of the incident intensity P_0 according to the \triangleright Lambert–Beer law.

$$P(x_{\text{abs}}) = P_0 \cdot e^{-\alpha x_{\text{abs}}} = \frac{P_0}{e},$$

which results in an absorption length

$$x_{\text{abs}} = \frac{\ln(e)}{\alpha} = \frac{1}{\alpha}$$

where α is the \triangleright absorption coefficient.

absorption line, the gap in the spectrum of electromagnetic radiation due to the \triangleright absorption of radiation in an atomic or molecular gas, a liquid, or a solid. The cause of the absorption line is the \triangleright excitation of the absorbing medium to a state of higher energy. As energy levels are usually discrete, absorption only occurs for certain wavelengths of the electromagnetic spectrum, hence absorption lines are obtained.

absorption measurement, the measurement of the \triangleright absorption of radiation by matter. The intensity of the radiation transmitted through a medium is dependent on the frequency and its measurement yields the \triangleright absorption spectrum

of the medium. The \triangleright Lambert–Beer law gives the decrease in radiation intensity. Absorption measurements are mainly used in \triangleright atomic absorption spectroscopy and other forms of \triangleright absorption spectroscopy.

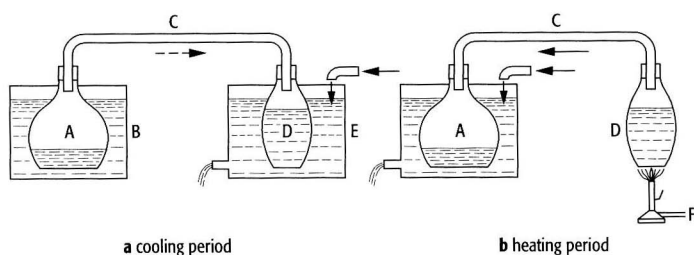
absorption probability, the probability of radiation being absorbed during its passage through matter for a given particle concentration (absorption of radiation). The absorption probability applies to both electromagnetic radiation and particle beams. The absorbing medium can be an atomic or molecular gas, a liquid, or a solid. If light, for example, hits an absorbing medium, the \triangleright Lambert–Beer law $P(x) = P_0 \cdot e^{-\alpha \cdot x} = P_0 \cdot e^{-k \cdot c \cdot A \cdot x}$, holds for the decrease in radiation intensity P , where c is the concentration of the absorbing atoms or molecules, A is the cross section of the beam, and k is the absorption probability.

absorption refrigerator, *sorption refrigerator*, a \triangleright refrigerator that works on the principle of periodically expelling a coolant from a carrier fluid (a solvent) and then absorbing the coolant, which is now in gas form, into the carrier.

The basic principle is illustrated in Figure 1. The coolant (e.g. ammonia) is initially dissolved in the carrier liquid (e.g. water, in container A), which is brought to the point of evaporation when the low temperature required is reached. The evaporation heat required from this is taken from the environment (air, the coolant in container B), which cools down as a result. In order that the evaporation of the coolant does not come to a standstill, the coolant vapor must be continually removed (pipe C). In order that this latter can be used for cooling again, it is condensed again in another container (D) by means of the coolant being absorbed into the carrier liquid. The heat released when the coolant is absorbed is removed by cooling the water (container E). In order to bring the coolant back to the initial container, container D is now heated using an additional heat source (F), as a result of which the coolant is, once again, expelled from the carrier and evaporates. Liquefaction takes place in A if the pressure there is greater than the liquefaction pressure at that temperature.

According to the principle detailed above, containers A and B each have a dual role as condenser/vaporizer and boiler/absorber, which means that the process has to be divided up into a cooling period and a heating period. However, if the functions are separated (Figure 2), the refrigerator can be operated continuously. When this system is used, the coolant is vaporized in the boiler B at high temperature (T_H) and high pressure (p_C). The coolant vapor flows over the rectifier R, where solvent vapor expelled at the same time is separated off, to the water-cooled condenser C (temperature T_M),

Absorption refrigerator 1: Diagram showing the basic principle behind an absorption refrigerator, A: condenser/vaporizer, B: volume to be cooled, C: connection pipe, D: boiler/absorber, E: water cooling, F: heat source. During the cooling period (a) heat is removed from the environment to be cooled by vaporizing the coolant; the coolant vapor flows through the connection pipe to the absorber, where it is absorbed. During the heating period (b), the coolant is boiled in the absorber/boiler and thus reintroduced to the condenser/vaporizer.



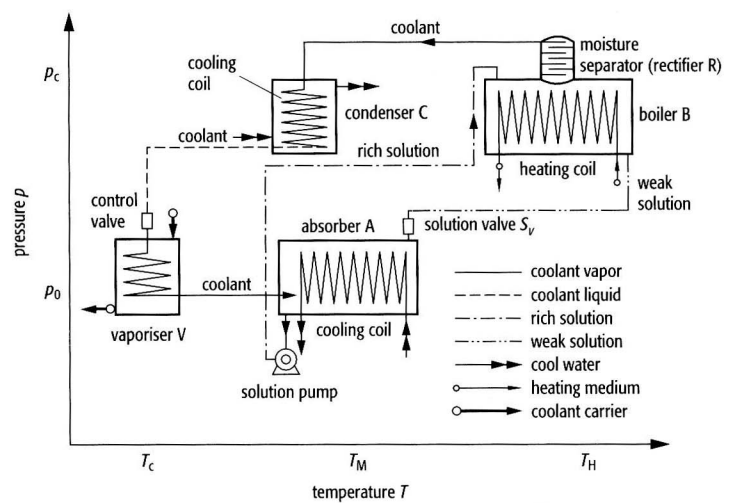
where it condenses and cools down. The condensed coolant now flows to the vaporizer V, and it is decompressed in the control valve to the liquefaction pressure p_0 corresponding to the cool temperature required (T_C). The coolant vaporizes in the vaporizer V, where it generates the refrigeration required. The circuit is closed in the water-cooled absorber A, where the coolant vapor and the carrier/coolant liquid, which is coming from the boiler and has been depleted of its coolant, come together. The solution is decompressed to the absorber pressure p_0 on its way from the boiler to the absorber by the solution control valve SV. In order to complete the circular process, the solution is conveyed back to the boiler by the solution pump SP.

If it is assumed that the process is ideal (circular processes in refrigeration technology), the working number of refrigerators can be worked out on the basis of the specified temperatures T_C (vaporizer), T_H (expulsion unit) and T_M (condenser and absorber). To do this, the refrigerator needs to be considered as a combination of a \triangleright heat engine HE and a \triangleright heat pump HP (Figure 3). If both the HE and the HP work as \triangleright Carnot engines, the following is the working number ε :

$$\begin{aligned}\varepsilon &= Q_{HP}/Q_{HE} = \frac{W \cdot \varepsilon_{HP}}{W/\eta_{HE}} \\ &= \varepsilon_{HP} \cdot \eta_{HE} = \frac{T_H - T_M}{T_H} \cdot \frac{T_K}{T_M - T_K}.\end{aligned}$$

In practice, it is always true that $\varepsilon < 1$. A discussion of real absorption refrigerators can be carried out with the aid of a $\lg p$ - $1/T$ diagram.

absorption spectroscopy, 1) *general*: a method for determining the spectra of gases, liquids or solids by measuring the \triangleright absorption of incident light passing through the substance. For atoms this is also called \triangleright atomic absorption spectroscopy. Absorption occurs when the light frequency coincides with a resonance frequency of the medium: the light energy effects the transition from an (already occupied) lower energy level to a higher energy level of the atoms or molecules. When the light is continuously distributed over a given frequency range (e.g. when using a tungsten filament lamp), the light spectrum generated by a spectral device reveals dark lines, the absorption lines. \triangleright Fraunhofer



Absorption refrigerator 2: Diagram of an absorption refrigerator in permanent operation, drawn within a pressure-temperature diagram. The separation of the vaporizer/condenser and absorber/boiler functions means that the system can run continuously. Note that three temperature levels are required.

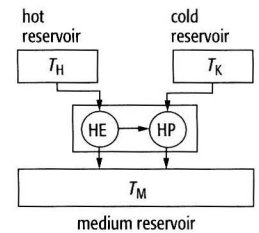
was the first to discover such \triangleright absorption lines in the spectrum of sunlight (Fraunhofer Lines).

\triangleright Lasers which can be tuned within a given frequency range are particularly suitable light sources for absorption spectroscopy. In this case, the narrow linewidth offered by laser light and its high spectral intensity are especially advantageous. The narrow linewidth makes it unnecessary to spectrally break up the emerging light from the sample; the laser frequency is sequentially set to the resonance frequencies of the medium. Absolute measurements of the laser frequency require considerable effort. However, the differences in frequencies, and thus the line distances, can be measured with great accuracy. Often the frequency values of already known calibration lines are used for comparison.

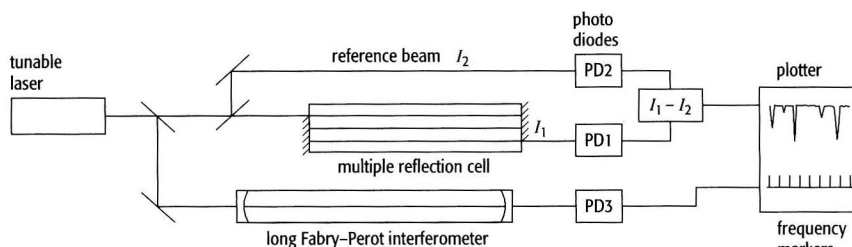
The shape and width of the absorption lines are determined by the lifetimes of the relevant energy levels as well as by the interaction processes of the molecules and their environment.

Collision processes at high pressures in gases cause a Lorentzian line shape with a linewidth proportional to the pressure. On the other hand, for sufficiently low gas pressures the thermal motion of the particles results in an absorption line with a Gaussian profile where the width is given by the Doppler width.

Conventional methods of absorption spectroscopy are, without exception, based on linear absorption, since the low spectral intensity of conventional light sources excludes any noticeable changes in the population conditions of the



Absorption refrigerator 3: Illustration of the theoretical maximum working number of a refrigerator on the basis of three temperature levels. The heat pump HP itself is powered by a heat engine.



Absorption spectroscopy: Absorption spectroscopy with a narrow-band tunable laser.

measured levels. The measurements are performed primarily as a *transmission measurement*, i.e. the intensity I of the measurement beam is registered after traversing the sample with length l , and is compared to the incident intensity I_0 . The intensity ratio is given by $I_0/I = \exp(\alpha lp)$, where p is the pressure and the pressure-unit-related absorption coefficient α is a measure of the strength of the absorption line. High pressures p or long absorption paths l are therefore required to detect very weak absorption lines. Long absorption paths can be achieved in a rather simple manner using collimated laser radiation. Tunable \triangleright **semiconductor lasers** in combination with a multipass absorption cell (folded radiation path) which allows absorption paths of several 100 m represent a highly sensitive and often-used variant. In addition, opto-acoustic, opto-thermic, opto-galvanic spectroscopy and spectroscopy within the laser resonator are based on linear absorption. The high spectral power density of laser radiation also makes possible the observation of nonlinear absorption effects. These are utilized in \triangleright **saturation spectroscopy**, specifically in \triangleright **Lamb dip spectroscopy**.

Absorption spectroscopy sometimes uses a setup in which the beam of a \triangleright **tunable laser** is split into a measurement and two reference beams via beam splitters (see Figure). The intensity of one reference beam is measured with a photodiode so that intensity variations of the laser can be corrected, whereas the other reference beam is sent through a Fabry–Perot interferometer in order to obtain frequency markers for calibrating the spectrum during changes of the laser wavelength. The actual measurement beam traverses a cell containing the substance to be examined. The intensity of the beam exiting from the cell is measured using a photodiode behind the cell.

The possibilities of absorption spectroscopy are limited by *detection sensitivity* and \triangleright **resolution**. The resolution defines the minimum distance which must separate two absorption wavelengths so that they can still be recognized as two separate lines. This is of particular importance for the identification of a specimen in a mixture of specimens with transitions lying near to one another within the spectrum (e.g. for different isotopes of an element). The detection sensitivity defines the minimum amount of the examined material that must be present, or the minimally detectable absorption corresponding to this minimum amount.

Since a relative absorption of $\Delta I/I \leq 10^{-5}$ can barely be determined even when using lasers for absorption spectroscopy, other methods are used to achieve particularly high detection sensitivity. These include \triangleright **emission spectroscopy** and \triangleright **ionization spectroscopy**.

2) *biophysics*: the most important \triangleright **biomacromolecules**, \triangleright **proteins** and \triangleright **nucleic acids** have \triangleright **chromophores** which absorb only at wavelengths smaller than 300 nm. A further problem lies in the fact that biological molecules need to be examined in an aqueous solution. The *in vivo* conditions are modeled quite well via buffer solutions with a pH value of approximately 7 and an electrolyte content of approximately 0.15 M NaCl. The large proportion of water limits the practically usable spectral region to wavelengths longer than 170 nm. Below this threshold, the absorption of even an extremely small layer of water with a thickness of merely 1 μ m is large enough to warrant extreme accuracy during the registration of signals of potential parts of biomacromolecules. The difficulties of using water as a solvent are circumvented for instance in \triangleright **infrared spectroscopy** by using heavy water (D_2O). Since water has a large dipole moment and thus adheres to polar biomacromolecules, their absorption bands in an aqueous solution are noticeably wider than in other solvents. The condition of the individual biomacromolecular chromophores in the given solution varies greatly due to the strong interaction with the solvent and the conformation fluctuations. Therefore the vibration structure of the electron transitions is practically unobservable. A further problem lies in the narrow temperature range (0 °C–100 °C) within which its water is in a liquid phase. Although this does not have an impact on measurements of proteins and nucleic acids since this is the temperature range of biological systems, it does drastically limit the possibilities of comparisons with model components.

The chromophores of proteins can be divided into three classes: i) the peptide groups (UV light: 210–220 nm); ii) the side chains of the aromatic amino acids phenylalanine, tyrosine, tryptophan and histidine as well as the disulfide bridge between two cysteines (UV light: 230–300 nm); and iii) prosthetic groups such as vitamins or nucleotides. Nucleic acids absorb with several maxima in the UV range of 180–300 nm with their nucleic acid bases. The specific position of the absorption lines is strongly affected by the molecular surroundings of the chromophore in the biomacromolecule. This allows the spectroscopic detection of biomolecular conformation transitions during changes in the surroundings of the chromophore. Normally the unfolded forms of biomacromolecules absorb more strongly in the UV region than the native conformations (hypochromism 10–50%), since the latter represent regular aggregates of chromophores closely positioned together. The hyperchrome effect is proportional to the cube of the distance between two chromophores.

absorption spectrum, result of atomic, molecular, or nuclear **▷absorption spectroscopy** that is obtained when the frequency dependence of an **▷absorption coefficient** is studied. For a known absorbing medium, the absorption spectrum can be used to determine the positions of the atomic or molecular energy levels through the frequencies of the observed transitions. Conversely, an absorption spectrum can sometimes be used to determine the absorbing substance by comparison with certain known energy levels. Absorption spectra are an important means of chemical analysis for the qualitative and quantitative characterization of substances.

The **▷solar spectrum**, too, is an absorption spectrum. It is created when the continuous, white light from the surface of the Sun is subjected to selective absorption in the solar atmosphere (Fraunhofer lines).

absorption surfaces, curved surface constructed for **▷crystals** in which various absorption values (for **▷electromagnetic waves** such as light) for the corresponding absorption axes are taken as the radius of the surface. For cubic crystals, the result is a spherical surface. For optically uniaxial crystals, the results are ellipsoids of rotation and for optically biaxial crystals, triaxial ellipsoids. Every non-cubic crystal has a characteristic absorption surface.

Ac, symbol for the element **▷actinium**.

acausality, **▷causality**.

acceleration, *acceleration vector, mechanics*, a change over time of **▷velocity** in **▷magnitude** or direction, consisting of a **▷vector** quantity with the **▷SI unit** m s^{-2} .

The acceleration $\mathbf{a}(t)$ at an arbitrary time t in the motion of a **▷particle** (instantaneous acceleration) is the first derivative of the velocity \mathbf{v} or the second derivative of the position \mathbf{x} with respect to time:

$$\mathbf{a}(t) = \frac{d\mathbf{v}(t)}{dt} = \frac{d^2\mathbf{x}(t)}{dt^2} \quad \text{or} \quad \mathbf{a} = \dot{\mathbf{v}} = \ddot{\mathbf{x}}.$$

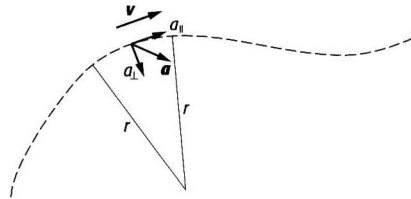
The average acceleration in the time interval $[t_1, t_2]$, in other words the mean of the acceleration in this interval, is given by:

$$\mathbf{a}(t_1, t_2) = \frac{\mathbf{v}(t_2) - \mathbf{v}(t_1)}{t_2 - t_1}.$$

Acceleration can be decomposed at every point of the **▷trajectory** into two components, namely a tangential component and a normal component. The *tangential* or *trajectorial acceleration* \mathbf{a}_{\parallel} , which is directed in the direction of the tangent to the trajectory and the magnitude of which is the second time derivative \dot{s} of the path length s , is responsible for the change in velocity. In contrast, the *normal*, *radial* or *centripetal acceleration* \mathbf{a}_{\perp} , the magnitude of which

is given by \dot{s}^2/r and is directed in the direction of the principle normal vector to the trajectory, i.e. towards the center of curvature (or radius r), has no influence on the change in the magnitude of the velocity (see Figure). A negative acceleration leads to a reduction in the magnitude of the velocity, also called *braking* or *deceleration*.

The relation between the acceleration of a body and the force acting on it is given by **▷Newton's second law** (**▷Newtonian axioms**).



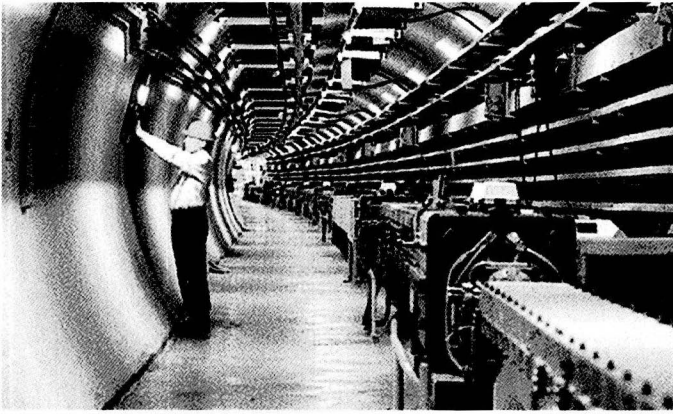
Acceleration: Decomposition of the instantaneous acceleration \mathbf{a} into the tangential acceleration \mathbf{a}_{\parallel} and the orthogonal acceleration \mathbf{a}_{\perp} , where \mathbf{v} : velocity, r : radius of curvature.

acceleration, total, material acceleration, the total **▷acceleration** of a point **▷mass** in a **▷velocity field**, e.g. the acceleration of a **▷particle** in a flow. The total acceleration \mathbf{a} is the total derivative of the flow rate \mathbf{v} as a function of time t :

$$\mathbf{a} = \frac{d\mathbf{v}}{dt} = \frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla) \mathbf{v}$$

The first term on the right is the *local acceleration*, which does not disappear when the velocity changes locally, that is, at the location of the particle. The last term on the right-hand side is the *convective acceleration*, which occurs when the particle passes through areas exhibiting differing flow rates.

acceleration force, aerospace, the **▷force** per unit area exerted on freely moving bodies in accelerated systems as a result of the **▷inertia** of **▷masses**. In aerospace engineering, this is considered as the force with which pilots or **▷astronauts** are pressed into their seats during every propulsion or braking phase opposing or assisting the direction of movement. The value of the total **▷acceleration** of a carrier system is often also specified in terms of acceleration due to gravity, g . This unit provides a direct indication of the factor by which the **▷weight** of a body is multiplied during an acceleration phase. *Resistance to acceleration* varies from one human being to another, and depends on their constitution, as well as the duration and direction of the acceleration pressure. For example, a healthy pilot can withstand $15g$ (dive, ejection seat)—i.e. 15 times the acceleration due to gravity—for short periods. In the case of the first capsules of the **▷Mercury program**, a value of $7g$ occurred during ascent shortly before burnout, and



Accelerator 1: View into the 27 km long tunnel of the Large Electron-Positron Collider (LEP) at CERN.

reached as much as $11g$ during steep return. The latter value corresponds to an acceleration of roughly 108 m s^{-2} , which would occur if a vehicle were braked from 100 km h^{-1} to 0 km h^{-1} in 0.26 s . In the case of the \triangleright space shuttle, the maximum acceleration is limited to $3g$ during launching and $1.5g$ during re-entry. To allow acclimatization to abrupt and extreme acceleration forces, every astronaut training course therefore includes a resistance test in large centrifuges, which generate \triangleright centrifugal forces.

acceleration sensors, \triangleright accelerometer.

acceleration–time diagram, a – t diagram, a graphical representation of the magnitude of \triangleright acceleration a of a moving \triangleright particle as a function of \triangleright time. The acceleration–time diagram of a uniformly accelerated \triangleright motion with the acceleration a_0 is parallel to the time axis: $a(t) = a_0$. Since only the magnitude, but not the direction, is given in an a – t diagram, these cannot be identified uniquely with a certain type of motion: the abovementioned a – t diagram, for example, describes both \triangleright free fall and a *uniform circular motion*.

acceleration vector, \triangleright acceleration.

accelerator, device for accelerating electrically charged particles (usually \triangleright electrons, \triangleright protons or \triangleright ions) to very high, often ultra-

relativistic, velocities (energies in the TeV range); in a wider sense any device with which the kinetic energy of charged particles is increased. The main goal of an elementary-particle accelerator is the production of a \triangleright particle beam with the following properties:

- i) the kinetic energy of the accelerated particles should be large compared to thermal energies;
- ii) the distribution of these energies should be as narrow as possible;
- iii) the particles in the beam should all move in the same direction;
- iv) the density of the beam should be as high as possible.

Accelerators can be divided according to their principle of acceleration into \triangleright linear accelerators (linacs) and \triangleright circular accelerators. Linear accelerators can be further divided into *potential accelerators*, in which the acceleration is achieved through an electrostatic potential (e.g. \triangleright Cockcroft–Walton accelerators or \triangleright Van de Graaf accelerators), and linear accelerators in which the acceleration is achieved via high-frequency fields (e.g. \triangleright drift tubes or \triangleright Wideroe–Alvarez accelerators). Sometimes linear accelerators are connected to one another through curved sections and deflecting magnets so that particles pass through the same acceleration regions many times (as happens in storage rings).

In circular accelerators, the particles are accelerated on circular orbits via magnetic and electric fields. Examples are the \triangleright cyclotron, the \triangleright betatron and the \triangleright microtron. In order to avoid the loss of particles, which would reduce the current in an undesired manner, particles which pass the magnets or high-frequency fields at the wrong acceleration phase are brought back into the correct phase, usually via the principle of *strong focusing*. In \triangleright storage rings, the particles circulate in closed circles in the accelerator, which makes high energies and particle densities possible. In \triangleright colliders, bunches of oppositely charged particles are accelerated and brought to collision at the interaction points. Most modern accelerators are storage rings or colliders (see Figures 1 and 2).

accelerator mass spectrometry, AMS, a method using a highly sensitive \triangleright mass spectrometer, which is increasingly replacing the radiological verification of trace isotopes as part of \triangleright dating in the fields of geophysics and environmental physics.

accelerometer, an instrument to measure \triangleright acceleration experimentally. Accelerometers usually consist of a \triangleright mass capable of oscillating, which is suspended in a housing (Figure 1). The \triangleright inertial force that occurs during an acceleration causes a shift of the mass relative to the housing. In modern accelerometers, so-called

Accelerator 2: View of the main experimental hall of the Hamburg Synchrotron Radiation Lab (HASYLAB) in Hamburg, Germany.

