DICTIONARY OF PHYSICS

COMPILED AND EDITED BY

H. J. GRAY, C.M.G., M.Sc., LL.B., M.P.A.(Harvard), A.Inst.P.

With contributions from a number of
leading scientists

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PREFACE

Dictionaries of Chemistry, Wireless and of other subjects exist, but, as far as the Editor is aware, there is no comprehensive Dictionary of Physics, although such a work should be of value to students, and to others concerned with other fields of science, and to the general public.

The present volume is designed to fill this need. The entries have been so written that they permit a reader to pursue a topic in further detail if desired, either by reference to one of the main articles or by the use of specialised books or original research papers which are quoted at the end of the article. It has been borne in mind that there is a wide range of potential readers—from whole-time physicists and physics students in schools and universities and their teachers, to practising engineers, chemists, physiologists and others, whose work brings them into frequent contact with some aspects of physics, but who may not have an intimate knowledge of the vocabulary, or of modern developments, of the subject.

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The compilation of a work of this magnitude inevitably occupies a considerable time. In the task of revising and supplementing the contributed material, the Editor received substantial assistance from Professor A. J. Woodhall, O.B.E., Ph.D., F.Inst.P., Royal Military College of Science, Shrivenham, and some of his colleagues, notably J. F. Croft, B.Sc., A.Inst.P., C. G. Wilson, M.Sc., A.Inst.P., C. B. Daish, M.Sc., A.R.C.S., D.I.C., and D. K. Thomas, B.Sc.

The Dictionary, which is alphabetically arranged, covers all branches of Physics. It contains articles on Magnetism and Electricity, Telecommunications, Electrical Engineering, Quantum Mechanics, Statics, Hydrostatics and General Physics. Each article consists of a self-contained description of the term in question, accompanied, where appropriate, by a diagram and by references to original papers and other publications on the subject to which the reader can refer.

Special features are the inclusion of articles on the elements, and on a wide selection of the materials which occur in physical work, information on isotopes of each element and biographical articles. These biographical articles are intended to give the kind of information most needed by a reader who comes across names in consulting the literature of physics. While this feature may be especially helpful to those teachers and lecturers who believe in stressing the humanistic aspects of their subject, the achievements of the scientists and others, to whom the articles relate, which are outside the realms of physics are only covered in a general way.

The Dictionary includes a certain amount of material in closely related fields (e.g. Astronomy, Mathematics and Electro-technology), such as is likely to be encountered in contexts dealing with physics and its applications, or to be required by physicists in the course of their normal work. There are bound to be gaps in this "fringe", however, and the Editor would welcome suggestions from readers on material to incorporate in future editions.

London, 1957 H. J. GRAY

ABBREVIATIONS

Å.	Angstrom.
a.c.	alternating current
a.m.u.	atomic mass unit
Å.U.	Angstrom unit
A.U.	Angstrom unit
abb.	abbreviation
amp.	ampere
At. no.	Atomic number
At. wt.	Atomic weight
B.P.	Boiling point
B.Th.U.	British thermal unit
C.	Centigrade
C.G.S.	Centimetre-gram-second (system of units)
Cals.	Calories
cc.	cubic centimetre
cf.	compare
cm.	centimetre
d.c.	direct current
e.m.f.	electromotive force
e.m.u.	electromagnetic unit
e.s.u.	electrostatic unit
F.	Fahrenheit
f.	farad
ft.	foot
gm.	gram
gm/l.	gram per litre
in.	inch
°K.	degree Kelvin
kc.	kilocycles
kgm.	kilogram
kV.	kilovolts
m.	metre
MeV.	million electron-volts
M.K.S.	Metre-kilogram-second (system of units)
M.P.	Melting point
N.T.P.	normal temperature and pressure
q.v	*quod vide* (which see)
R.M.S.	Root mean square
Ref.	Reference
S.G.	Specific gravity
S.H.M.	Simple harmonic motion
S.T.P.	Standard temperature and pressure
Syn.	Synonomous with
yd.	yard

EXPLANATORY NOTES ON ARTICLES ON ELEMENTS AND NUCLEAR PHYSICS

Reference for Isotopes as listed

Revs. of Modern Physics, Vol. 25, No. 2, April 1953.

Isotopes listed are those classified as :

A Element and mass number certain.

Those also reported :

B Element certain and mass number probable.
C Element probable and mass number certain or probable.
D Element certain and mass number not well established.
E Element probable and mass number not well established.

Types of decay

β^- Negative beta-particle (negatron) emission.
β^+ Positive beta-particle (positron) emission.
α Alpha-particle emission.
EC. Orbital electron capture. It may be assumed that X-rays have been observed or actually identified in virtually all cases of orbital electron capture listed.
IT. Isomeric transition, i.e. transition from upper to lower isomer state of the same nucleus.
n Neutron emission.

The half-life quoted is only a typical experimental value, not an average, or necessarily the *best* value (in most cases it is the most recent determination).

Method of Production of Isotopes

Target element (projectile, outgoing particle). E.g. U^{236} produced by $U^{235}(n,\gamma)$.

p	proton	t	triton
d	deuteron	γ	gamma or X-ray
n	neutron	e	electron
α	alpha-particle	π	pi-meson
β	beta-particle	C	Carbon ion

Notation used for nuclear physics

An atomic nucleus may be represented by the chemical symbol of the element, together with its mass number A as a superscript and its atomic number Z as a subscript. For example, ${}_{92}U^{235}$ and ${}_{92}U^{238}$ are isotopes of uranium, the first having a mass close to 235 on the atomic mass scale and the second having mass number 238. The atomic number (here 92) is really redundant because it is implied by the symbol U, so it is often omitted. An α (alpha) particle is a helium nucleus, so it may be written ${}_2He^4$ and similarly a proton may be written p or ${}_1H^1$, a neutron as n or as ${}_0n^1$, and a β (beta) particle, which is a fast-moving electron, as β^-, ${}_{-1}\beta$ or as ${}_{-1}e^0$, the mass being effectively zero so far as mass numbers are concerned. A positron (positive electron) is β^+, $_{+1}\beta$ or $_{+1}e^0$.

Nuclear reactions, most of which involve a fast-moving particle entering a nucleus and rendering it unstable so that it emits particles or γ (gamma) rays, or both, may be represented by equations much as are used for ordinary chemical reactions, but a very concise notation has been developed to abbreviate such equations. Thus, the action of an α particle on U^{235} is to create an isotope of plutonium, with the liberation of three neutrons and this may be written :

(*a*) $_{92}U^{235} + {_2He^4} \rightarrow {_{94}Pu^{236}} + 3n$;

or as (*b*) $U^{235}\,(\alpha, 3n)Pu^{236}$.

The bracket notation is frequently used in indicating origins of the various isotopes listed in some articles on individual elements. The process denoted by EC is *electron capture*, an electron from an inner shell (usually a K-shell electron) entering the nucleus, wherein, it is presumed, it participates in the transformation of a proton into a neutron.

A

Å (or Å.U. or A.U.). Symbol for Ångstrom or Angstrom unit (*q.v.*).

A.c. Abbreviation for Alternating current.

α particle. Nucleus of a helium (^4He) atom ; i.e. a helium atom which, having been stripped of both its extra-nuclear electrons, carries a positive charge of $2e$. It has a mass of 4·0029 mass units.

α rays. Streams of α particles which are ejected from many radioactive substances with speeds (of the order of 10,000 miles per sec.) characteristic of the emitting substance. They have a penetrating power, in air, of a few centimetres ; the maximum range varying as the cube of the velocity. They produce intense ionization along their track, and can be detected by their effect on a photographic plate, by the scintillations they produce on a fluorescent screen, or, most conveniently, by means of a thin-window Geiger counter (*q.v.*).

Ab-. When prefixed to the name of a practical electrical unit on the *C.G.S.* (*cm. gm. sec.*) absolute system denotes the corresponding unit on the absolute system of units ; e.g. *abampere*, the absolute unit of current ; *abvolt*, the absolute unit of potential.

Abampere. *See* Ab-.

Abbe, Ernst (1840-1905), German physicist, played a great part in the development of the important optical firm of Carl Zeiss, Jena. Responsible for many improvements in optical instruments, introducing the modern type of sub-stage condenser for microscopes, the oil-immersion objective and greatly improved achromatic systems. Also designed the Abbe refractometer (*see* Refractive index measurement, § 3; *see* also Sine condition (1873)), and various constant-deviation prisms (*see* Constant deviation prism), a spectrometer with self-collimating telescope, and many other devices. (The name Abbe is frequently rendered, incorrectly, as Abbé.)

Abbe criterion. For resolving power. *See* Resolving power, § 3.

Abbe number. *Syn.* Constringence (*q.v.*) ; reciprocal of the dispersive power (*see* Dispersion).

Aberration. Of lens or mirror, in a general sense refers to a defect of the image revealed as blurring or distortion, and is classified as *Chromatic* (due to dispersion) and *Spherical* (due in the main to curvature of surface) (*q.v.*). In a particular sense it refers to a measure of the amount rays fail to focus accurately, distortion of the wave front, etc. (*See* Aberrations of optical systems ; Lateral aberration ; Longitudinal aberration.) Aberrationless points and systems in which all rays from an object point pass through a point image over a wide aperture (*Cartesian systems*) should be distinguished from *aplanatic systems* (*see* Aplanatic), although frequently the terms have been used synonymously.

Aberration of light. The seasonal small displacement of stars attributable to the effect of the orbital motion of the Earth round the Sun on the direction of arrival of the light. If the observer has velocity v (Fig. 1), i.e. the Earth's velocity in its orbit,

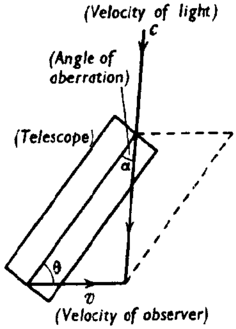

Fig 1 : Aberration of light.

and c is the velocity of light, a telescope must be inclined forward by an amount α, the **angle of aberration**, to receive the starlight, where $\sin\alpha = (v/c)\sin\theta$. This has a maximum value for $\theta = 90°$ when $\sin\alpha = (v/c)$ and $\alpha \equiv 20{\cdot}5''$. Bradley, who first observed the phenomenon (1727), used it to estimate the velocity of light. Modern explanations are given in terms of relativity. *See* Relativity theory.

Aberrationless systems. *See* Aplanatic.

Aberrations of optical systems. § 1. *General.* The simple theory of centred optical systems (*q.v.*) holds good only for paraxial rays, i.e. those passing near the axis. When the angles involved become so large that it is no longer accurate to replace the sine of the angle by the angle itself (as is done in the simple theory), the point, line and plane correspondence between object and image no longer holds good, and certain defects in the image or aberrations occur.

By expanding the sine terms to two or more terms in the series $\sin\theta = \theta - \frac{\theta^3}{3!} + \frac{\theta^5}{5!} - \ldots$, the deviations of the path of a ray from that predicted by the simple theory can be expressed in terms of five sums called the *Seidel sums* or the *Seidel terms*. The presence of one or more of these terms can be linked with certain recognizable defects in the image. They are the defects which bear the names of Spherical aberration, Coma, Astigmatism, Curvature of field, and Distortion. In addition, if light of more than one colour is involved, false colour effects may be introduced in the image, a defect which is known as Chromatic aberration.

Of these six defects only spherical and chromatic aberrations are found in the images of axial points. The other four aberrations occur only when extra-axial points are involved.

§ 2. *Spherical aberration.* The rays meeting a spherical concave mirror near the periphery are brought to a focus nearer the mirror than are those meeting the mirror near the pole, as indicated in Fig. 2.

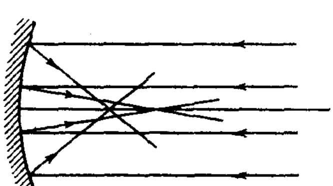

FIG. 2 : Spherical aberration (mirror).

The result is that the image of a point appears as a circular disc. The best focus will be found somewhere between the two extreme foci shown in the diagram. The disc-like image at this point is called the *circle of least confusion.*

The spherical aberration of a mirror may be eliminated by grinding the surface of the mirror to give it the shape of a paraboloid (for use with distant objects) or of an ellipsoid (where the object is at a finite distance).

A second method is to place at the centre of curvature of the spherical mirror a transparent plate known as a *Schmidt corrector.* This plate has the shape of a convex lens near the centre and that of a concave lens near the periphery. The central rays thus converge to a focus nearer the mirror than normally, while the outer rays diverge to a focus further away from the mirror than normally, so that it is possible to bring all rays together into one focus. The use of this plate has the advantage over a paraboloidal mirror that a larger field of view is sharply focused. It is also more useful when a mirror of short focal length is required.

In the case of lenses spherical aberration is encountered as indicated in Fig. 3.

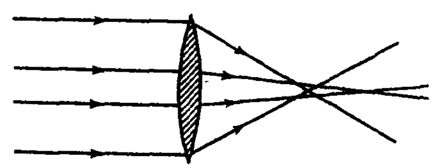

FIG. 3 : Spherical aberration (lens).

In the diagram the rays refracted at the periphery of the lens cross the axis nearer to the lens than do those refracted at the centre. Such a lens is said to be *under corrected* for spherical aberration. An *over-corrected* lens will show the opposite effect.

The aberration is reduced by choosing a lens of the right shape for the particular work required. In general terms the aberration will be small if the angles of incidence of the rays on the lens surfaces are small. The solution is therefore to share the necessary deviation of the ray equally between the two faces of the lens. Thus a telescope objective, which is used to form an image of distant objects is roughly plano-convex with the convex face pointing towards the object. The deviation of the rays is then about the same at the two faces of the lens. In a microscope objective, a number of lens components are used so that the necessary deviation of the rays is shared between a number of refracting surfaces.

For a particular zone of the lens, the *longitudinal spherical aberration* is the axial separation of the images formed by rays passing through that zone and those through the centre of the lens. The *transverse spherical aberration* is the height of the intercept of a ray through the zone on a screen placed at right angles to the axis at the paraxial image.

§ 3. *Coma.* A lens may be shaped to eliminate spherical aberration for one pair of axial object and image points, so that

 Aberrations

all the light from the object point passes after refraction through the one image point. It does not follow, however, that light from an object point adjacent to the first but off the axis will similarly pass through a single image point after refraction. In general this will not be so. Instead, the image formed by each zone of the lens of such an extra-axial point will consist of a ring of light. The rings formed by the various zones of the lens are of different diameters and are displaced from each other, the diameter being larger and the displacement greater for the outer zones than for the inner. The composite image is thus something like that shown in Fig. 4, the appearance resembling that of a comet with a luminous tail. For this reason the aberration is known as coma.

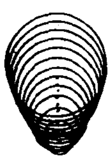

FIG. 4 : Coma.

It is found that, provided spherical aberration has first been eliminated, the condition for absence of coma for points near the axis is that the ratio of the sines of the angles made with the axis by the incident and emergent rays must be the same for all zones of the lens system. This is the so-called *optical sine condition*. The object and image points for which this condition is satisfied are known as the *aplanatic points* of the system. The term "aplanatic" signifies freedom from both coma and spherical aberration.

§ 4. *Astigmatism*. With a simple lens it is found that a point object off the axis gives rise to two images each in the form of a line. In Fig. 5, the tangential fan of rays

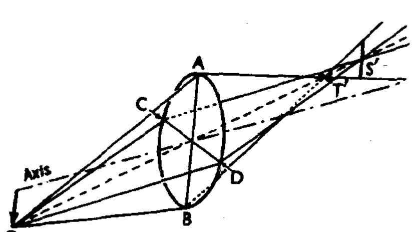

FIG. 5 : Astigmatism (lens).

OAB is brought to a focus at T′, while the so-called sagittal fan OCD is focused at S′. If the object were a wheel centred on the axis the spokes would be seen at S′ and the rim at T′. This defect is called astigmatism.

A similar effect is found in the images of extra-axial points formed by spherical mirrors.

§ 5. *Curvature of field*. In general, a plane object at right angles to the axis of an optical system will not give rise to a plane image. Instead, in the absence of astigmatism, the image would lie on a paraboloidal surface known as the *Petzval surface*. This aberration is called curvature of field (or of image). The effects of astigmatism will be superimposed on those of curvature of field with the result that the tangential and sagittal focal planes T and S are displaced from the Petzval surface P. Two possible cases are indicated in Fig. 6.

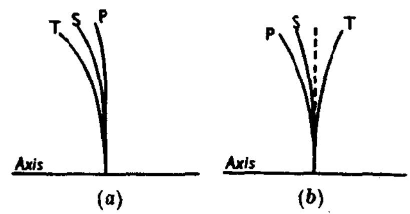

FIG. 6 : Curvature of field.

It will be noticed that in the case shown in Fig. 6 (*b*) the effects of astigmatism have been used to offset the curvature of the Petzval surface, and a flat screen placed in the position indicated by the dotted line would show a reasonably focused image. Variations of this sort are achieved in practice using optical systems with more than one lens, and altering the spacing of the various component lenses and adding suitably positioned stops.

In the so-called *anastigmat* photographic lenses, this procedure has been carefully applied so that the image obtained is substantially free from the defects of astigmatism and curvature of field.

§ 6. *Distortion*. If the magnification produced by an optical system varies over the field of view it covers, then a plane object placed normally to the axis will give rise to an image of different geometrical shape. Thus, if the magnification increases with the distance of the object point from the axis, the diagonals of a square object will be magnified more than the sides, and the resulting image will have the defect called *pin-cushion distortion* (Fig. 7). In the converse case, the defect is called *barrel distortion*.

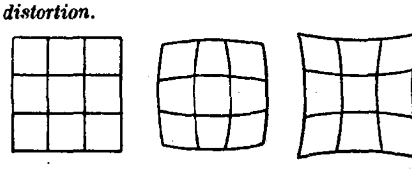

FIG. 7 : Distortion.

Distortion is controlled by introducing suitably-placed stops into the system.

§ 7. *Chromatic aberration.* The refractive index of all transparent substances varies with the colour of the light. A simple lens will therefore form a series of images. one for each colour of light present. This is illustrated in Fig. 8. The result is that coloured haloes are seen round the focus.

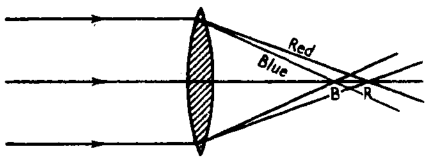

FIG. 8 : Chromatic aberration.

Moreover, because the focal length alters, the magnification will also vary with the colour. The effect of this *chromatic difference of magnification* will be that the image of, say a star off the axis of the lens will consist of a short radial spectrum.

Chromatic aberration such as that indicated in Fig. 8 is reduced in practice by employing a composite lens. Two or more lenses, made of different types of glass, are cemented together to form an *achromatic doublet* or *triplet.* A typical doublet telescope objective is shown in Fig. 9. The general idea is that a "powerful" convex lens (one of short focal length) made of weakly-dispersing crown glass is combined with a weak concave lens made of strongly-dispersing flint glass. In this way it is possible to bring two colours, say the blue and the red, to the same focus. For thin lenses, the condition is that the focal lengths of the two component lenses are numerically proportional to the dispersive powers of their respective glasses. There will still be some residual colour effects, known as a *secondary spectrum*, but these will be slight. If desired a triplet lens can be used which will bring three colours together at the same focus and still further reduce the aberration.

FIG. 9 : Achromatic lens.

In case of eyepieces, the chromatic difference of magnification can be avoided by using separated components of the same glass. For thin lenses the condition that the focal length of the combination should be the same for all colours is that the separation should be equal to the mean focal length of the two components.

(*Refs.:* W. H. A. Fincham, *Optics*, Hatton Press; A. C. Hardy and F. H. Perrin, *The Principles of Optics*, McGraw-Hill.)

Abney, Sir William (1843-1920), Brit. chemist and physicist, noted especially for his work on the chemistry of the photographic processes, on colour photography and on printing and for his extension of photographic registration well into the infra-red, to some 11,000 Å.U. He invented a form of flicker photometer. *See* Photometry, § 6.

A-Bomb (or Atom bomb). A weapon in which the great amount of energy liberated by fission of the uranium isotope U^{235} or of plutonium is put to destructive use. The weapon is fired by bringing into intimate contact sufficient of the fissile (fissionable) material to exceed the critical mass, i.e. the neutrons liberated by each fission of an atom generate more fissions and the process builds up rapidly until the material begins to disperse. Before firing, the fissile material is so disposed that the neutrons generated by any particular fission have a good chance of escaping or being harmlessly absorbed before encountering another fissile atom. The fission chain-reaction vaporizes the material of the bomb and brings it to a temperature of some millions of degrees and this fire-ball, as it expands, gives out intense thermal radiation and generates a powerful shock-wave which gives rise to the characteristic blast effects of the weapon. Intense gamma radiation arises from the fission and from the radioactive fission products. The hot vaporized mass expands, entrains surrounding air, and cools; a strong convective column is formed and condensation occurs in the upper part of the column as it spreads out in the well-known "mushroom" shape. (*Refs.: The Effects of Atomic Weapons*, U.S. Government Printing Office; J. M. A. Lenihan, *Atomic Energy and its Applications*, Pitman, chap. x.)

Abscissa. *See* Graph.

Absolute electrometer. *See* Attracted disc electrometer.

Absolute joule. *See* Joule.

Absolute pyrheliometer. *See* Pyrheliometer.

Absolute temperature. Temperature measured from an absolute zero. For ordinary work the absolute temperature corresponding to a temperature $\theta°$ C. measured on any centigrade scale (e.g. the constant volume gas scale) is obtained by adding 273° C. giving $(\theta + 273)°$ Absolute. On the Kelvin scale the corresponding absolute temperature would be $(\theta + 273{\cdot}2)°$ K. *See* Degree.

Absolute thermodynamic scale of temperature (Kelvin work scale). Scale of temperature which is independent of the properties of any working substance.

Temperatures on this scale are such that if a reversible engine takes a quantity of heat Q_1 at a temperature of T_1 and rejects a quantity of heat Q_2 at a temperature T_2 then $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$. It may be shown theoretically that the ideal gas scale is identical with this work scale.

Absolute unit. Unit defined in terms of a recognised system of fundamental units: usually those of length, mass and time. For electrical quantities four fundamental units are required. In the *absolute electrostatic system* these are the centimetre, the gram, the second and the dielectric constant of free space; in the *electromagnetic system* the fourth unit is the magnetic permeability of free space. *See* Units.

Absolute value. *Syn.* Modulus. Magnitude of a quantity without regard to its sign.

Absolute zero. Lowest temperature theoretically attainable on any temperature scale since at this temperature the property of the working substance used to realize the scale would become zero. On the work scale (*see* Absolute thermodynamic scale of temperature), from the equation $\frac{Q_1}{Q_2} = \frac{T_1}{T_2}$ it is seen that if $T_2 = 0$ then no heat is rejected. Absolute zero therefore represents the temperature of a condenser to which a reversible heat engine would reject no heat, all the heat taken from the source being converted into work. On the thermodynamic centigrade scale, its value is $-273{\cdot}2°$ C. and on the constant volume hydrogen scale its value is $-273{\cdot}03°$ C. The temperature $-273{\cdot}2°$ C. is the temperature at which the product $(p \times v)$ for an ideal gas would vanish. (*See* Coefficient of expansion.) Alternatively, it may be regarded as the point corresponding to the complete absence of translational molecular motion.

Absolute-ampere. *See* Ampere,

Absorber, surge. *See* Surge modifier.

Absorptance. *Syn.* Absorptive power (*q.v.*).

Absorption. Penetration into the interior of a substance by foreign matter. (Cf. Adsorption and sorption.) *See* Absorption coefficient; Absorption spectrum.

Absorption, dielectric. Phenomenon, analogous to hysteresis or elastic after-effect, shown by many dielectrics when subjected to a changing electrical strain. A condenser having one of these substances as dielectric can be neither completely charged nor discharged instantaneously. On charging, a small current continues to flow into the condenser for some time after its plates have reached the potential of the source: and, if the condenser is discharged by short circuiting and then allowed to stand for a few minutes, a second discharge in the same sense but smaller in amount can be obtained from its plates. The phenomenon suggests an absorption and re-emission of the charge in the substance of the dielectric, but there is, as yet, no entirely satisfactory explanation. The effect entails a loss of electrical energy when the dielectric is subjected to an alternating electric field. It is negligible in air.

Absorption, law of. *See* Absorption coefficient.

Absorption bands (and lines). Dark bands or lines present in a spectrum which would have appeared continuous were it not for absorption by some intervening medium. The absorption lines of the solar spectrum were first observed by Wollaston but rediscovered by Fraunhofer who labelled the more prominent ones *A*, *B*, *C*. etc. *See* Absorption spectrum.

Absorption coefficient. During its passage through a medium, radiation is absorbed by amounts dependent on the medium itself, thickness and wavelength. Thus, if dI is the change in intensity of a parallel beam of radiation of intensity I in passing through a small thickness dx of some absorbing material, the absorption coefficient is $\frac{1}{I} \cdot \frac{dI}{dx}$. For monochromatic radiation, dI is proportional to I, the intensity of the radiation. Thus $(dI = -\lambda I \cdot dx)$ where λ is the linear coefficient of absorption. The solution of the equation gives $I_x = I_0 e^{-\lambda x}$. If I_0 is incident flux, I_x the transmitted flux after traversing a distance x, and λ the *coefficient of absorption:* the Bouguer or Lambert law of absorption states $I_x = I_0 e^{-\lambda x}$. (*See* Extinction coefficient; Transmission coefficient.) When all wavelengths are equally absorbed, the absorption is said to be *neutral* or *general;* otherwise preferential absorption of certain wavelengths is *selective.* For X-rays, it is often more convenient to consider the mass per unit area, rather than the thickness, of the absorbing material. The corresponding coefficient is known as the *mass coefficient of absorption.* It is equal to λ/ρ, where ρ is the density of the material.

Absorption coefficient (of sound). Fraction of the incident sound energy which is not reflected. In a number of technical applications of sound no distinction is made between what is literally absorbed by a specimen and what is transmitted through it at the other side. Thus, an open window is said to have an absorption coefficient of 1 because all the sound which falls upon one side of it passes out at the other side.

Absorption coefficient of materials to sound. When a sound is produced in a room part of the sound energy is reflected and part of it is absorbed. The dissipation of energy in penetrating any wall is due mainly to porosity and flexural vibrations. So the thickness of the wall as well as whether it is painted or non-painted makes a marked variation in the absorption. It has been found that the absorption coefficient of materials to sound varies very markedly with frequency ; as a rule it increases with increase of frequency, although a few types absorb more at low frequency than at higher. This fact can be made use of in acoustics of buildings. Sabine referred the absorption coefficient of any material to that of an open window, which he considered as unity. There are two methods of determining the absorption coefficient of materials :

(1) Small scale stationary methods (J. Tuma) in which the specimen in the form of a flat sheet closes one end of the tube. Stationary waves are set up in the tube by means of a source at the opposite end, and by measuring the ratio of the minimum and maximum amplitudes in the waves set up the absorption coefficient can be calculated.

(2) Full scale reverberation method (Sabine), by finding the surface of material equivalent to a certain surface of open window which gives the same time of reverberation in a certain room.

Comparison between results of both methods shows that the second usually is higher ; this is due to the normal incidence of sound in the first method whereas in the second the sound reflected to and fro in a room meets the walls at all angles of direction. It has been shown by Paris that the absorption coefficient increases as the angle of incidence increases from 0° at normal incidence to about 80° and then drops rapidly to zero at the grazing incidence 90°.

The mounting and position of the source of sound also affect the value of the coefficient of absorption. Tables of absorption coefficients obtained by various methods are given by Richardson. These values vary over wide limits according to the porosity of the material and also with frequency (*vide supra*). (*Refs.:* J. Tuma, *Sitz. K. Akad. d. Wiss. Wien.*, 1902, **3**, 402 ; Sabine, *Collected Papers on Acoustics*, 1922 ; Paris, *Proc. Roy. Soc.*, 1927, **115**, 407 ; Richardson, *Acoustics for Architects*, p. 56 Arnold, 1945.)

Absorption discontinuity. *Syn.* Absorption edge (*q.v.*).

Absorption edge (discontinuity, or limit). Abrupt discontinuity in the graph relating the coefficient of absorption 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 (Fig. 10). This occurs

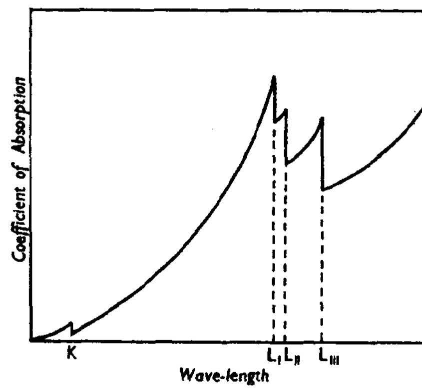

FIG. 10 : Absorption discontinuity.

when the energy quantum of the radiation becomes smaller than the work required to eject an electron from one or other of the energy levels in the absorbing atom, and the radiation thus ceases to be absorbed in that level. Thus, radiation of wavelength greater than the K absorption edge cannot eject electrons from the K level of the absorbing substance.

Absorption limit. *Syn.* Absorption edge (*q.v.*).

Absorption of sound (general). Sound, as a wave motion, will decay in intensity as it passes through a medium according to the equation $I_x = I_0 e^{-\mu x}$ where I_0 is the intensity of sound at origin, I_x is the intensity at a distance x apart from origin ; μ is thus the coefficient of absorption of this medium. The absorption of energy in sound waves is due to various causes :

(1) The viscous forces opposing the relative motion of the particles as the sound passes. This involves the transformation of mechanical energy into heat.

(2) The heat conducted from the compressed particles, which are at higher temperature, to the rarefied ones at lower temperature. This irreversible process means an increase of entropy (*q.v.*) and thus a decrease of energy.

(3) The heat radiated from compressions to rarefactions, similar to conduction but with less magnitude, also causes some dissipation of energy at low frequencies.

(4) Mutual diffusion of the gas molecules (especially if the gas is admixed with some impurities) also produces an additional absorption by reason of the lighter molecules being driven in the sound wave from a position of compression to a position of rarefaction which is equivalent to transformation of energy into heat in the sound wave.

The classical equation known as Stokes-Kirchhoff equation, summing up the first two main factors, namely viscous drag and heat conduction, is given by

$$\mu = \frac{4\pi^2}{\rho\lambda^2 c}\left(\frac{4}{3}\eta + \frac{\gamma - 1}{c_p}k\right)$$

where ρ is the density of medium, η is the viscosity, γ is the ratio of the two specific heats, k is the heat conductivity, and c_p is the specific heat under constant pressure.

By this equation $\mu\lambda^2$ should be constant, λ being the wavelength of the sound.

When this equation is tested in air, other gases and liquids, much higher values than the theoretical are found especially at higher frequencies. Herzfeld and Rice explained this discrepancy by developing a clue given by Jeans who suggested that some of the absorption of sound might be attributed to an exchange of energy between the internal degrees of freedom of the molecules of the gas and its translational degrees of freedom. There is a certain time delay (called time of relaxation) in this exchange, and if this time is comparable with the period of vibration of sound waves, part of the internal vibrational energy will be absorbed with a resulting increase of γ. Thus, the velocity of sound in the gas will increase and there will be an anomalous absorption of sound (*q.v.*).

A very complete summary of the factors affecting absorption is given by Rocard. The following table, given by him, shows the order of magnitude of the coefficient of absorption due to the different factors.

Factor	Value of μ in C.G.S. units at		
	6,000 c./sec.	8×10^5 c./sec.	∞
Viscosity	$3{\cdot}6\times10^{-6}$	$6{\cdot}4\times10^{-2}$	∞
Heat conduction	4×10^{-7}	7×10^{-3}	6×10^4
Heat radiation	$1{\cdot}5\times10^{-8}$	Negligible	Negligible
Internal degrees of freedom	$1{\cdot}16\times10^{-5}$	10^{-1}	2×10^{-1}
Diffusion	3×10^{-7}	5×10^{-3}	∞

It is to be noted that he deals with absorption due to diffusion in a gaseous mixture like air where the lighter nitrogen molecules diffuse more rapidly than the heavier oxygen molecules, thus tending to produce a decay in the amplitude.

While in the case of gases and liquids there is only one sort of elastic wave, i.e. purely longitudinal, in solid bodies, transverse and torsional vibrations may also be present. As a consequence the velocities of propagation and the attenuation of the different elastic waves are different, being determined by the elastic constants. The number of these constants in the simplest case, namely that of an isotropic body, is two, while in the case of anisotropic bodies, crystals, it depends upon the particular system of the crystal. The differences between the adiabatic and isothermal elasticities (*q.v.*) are in all cases less than 0·5 % and hence the influence of thermal conductivity on the propagation of sound is negligible. (*Refs.*: Herzfeld and Rice, *Phys. Rev.*, 1928, **31**, 691 ; Rocard, *Propagation et Absorption du Son*, Hermann et Cie., Paris, 1935.)

Absorption of sound in atmosphere. On account of absorption due to viscosity (*see* Absorption of sound), the intensity of sound waves spreading in free air falls more rapidly than the inverse square law would indicate, especially if the sound wave is of large amplitude where serious loss due to heat conduction and radiation will occur.

M. D. Hart proved by experiment, with a siren operated at 4 to 5 lb. per sq. in., that 15·5% of the energy is lost between 40 and 100 cm. from the source, and a much greater fraction between 0 and 40 cm. Thus, for the design of efficient sound signalling devices, high pressure intensities should be avoided.

Another factor affecting absorption in air is humidity. It has been noticed by meteorologists that under conditions of high humidity, distant sounds could be heard with abnormal loudness while under very low humidity conditions these same sounds might be comparatively inaudible. Sabine gave a similar conclusion, using a reverberation method, for a range of frequency up to 2000 cycles per sec.

Knudsen, taking the measurements of absorption coefficients of air, oxygen and nitrogen with varying degrees of relative humidity at frequencies ranging from 1·5 to 10 kc. per sec., found that the absorption coefficient passed through a maximum value between 10 and 20% relative humidity at 20° C., falling off rapidly with increase or decrease of humidity and increasing linearly with the frequency. (From the classical theory, the absorption coefficient increases in proportion to the square of the frequency and depends very little on small amounts of admixed impurities.) In the high frequency range, Mokhtar and Richardson found, too, that there is a value of the humidity for which the sound radiation suffers its maximum of absorption. Laidler and Richardson made smokes of measured concentration by burning stearic acid or magnesium in a chamber in which a quartz oscillator was working and measured the supersonic absorption. In this experiment as well as in others, a rapid increase of absorption with frequency was noted. This type of absorption becomes conspicuous as the wavelength of sound approaches the average size of the particles in suspension in the medium. Work on the eddies set up by turbulence in the atmosphere is being carried on with regard to its relation with absorption of sound.

The values of coefficient of absorption of air as obtained by different researches have been collected by Bergmann in the following table in which $A = \alpha/n^2 = \mu/2n^2$, α being the coefficient of decay of amplitude (half the value of μ) since $a_x = a_0 e^{-\alpha x}$; a_0 and a_x are the amplitudes at origin and at distance x and n is the frequency.

Author	Frequency (kc./sec.)	α/n^2 measured (cm^{-1}. sec^{-2}.)	σ/n^2 calculated (cm^{-1}. sec^{-2}.)
Neklepajen	132·415	2·94—3·99 × 10^{-13}	1·45 × 10^{-13}
Pulemein	1158-1408	1·67—1·99 ,,	1·45 ,,
Grossman	178	2·72 ,,	1·45 ,,

(*Refs.*: Hart, *Proc. Roy. Soc.*, 1924, **105**, 80; Sabine, *J. Frank Inst.*, 1929, **207**, 347; Knudsen, *J. Acoust. Soc. Amer.*, 1931, **3**, 126, and 1933, **5**, 64 and 112; Mokhtar and Richardson, *Proc. Roy. Soc.*, 1945, **184**, 117; Laidler and Richardson, *J. Acoust. Soc. Amer.*, 1938, **9**, 217; Bergmann, *Ultrasonics*, John Wiley & Sons.)

Absorption of sound in narrow tubes. The importance of absorption in tubes comes from the fact that most absorbents used in public buildings are porous materials such as felt, cork, wool, and various forms of plasters. These can be considered as made up of small narrow tubes where air or gas penetrates the solid wall.

The effects of viscosity and heat conduction in attenuating the sound energy are greatly increased when the particles of a gaseous medium in vibration are brought into contact with the surface of a solid wall. Rayleigh showed that the form of the wave at a distance x along narrow tubes is represented by $e^{-\alpha x}\cos \omega t$, where $\alpha = \frac{2\sqrt{\nu\gamma n}}{cr}$ and is the absorption coefficient, ν is the kinematic viscosity and γ is the ratio of the two specific heats, $\omega = 2\pi n$ where n is the frequency, c is the velocity of sound and r is the radius of the tube. Therefore the smaller the radius of the tube or cavity, the greater are the viscous forces and the more rapidly is the sound energy absorbed as it passes through.

Norton and May, working with high frequencies in narrow tubes, found that the absorption coefficient was much greater than the theoretical value as calculated from the above formula. Also they found that the velocity of sound decreases with rise of frequency. This type of dispersion may be attributed to anomalous viscous absorption at high frequencies but the further development of this theory awaits more data both on the theoretical and experimental side. (*Refs.*: Rayleigh, *Sound*, II. p. 231, Macmillan; Norton, *J. Acoust. Soc. Amer.*, 1935, **7**, 16; May, *Proc. Phys. Soc.*, 1938, **50**, 563.)

Absorption spectrum. When light from a high temperature source producing a continuous emission spectrum is passed through a medium (absorbing and at a lower temperature) 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 which 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.

Absorption units. The unit of equivalent absorption is the sabin, or "open window" unit which is equal to the absorption of 1 sq. ft. of a surface which absorbs all the incident sound energy. If the absorption coefficients of the various surfaces in a room are known, the number of absorption units may be obtained from the sum of the products of the surface areas and their appropriate absorption coefficients. Sabine first determined the absorption of a given material by comparing it directly with an open window which has a coefficient of unity. He found the area of open window which produced the same reduction of reverberation time as the material under test. In another method due to Sabine, several identical organ pipes are used and the duration of audibility is found in a room with one pipe and with n pipes (*see* Reverberation). If t_1 and t_n are the respective periods, then the absorptive power of the room is given by $(4V \log_e n)/c(t_n - t_1)$, where V is the volume of the room and c the velocity of sound. This is repeated with absorbent material in the room, the difference between the two absorptive powers being the number of absorptive units due to the material. Since absorption may vary with pitch this should be repeated at different frequencies. Large areas of material should be tested if possible or the absorption coefficient will depend on the area. Owing to the varying conditions under which materials are used in practice, it is often found that their absorption *in situ* is different from that obtained in laboratory tests. (*Ref.:* Symposium on Absorption, *J. Acoust. Soc. Amer.*, 1939, **11**, No. 1, Part 1.)

Absorptive power (or Absorptance). *See* Absorptivity.

Absorptivity. *Syn.* Absorptance ; Absorptive power. Fraction of radiant energy incident from a vacuum on a body at a temperature T which is absorbed by the body. Thus if a fraction a_λ of a given amount of radiant energy, whose wavelength lies between the limits $\lambda \rightarrow \lambda + d\lambda$, is absorbed by a body at a temperature T, then a_λ is the absorptivity of the body at a temperature T for the wavelength λ. A black body is by definition one for which a_λ is equal to unity for all values of λ and T. *See* Kirchhoff's law.

Abvolt. *See* Ab-.

Acceleration. (*a*) Linear. Rate of increase of velocity with time expressed in (cm. per sec.) per sec. (properly written as cm. sec.$^{-2}$) or other similar units. (*Ref.:* Humphrey, *Dynamics*, Longmans Green, 1948, p. 24.) (*b*) Angular acceleration. The time rate of increase of angular velocity in radian-sec.$^{-2}$ or other similar units.

Acceleration due to gravity. *See g.*

Acceptor. The impedance (*q.v.*) of a circuit comprising inductance (*q.v.*) and capacitance (*q.v.*) in series (*q.v.*) has a minimum value at one particular frequency (the frequency to which the circuit is tuned—*see* Tuned circuit). Such a circuit is an acceptor for that frequency. In practice, the effective resistance of such a circuit cannot be made zero and hence the impedance at the frequency to which the circuit is tuned cannot be zero either. *See* Rejector.

Accidental error. *See* Errors of measurement.

Accommodation. From a general point of view the ability of the eye to alter its focal length and to produce clear images of objects at different distances. (*See* Far point ; Near point.) Through the action of the ciliary muscle and the elasticity of the crystalline lens, the power of the latter and of the whole eye is varied. (*See* Amplitude of accommodation.) With age, the elasticity of the lens decreases and the accommodation decreases. (*See* Presbyopia.) The Helmholtz theory (*see* Helmholtz) assumes that the ciliary muscle acts so that the lens under its own elasticity becomes more convex ; the Tscherning theory assumes that the ciliary muscle pulls on the lens making it more convex centrally.

Accommodation coefficient. Of a surface. Ratio of the change in temperature of gas molecules occurring on collision with a surface to the difference between the temperature of the surface and that of the incident molecules. The coefficient, α, is therefore a measure of the extent to which the gas molecules leaving the surface of a solid in an atmosphere of the gas accommodate themselves to the surface temperature of the solid T_s. It is defined as

$$\alpha = \frac{T'_g - T_g}{T_s - T_g}.$$

(T_g is the temperature of the gas before and T'_g that corresponding to the mean kinetic energy of the gas molecules leaving the surface.) (*Refs.:* Adam, *Physics and Chemistry of Surfaces*, Oxford, 1938, p. 274 ; Knudsen, *Ann. der Physik.*, 1930, **6**, 129.)

Accumulator. (*a*) (Electrical.) Device for the reversible interchange of electrical and chemical energy. 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 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 :

$$\underset{(+\text{ plate})}{PbO_2} + \underset{(-\text{ plate})}{Pb} + 2H_2SO_4 \underset{\text{charge}}{\overset{\text{discharge}}{\rightleftharpoons}} 2PbSO_4 + 2H_2O$$

An accumulator employing electrodes of nickel and iron immersed in a solution of potash is also employed for special purposes.

(*b*) (Hydraulic). *See* Hydraulic accumulator.

Achromat. *See* Optical glass ; Achromatic lens.

Achromatic fringes (interference). The spacing of most systems of fringes formed by interference (*q.v.*) is dependent on the