THE INTERNATIONAL DICTIONARY OF PHYSICS AND ELECTRONICS

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PREFACE

In planning this dictionary of physics and electronics the editor and contributors have constantly held before themselves the ambitious objective of serving the greatest possible number of those people who are working with physics. This group includes not only professional physicists, and those intending to make physics their profession, but also the far greater number of workers in other fields who have frequent need for information about terms used in physics. Among these are men whose primary activity lies in some other field of science and physics, such as chemistry or biology, as well as engineers and technologists.

Obviously, the attempt to realize so ambitious a program in one volume has necessitated a number of compromises and many arbitrary decisions. The compromise on units is explained in the extended Introduction to this Dictionary, in which the subject of units is dealt with, it is hoped, at sufficient length to overcome any confusion that may confront the reader on this score. The question of level of difficulty has been answered as far as possible by including in most definitions both formal and discursive statements and entries. This policy serves the two-fold purpose of giving the reader both a "simple" explanation and a more rigorous definition at the same time that it lightens the general tone of the work for those who do not have an extensive mathematical background. The needs of this particular type of reader have also been served by including definitions of many of the more common mathematical terms encountered in present-day physics.

The terms defined in this book include laws,. relationships, equations, basic principles and concepts, as well as the most widely used instruments and apparatus. In short, this treatment comprises the terms both of pure science and of its applications. The fields covered include mechanics, heat and thermodynamics; low temperature physics; the properties of gases, liquids, and solids; acoustics; optics; electricity; electronics; nuclear physics; mathematical physics; and representative topics in relativity and a few other of the more advanced and specified fields. Further to serve the needs of the teacher, student and worker in the field of physics, as well as in related fields, a considerable number of terms have been included from the subject-areas bordering on physics, not only mathematics, but physical chemistry, applied electronics, applied electricity, etc. Obviously, all the terms in pure and applied physics cannot be defined adequately in a book, or for that matter in a library. The objective of editors and contributors has been the more modest one of providing a book useful as a general reference in physics, helpful even to the specialist in regions outside of his domain of specialized knowledge.

Further to facilitate the use of this book for reference purposes, a comprehensive plan of cross referencing has been devised. Wherever, in the definiton of a given term other words or expressions are used for which cross reference is necessary, those words or expressions are printed in bold-face type, so that the reader need only to turn to the corresponding entry to find the additional information he may need. This plan has proved most successful in other books, and it should increase materially the reference value of this Dictionary. When the term to which reference is made has more than one meaning, and possible confusion might result, the usage intended in the given case is designated by a corresponding bold-face number following the term in the original entry.

The general choice of subject matter has been, as might be expected, the question on which the largest number of arbitrary decisions has been necessary. The policy has been followed of including, wherever possible, all definitions which have been established or recommended by established groups. For such definitions the editor and contributors wish to express their deep indebtedness to the Acoustical Society of America, the Optical Society of America, the American Standards Association, the Institute of Radio Engineers, the National Research Council and other societies and organizations who have established clear statements of basic physical concepts and relationships and definitions of equipment used in pure and applied physics.

It is the hope of all who have worked on this book that it may contribute in some measure toward a widening of interest in the field of physics and toward an extension of the range of its applications. Whether the Dictionary will continue to fulfill this hope depends in a large part on the willingness of our readers to criticize our work and to suggest additions and improvements. With such aid, future issues of this Dictionary can achieve the highest standard of usefulness.

THE EDITORS

INTRODUCTION

UNITS AND DIMENSIONS

Policies Followed in This Volume

Since physics is a quantitative science, its definitions should be exact and unambiguous. It has become increasingly apparent during the last half century that exactness in the definitions of physical terms in general can be best achieved, and that ambiguity can be best avoided, if definitions are operational, i.e., if each definition indicates a process by which the defined quantity can be measured. The process of measurement specified by the definition need not be the one used practically, but the latter must always be reducible in principle to the former. For example, the *distance* between two points is defined as the number of times that a specified measuring rod must be successively applied along a straight line joining the two points in order to cover this line completely. It would hardly be practical to measure the distance from the earth to the moon by this process, but the method of triangulation, by which this distance is measured, may be shown to be equivalent to the successive application of a rod.

Every physical measurement involves the comparison of two quantities of the same nature, e.g., two lengths, two electrical currents, etc. The same results will be achieved by two different observers only if they have agreed to use the same standard as one of these quantities. To provide such standards, certain fundamental units have been established by custom, by national legislation, and by international agreement. The definitions of these fundamental units throughout this volume are consistent with the legal definitions or with accepted custom in the United States and in Great Britain. In a few cases, such as that of the inch, the two countries have definitions which do not agree precisely; in these instances both definitions are given.

The specification of a physical quantity must tell both what standards were used in the measurement and how the quantity compares with these standards. The quantity is therefore expressed as the product of a pure number, giving the latter piece of information, and a unit which gives the former. Two equal quantities may be represented by quite different numbers if they are measured in different units. Thus:

$$1 \text{ mile} = 5280 \text{ feet} = 1609 \text{ meters}.$$

All quantities which can be expressed in the same units are said to have the same physical dimensions. Thus two square miles and ten acres, while they are not equal, have the same dimensions, those of area, or of length squared.

The great majority of physical quantities can be measured in terms of derived units, which are defined in terms of the fundamental units. Thus *velocity* is defined as the time rate of change of position and is determined by a measurement of the change of position, i.e., a length, l, during a time interval, t. The average velocity during this interval is $v = l/t$. The unit of velocity is therefore a unit of length divided by a unit of time, such as feet/second, miles/hour, meters/minute, etc. When quantities measured in terms of derived units are given in this dictionary, their dimensions in terms of fundamental units are usually specified. To avoid the complexity that would result if every quantity were expressed directly in terms of fundamental units, the dimensions are often expressed in terms of derived units intermediate between those of the defined quantity and the primary standards. Thus the **Planck constant,** h, is given dimensions of erg seconds. The erg itself has the dimensions of force times distance, and force has the dimensions of a mass times a length divided by the square of a time. Hence, letting m, l, and t represent mass, length, and time, respectively, we find that the dimensions of the Planck constant are

$$[h] = [(ml/t^2)(l)(t)] = [ml^2/t],$$

or that it could be expressed in units of the gram centimeter squared per second.

Which physical quantities should be chosen as fundamental, or even how many should be chosen, are matters of choice and convenience. This is true because most physical laws express proportionalities, rather than equalities. As an example, we may consider the usual statement of the **Newton second law of motion,** that the acceleration, a, produced in a body of mass m by a force, f, is directly proportional to the force and inversely proportional to the mass. This law may be written as

$$a \propto f/m.$$

It is usually convenient to change this proportionality to an equation by the insertion of a constant of proportionality, K:

$$Ka = f/m.$$

This equation involves three physical quantities, a, f, and m. If all three of these are defined arbitrarily, either as fundamental units or in terms of derived units, the dimensions of K will be determined by the equation. On the other hand, any two of the physical quantities may be defined arbitrarily, and a further arbitrary choice may be made as to the dimensions and magnitude of K. The equation may then be used as a defining equation of the third quantity. Whether one or the other choice is convenient depends on the problem to which Newton's second law is being applied. The consequences of the various possible choices in this case are discussed below, in the section on Mechanical Units.

Each time that an arbitrary choice such as that just discussed is made, a new system of units is established. Each of these systems is self-consistent but the various systems are not necessarily consistent with each other. Whenever a choice exists as to the system of units in which a quantity may be defined, this Dictionary has either given two or more definitions, specifying the system in which each is appropriate, or has stated the dimensions of the quantity in such a way that the definition may be modified when a different system is employed. The inclusion of all of the hundred or more systems that have been used would have resulted in confusion, hence only a limited number of systems are accepted here. These systems are listed in the next few pages, and the relations among them are outlined.

Nearly all physical measurements can be reduced to the measurement of mechanical, thermal, or electromagnetic quantities, or to some combination of these. The systems of units which are used for each are treated below.

Mechanical Units

All mechanical measurements involve the motion of material bodies, described in terms of space and time coordinates. Hence length and time are almost universally chosen as fundamental quantities. The present standard of time is the *mean solar day,* defined as the average period between two successive transits of the sun across the meridian at any given spot on the earth's surface. The most commonly used unit of time is the *second,* defined as 1/86,400 part of a mean solar day.* Two independent length standards, the *meter* (M) and the *yard* (yd), are in common use. From the former is derived the *centimeter* (1 cm = 1 M/100) and from the latter, the *foot* (1 ft = 1 yd/3). The fundamental length units used in this volume will be limited to the meter, the centimeter, the inch, and the foot.†

In physics, chemistry, and electrical engineering, as well as in much of mechanical engineering, the commonly employed systems of mechanical units use length, mass, and time as fundamental quantities. These are known as *length-mass-time* systems. Three such systems, the *meter-kilogram-second* (MKS), the *centimeter-gram-second* (cgs), and the *foot-pound-second* (f lbm s) systems, are used in this volume. In all three systems the constant of proportionality in Newton's law is chosen as a dimensionless quantity of unit magnitude.

In structural engineering and in some mechanical engineering applications, forces play a more important part than do masses. Systems which use length, force, and time as fundamental units are therefore convenient. The only length-force-time system which is used here is the *foot-pound-second* system. The unit of force, the *pound (force)*, is defined as the weight of a pound mass at a point on the earth's surface at a point where the acceleration due to gravity is 32.174 ft/sec². In this system the unit of mass, the *slug,* is a derived unit, equal to 1/32.174 lbm. In order that confusion may not be caused by the use of the pound both as a unit of mass and as a unit of force, the pound (mass) is abbreviated as lbm, the pound (force) as lbf.

A third type of system defines both the mass and force as well as units of length and time. In such *mass-force-length-time systems,* the constant of proportionality in Newton's second law takes on dimensions and a non-unitary value. Two such systems, the lbm-lbf-ft-sec and the gm-gf-cm-sec system are employed here. The abbreviation gf is used to indicate a *gram (force)*, the unit of force, which is defined as the weight of a one-gram mass under the action of a gravitational acceleration of 980.665 cm/sec².

The more important units in each of the six systems and the relations among these units are shown in Table 1. As an example of the use of this and similar

* This is not a completely satisfactory definition, because tidal action is gradually slowing the rotation of the earth. It therefore seems probable that the second will be redefined in the near future, as a specified multiple of a period of vibration of some particular molecule, probably ammonia.

† Two slightly different definitions of the foot are in use in the United States. They disagree with each other and with the definition used in Great Britain by a few parts in a million. The British foot is defined as exactly one-third of an Imperial yard; the National Bureau of Standards and the U.S. Coast and Geodetic Survey define the foot as exactly 1200/3937 meter; the American Standards Association, B48.1, 1933 and 1947, defines the foot as exactly 0.3048 meter. The differences are significant only in refined measurements, the relative lengths of the three feet defined above being

0.914399 : 0.914402 : 0.914400.

It seems possible that both the meter and the yard may be redefined within a few years in terms of the wavelength of a particular spectral line, instead of as material standards.

tables, suppose that a moment of inertia is specified as 1050 gm cm², and that it is desired to express this quantity in the f lbm s system. The use of conversion factors from the table shows that

$$1050 \text{ gm cm}^2 \times \frac{2.205 \text{ lbm}}{1000 \text{ gm}} \times \frac{(3.281 \text{ ft})^2}{\text{M}^2} \times \frac{\text{M}^2}{(100 \text{ cm})^2} = 0.002492 \text{ lbm ft}^2.$$

Table 1. Relations among the Systems of Mechanical Units

Quantity	MKS System	Equivalents in Other Systems				
		cgs System	f lbm s System	f lbf s System	f lbm lbf s System	cm gm gf s System
Length	1 Meter	10^2 cm	3.281 ft	3.281 ft	3.281 ft	10^2 cm
Mass	1 Kilogram	10^3 gm	2.205 lbm	70.94 slug	2.205 lbm	10^3 gm
Density	1 K/M³	10^{-3} gm/cm³	$62.43(10)^{-3}$ lbm/ft³	2.009 slug/ft³	$62.43(10)^{-3}$ lbm/ft³	10^{-3} gm/cm³
Force	1 Newton	10^5 dyne	7.015 poundal	0.2180 lbf	0.2180 lbf	102.0 gf
Work (Energy)	1 Joule	10^7 erg	23.02 ft poundal	0.7153 ft lbf	0.7153 ft lbf	$1.020(10)^4$ gf cm
Power	1 Watt	10^7 erg/sec	23.02 ft poundal/sec	$1.301(10)^{-3}$ horse power	0.7153 ft lbf/sec	$1.020(10)^4$ gf cm/sec

Thermal Units

Thermal measurements involve, in addition to the mechanical quantities outlined above, the specification of temperature. Two temperature scales are in common use, both being defined in terms of measurements made with a mercury-in-glass thermometer and both having the freezing and boiling points of pure water at normal atmospheric pressure as fixed points. The *Celsius*, or *Centigrade*, scale is obtained if the freezing point is taken as zero degrees and the boiling point as 100 degrees.* The Fahrenheit scale is obtained if these points are taken as 32 degrees and 212 degrees, respectively. Thus the *degree Celsius* (°C) is the temperature difference which causes the mercury in a thermometer to expand by 0.01 as much as it expands between the freezing and boiling points. The *degree Fahrenheit* (°F) is defined similarly, and is therefore 5°C/9.

The original definitions of the Celsius and Fahrenheit scales would limit the measurement of temperature to the range in which the mercury-in-glass thermometer can be used. These scales are extended upward and downward with

* The definition given is that in common use at present. It is in close agreement with the recommendation of the International Union of Pure and Applied Physics in 1955 that the triple point of water (i.e., the temperature at which ice, water, and water vapor can exist in equilibrium) be defined as 273.16°K and be used as the basis of determining the size of one degree Kelvin. This recommendation would make the Kelvin scale fundamental, rather than the Celsius scale.

the help of the gas thermometer and of well established thermodynamic laws. The *Kelvin,* or *absolute,* temperature scale is based on the second law of thermodynamics, and is independent of the properties of any particular substance, except for the definition of the size of a degree. Its zero is the lower limit of temperature, which can be approached but never reached, and the size of a *degree Kelvin* (°K) is taken in such a way that the difference of the temperatures of the freezing and boiling points of water shall be 100°K. Careful measurements have demonstrated that the zero of the Celsius scale is at 273.16°K. The *Rankine* temperature scale is an absolute scale in which the degree (°R) is matched to the Fahrenheit thermometer.

Since heat is a form of energy, any of the mechanical units of energy, such as the erg, joule, or foot pound, may be used to measure quantity of heat. Other units, based on the thermal properties of water, had become well established before the first law of thermodynamics was enunciated. The use of these units persists, and several of them are used interchangeably with the mechanical units in this dictionary. The most widely accepted is the *calorie* (cal) which was originally defined as the heat necessary to raise the temperature of one gram of water through a temperature increase of one degree Celsius. This definition makes the unit depend on the initial temperature of the water, so the calorie has been redefined as equal to 4.1840 joules. The *kilocalorie* or *large calorie* (kcal) is exactly 1000 cal. The *British thermal unit* (BTU) is the heat required to raise the temperature of one pound of water through one degree Fahrenheit.

The four basic systems of thermal units employed in this volume are summarized in Table 2. Relations among derived units, such as those of specific heat,

TABLE 2. RELATIONS AMONG THERMAL UNITS

Quantity	MKS °C System	Equivalents in Other Systems			
		MKS °K System	cgs °K System	f lbm s °F System	f lbm s °R System
Temperature difference	1°C	1°K	1°K	1.80°F	1.80°R
Temperature	x°C	(273.16 + x)°K	(273.16 + x)°K	(32 + 9x/5)°F	(491.7 + 9x/5)°F
Energy	1 joule = 0.2390 cal	1 joule	$(10)^7$ erg	$9.478(10)^{-4}$ BTU 0.7153 ft lbf	$9.478(10)^{-4}$ BTU

entropy, etc., may be obtained by methods identical with that outlined in connection with Table 1. For example:

$$\frac{0.0235 \text{ BTU}}{°\text{F}} = \frac{0.0235 \text{ BTU}}{°\text{F}} \times \frac{1 \text{ joule}}{9.478(10)^{-4} \text{ BTU}} \times \frac{1.80°\text{F}}{1°\text{K}} = \frac{44.6 \text{ joule}}{°\text{K}}.$$

Electromagnetic Units

At least eight or ten different systems of electrical and magnetic units are in common use. Each of these is based on a particular choice of a constant of proportionality in an experimentally verified physical law. Some systems start with Coulomb's law, which states that the force, f, between two electrical charges, q_1 and q_2, separated by a distance r in empty space is directly proportional to the product of the charges and inversely proportional to the square of the distance between them, i.e.:

$$r = K_e q_1 q_2 r^2,$$

where K_e is a constant that may be chosen for convenience. Such systems are known as electrostatic systems. The choice of K_e as unity and dimensionless, together with the use of the dyne and the centimeter as units of force and length, leads to the *cgs electrostatic system* in which the unit of charge, the *statcoulomb,* is the charge which repels an exactly similar charge, separated from it by one centimeter *in vacuo,* with a force of one dyne. This system is frequently called the esu system. Another choice, which is sometimes convenient, takes K_e as a dimensionless constant equal to $1/4\pi$. This leads to the *rationalized cgs electrostatic* system. In either of the two systems, charge has the dimensions of dyne$^{1/2}$cm, equivalent to cm$^{3/2}$gm$^{1/2}$sec^{-1}. All other electrical quantities also have identical dimensions in the two systems, although the sizes of their units differ. In order that ambiguity may be avoided, all quantities stated in esu in this dictionary are given values consistent with the unrationalized system and all formulae involving esu are written in the form appropriate to that system.

In distinction to the electrostatic systems are the *electromagnetic systems* (emu systems), which start with the law of attraction between currents. If two currents of magnitudes I_1 and I_2 flow in long parallel wires, separated by a distance d *in vacuo,* they attract each other with a force per unit length, f_l, given by

$$f_l = K_m I_1 I_2 / d.$$

Here the constant of proportionality, K_m, may be chosen quite arbitrarily. The *cgs emu system* is based on the dyne and the centimeter as units of force and length and on the choice of K_m as a dimensionless constant of magnitude two. The emu of current, the *abampere,* then has the dimensions of dyne$^{1/2}$, or cm$^{1/2}$gm$^{1/2}$sec^{-1}.

The emu of charge, the *abcoulomb,* is defined as the charge which passes a given surface in one second if a steady current of one abampere flows across the surface. Its dimensions are therefore cm$^{1/2}$gm$^{1/2}$, which differ from the dimensions of the statcoulomb by a factor which has the dimensions of a speed. This relationship is connected with the fact that the ratio $2K_e/K_m$ must have the value of the square of the speed of light in any consistent system of units. It follows further that

$$1 \text{ abcoulomb} = 2.998(10)^{10} \text{ statcoulomb},$$

the speed of light in vacuo being $2.998(10)^{10}$ cm/sec.

A *rationalized emu* system, in which K_m is taken as $1/2\pi$, has also been developed, but it is not used in this volume.

The electrostatic system is convenient for problems in which the principal equations may be deduced from Coulomb's law. Similarly, the electromagnetic system is convenient for problems involving the interactions between currents. In many physical problems, both electrical and magnetic interactions take place. Both systems suffer from certain inconveniences under these circumstances, and the *Gaussian* system of units has, as a result, gained wide popularity. In this system, magnetic quantities, such as magnetic field strength and magnetic flux density, are expressed in emu, while electric field strength, charge, and current are expressed in esu. To maintain self-consistency, it is essential that a factor c, the speed of light, be introduced into many of the equations which describe electromagnetic phenomena. *It is our practice, whenever confusion might otherwise arise, to state equations appropriate both to the simple systems (esu, emu, etc.) and to the mixed Gaussian system.* Whenever the factor c occurs in such equations, it is the speed of light *in vacuo*, having the dimensions of cm/sec, not a pure number. A *rationalized Gaussian* system is sometimes employed, but it is not used in this volume.

In all of the systems discussed thus far, cgs mechanical units have been employed. New systems of electrical units evolve if other sets of mechanical units are substituted. Only two such systems, both based on the mks mechanical units, have found wide acceptance. Of these two, only the *rationalized mksa* system is used here. The arbitrary choice which leads to this system is that of the unit of current. The *absolute ampere* is defined as exactly one-tenth of an abampere. With this choice, and with the newton and the meter as the units of force and length, the two constants which were chosen arbitrarily in the esu and emu systems are determined and have dimensions. They become:

$$K_e = 8.986(10)^9\ km^3s^{-4}a^2,$$

and

$$K_m = 2.000(10)^{-7}\ kms^{-2}a^2.$$

One virtue of the mksa system is that nearly all of the electrical quantities expressed in it coincide closely with the *practical system* of units which grew up during the nineteenth century. Thus the volt, the ampere, the henry, the farad, and the ohm are all units in the mksa system. In fact, the legal electrical units have been fixed by international agreement since 1950 as the absolute mksa units. Prior to that time, the *International system* of electrical units had been used. This system had been intended to coincide with the absolute system, but had been defined in terms of fixed standards, which are slightly in error. There are therefore small differences between the two sets of electrical quantities, of the order of a few parts in ten thousand. Because many quantities stated in the literature are expressed in international units, these obsolescent definitions are included here.

One more remark needs to be made in regard to the dimensions of certain electromagnetic units. Two electrical quantities, the field strength **E** and the displacement **D**, are closely related, as are two magnetic quantities, the field strength **H** and the flux density **B** In the electrostatic system, **E** and **D** have the same dimensions and are identical in magnitude in empty space; in the electromagnetic system, **H** and **B** have a corresponding relation Thus in air, the electrical properties of which are practically those of empty space, the flux density is identical with the magnetic field strength if both are expressed in emu. The old unit of field strength, the *gauss*, has therefore been used to denote both **H** and **B**. In an attempt to avoid confusion, the name of the emu unit of **H** was changed to the *oersted* about 20 years ago. The gauss had become so well established, however, that it is still used, and its meaning (either oersted or maxwell per square cm) must be judged from context.

The relations among the five systems of electrical units which we employ are displayed in Table 3.

TABLE 3. RELATIONS AMONG THE SYSTEMS OF ELECTRICAL AND MAGNETIC UNITS

(The dimensions of the various quantities are shown in square brackets)

Quantity	mksa (Absolute) System	Equivalents in Other Systems			
		Old International System	cgs esu System	cgs emu System	Gaussian System
Permittivity of empty space (ϵ_0)	8 855(10)$^{-12}$ Farad/M [$m^{-3}k^{-1}s^4a^2$]	8.859(10)$^{-12}$ Int. Farad/M	1 [Dimensionless]	1.1126(10)$^{-21}$ [$cm^{-2}S^2$]	1 [Dimensionless]
Permeability of empty space μ_0	1 2566(10)$^{-6}$ Henry/M [$mks^{-2}a^{-2}$]	1.2560(10)$^{-6}$ Int. Henry/M	1.1126(10)$^{-21}$ [$cm^{-2}S^2$]	1 [Dimensionless]	1 [Dimensionless]
Charge (Q)	1 Coulomb [sa]	1.000165 Int. Coulomb	2.998(10)^9 Statcoulomb [$cm^{3/2}gm^{1/2}s^{-1}$]	0.1 Abcoulomb [$cm^{1/2}gm^{1/2}$]	2.998(10)^9 Statcoulomb [$cm^{3/2}gm^{1/2}s^{-1}$]
Potential difference (V)	1 Volt [$m^2ks^{-3}a^{-1}$]	0.999670 Int. Volt	3.336(10)$^{-2}$ Statvolt [$cm^{1/2}gm^{1/2}s^{-1}$]	(10)^8 Abvolt [$cm^{3/2}gm^{1/2}s^{-2}$]	3.336(10)$^{-2}$ Statvolt [$cm^{1/2}gm^{1/2}s^{-1}$]
Current (I)	1 Ampere [a]	1.000165 Int. Ampere	2.998(10)^9 Statampere [$cm^{3/2}gm^{1/2}s^{-2}$]	0.1 Abampere [$cm^{1/2}gm^{1/2}s^{-1}$]	2.998(10)^9 Statampere [$cm^{3/2}gm^{1/2}s^{-2}$]
Resistance (R)	1 Ohm [$m^2ks^{-3}a^{-2}$]	0.999505 Int. Ohm	1.1126(10)$^{-12}$ Statohm [$cm^{-1}s$]	(10)^9 Abohm [cms^{-1}]	1.1126(10)$^{-12}$ Statohm [$cm^{-1}s$]
Electric displacement (D)	1 Coulomb/M^2 [$m^{-2}sa$]	1.000165 Int. Coulomb/M^2	2.998(10)^5 Statcoulomb/cm^2 [$cm^{-1/2}gm^{1/2}s^{-1}$]	(10)$^{-5}$ Abcoulomb/cm^2 [$cm^{-3/2}gm^{1/2}$]	2.998(10)^5 Statcoulomb/cm^2 [$cm^{-1/2}gm^{1/2}s^{-1}$]
Capacitance (C)	1 Farad [$m^{-2}k^{-1}s^4a^2$]	1.000495 Int. Farad	8.988(10)^{11} cm [cm]	(10)$^{-9}$ Abfarad [$cm^{-1}s^2$]	8.988(10)^{11} cm [cm]
Magnetic dipole moment	1 Ampere M^2 [m^2a]	1.000165 Int. Ampere M^2	3.336(10)$^{-6}$ Statmaxwell/cm [$cm^{-1/2}gm^{1/2}$]	(10)^5 Maxwell/cm [$cm^{1/2}gm^{1/2}s^{-1}$]	(10)^5 Maxwell/cm [$cm^{1/2}gm^{1/2}s^{-1}$]
Magnetic field strength (H)	1 Ampere turn/M [$m^{-1}a$]	1.000165 Int. Ampere turn/M	3.767(10)^8 Statoersted [$cm^{1/2}gm^{1/2}s^{-2}$]	1.257(10)$^{-2}$ Oersted [$cm^{-1/2}gm^{1/2}s^{-1}$]	1.257(10)$^{-2}$ Oersted [$cm^{-1/2}gm^{1/2}s^{-1}$]
Magnetic flux density (B)	1 Weber/M^2 [$ks^{-2}a^{-1}$]	0.999670 Int. volt S/M^2	3.336(10)$^{-7}$ Statmaxwell/cm^2 [$cm^{-3/2}gm^{1/2}$]	(10)^4 Maxwell/cm^2 [$cm^{-1/2}gm^{1/2}s^{-1}$]	(10)^4 Gauss [$cm^{-1/2}gm^{1/2}s^{-1}$]
Inductance (L)	1 Henry [$m^2ks^{-2}a^{-2}$]	0.999505 Int. Henry	1.1126(10)$^{-12}$ Stathenry [$cm^{-1}s^2$]	(10)^9 cm [cm]	(10)^9 cm [cm]
Power	1 Watt [m^2ks^{-3}]	0.999835 Int. Watt	(10)^7 erg/s [cm^2gms^{-3}]	(10)^7 erg/s [cm^2gms^{-3}]	(10)^7 erg/s [cm^2gms^{-3}]

Units Not Included in Absolute Systems

Although nearly all physical measurements, from those of the dimensions of the universe to those involving nuclei of atoms, *can be* expressed in terms of the mechanical, thermal, and electromagnetic systems discussed above, many physical quantities *are* expressed in terms not reducible to any of the systems given. During the early development of many parts of physics, measurements of the relative properties of various substances were all that were possible or required. Hence terms like specific gravity, specific heat, candle power, and curie have come into the literature of the subject. As the art of measurement progresses, such terms are usually redefined in such a way that they acquire absolute meanings. It has been our practice to give both definitions of terms of this type, with some indication of when the change in meaning took place.

Many special systems of units are convenient for particular calculations. Thus, many atomic calculations are facilitated if the electronic charge, the radius of the lowest Bohr hydrogen orbit, and mass of the electron are taken as fundamental units of charge, length, and mass, respectively. Whenever units of this type are used in this dictionary, they are expressed in terms which allow cross reference to be made to the quantities involved, hence they can be converted into absolute units.

A

A. (1) Linear acceleration (a). (2) Mean sound absorption coefficient (a). (3) Element argon (A). (4) Angstrom unit (A or Å). (5) First van der Waals constant (a). (6) Chemical activity (a). (7) Accommodation coefficient (a). (8) Amplification of amplifier (A). (9) Amplitude (A). (10) Refracting angle of prism (A). (11) Area (A). (12) Specific rotation of light $|a|$. (13) Free energy, Helmholtz, which is also known as isothermal work function, total (A), per unit mass (a), per mole (a, A or A_m). (14) Factor in Richardson-Dushman equation (A). (15) Width of slit (transparent portion) (a). (16) Atomic weight (A). (17) First Couchy constant (A). (18) Strength of simple acoustic source (A). (19) Magnetic vector potential (A). (20) Bohr radius (a_1). (21) Radius of acoustical tube, disc or membrane (a).

A+, A−. Terminal markings for sources of filament voltages in electronic equipment. (See **A supply.**)

A BATTERY. Power source for **filaments** in battery-operated electronic equipment.

A SUPPLY. The source of the heating current for the cathode of an electronic tube. In the early days of radio the various voltages needed to operate a receiver were obtained from batteries, called A, B and C batteries, supplying the filament, plate and grid voltages respectively. These letter designations have carried over to the present-day sources, although the voltages are usually obtained now from an a-c source, either directly as in the case of the A supply or indirectly for B and C voltages.

AB-. A prefix attached to the names of the practical electrical units to indicate the corresponding unit in the cgs electromagnetic system (emu), e.g., abampere, abvolt.

AB PACK. A combined package of **A and B batteries.**

ABAMPERE. The cgs **electromagnetic unit** of current. It is that current which, when flowing in straight parallel wires 1 cm apart in free space, will produce a force of 2 dynes per cm length on each wire. One abampere is ten amperes.

ABBE CONDENSER. A compound **lens** used for directing light through the object of a compound **microscope.** All the light enters the object at an angle with the axis of the microscope.

ABBE NUMBER. The reciprocal of the **dispersive power** of a material.

ABBE REFRACTOMETER. See **refractometer, Abbe.**

ABBE SINE CONDITION. The relationship $ny \sin \theta = n'y' \sin \theta'$, where n, n' are indices of refraction, y, y' are distances from optical axis, and θ, θ' are angles light rays make with the optical axis. A failure of an optical surface to satisfy the sine condition is a measure of the **coma** of the surface.

ABBE THEORY OF THE RESOLUTION OF A MICROSCOPE. A theory relating the **resolution** of the instrument to the wavelength of the light and the **aperture** of the instrument.

ABC. Abbreviation for automatic brightness control; automatic bass control.

ABEL EQUATION. When a particle falls on a smooth curve, $s = s(z)$ in a vertical plane from $z = z_0$ to $z = z$, the time of descent is

$$t(z_0) = \frac{1}{\sqrt{2g}} \int_0^s \frac{s'(z)}{\sqrt{z_0 - z}}\, dz$$

where g is the acceleration of gravity. Abel's problem is to find a curve for which the time of descent is a given function of z, $t(z_0) = f(z_0)$. The result is

$$f(z_0) = \int_0^{z_0} \frac{\phi(z)}{\sqrt{z_0 - z}}\, dz$$

where

$$\phi(z) = -\frac{s'(z)}{\sqrt{2g}} > 0.$$

It is a **Volterra integral equation** of the first kind.

ABELIAN GROUP. A commutative group, thus $AB = BA$ where A, B are any two elements contained in it. A simple example is the **cyclic group** of order n.

ABERRATION, ANGLE OF. See **aberration of light, Bradley.**

ABERRATION(S), FIVE GEOMETRICAL. (1) **Spherical Aberration.** (2) **Coma.** (3) **Astigmatism.** (4) **Curvature of Field.** (5) **Distortion.** Also called the "third-order" aberrations and first comprehensively analysed by Von Seidel.

ABERRATION, LEAST CIRCLE OF. The area of minimum cross section of the rays from an optical system with **spherical aberration.**

ABERRATION OF LIGHT (BRADLEY). The apparent displacement of a star due to the motion of the earth in its orbit. Maximum value about 20.5 seconds of arc when the star is viewed normal to the velocity of the earth. Distinct from **parallax.**

ABERRATION, OPTICAL. The failure of an optical system to form an image of a point as a point, of a straight line as a straight line, and of an angle as an equal angle. (See **spherical aberration, astigmatism, coma, curvature of field, distortion** (of the image), and **chromatic aberration.**)

ABNEY COLORIMETER. See **colorimeter, Abney.**

ABNEY EFFECT. A shift in **hue** which is the result of a variation in **purity** and, therefore, in **saturation.** The Abney effect may be represented by **chromaticity loci,** of specified **luminance,** with the **hue** and **brightness** constant, when **purity** and, therefore, **saturation** are varied. It is a relationship, of psychophysical nature, between psychophysical specifications and color sensation attributes.

ABNEY MOUNTING. A method for mounting a **grating,** plateholder and **slit** on a **Rowland circle** and moving only the slit to observe different parts of the spectrum.

ABNORMAL GLOW. In a **glow-discharge** device, the flow of current equal or greater than the magnitude which causes the cathode to be completely covered with glow.

ABNORMAL REFLECTIONS. Ionospheric reflections of radiowaves at frequencies higher than the **critical frequency** of the layer. Sometimes referred to as sporadic reflections.

ABRAHAM THEORY OF THE ELECTRON. Model of the electron as a rigid spherical ball of charge, the mass being regarded as of purely electromagnetic origin (1903). Yields an incorrect expression for the variation of mass with velocity, and abandoned when the predictions of special relativity theory (see **relativity theory, special**) were confirmed.

ABSCISSA. The horizontal coordinate of a point in a two-dimensional system, commonly rectangular Cartesian, and usually designated by x. Together with the **ordinate** it locates the position of the point in a plane.

ABSOLUTE FUTURE OF AN EVENT. All events which could be reached by a signal emitted at the event and moving with velocity less than or equal to that of light in a vacuum.

ABSOLUTE HUMIDITY. See **humidity, absolute.**

ABSOLUTE PAST OF AN EVENT. All events from which a signal, moving with velocity less than or equal to that of light in a vacuum, could be emitted to reach the event in question.

ABSOLUTE SPACE-TIME. A fundamental concept underlying **Newtonian mechanics** is that there exists a preferred reference system to which all measurements should be referred. This is known as absolute space-time. The assumption of such a system is replaced in **relativistic mechanics** by the principle of equivalence. (See **equivalence, principle of.**)

ABSOLUTE TEMPERATURE SCALE. See **temperature scale, absolute.**

ABSOLUTE UNITS. Any set of units defined in terms of fundamental (arbitrary) units of mass, length, and time by connecting physical equations. Compare **international units.** (**Cgs electrostatic, cgs electromagnetic,** and **MKSA units** are absolute units.)

ABSOLUTE ZERO. The temperature at which a system would undergo a reversible **isothermal** process without transfer of heat. This is the temperature at which the volume of an ideal gas would become zero. The value calculated from the limiting value of the coefficient of expansion of various real gases is −273.16°C.

ABSORBANCE. The common logarithm of the **absorptance.** It may be applied to the total radiation, the visible radiation or to a particular part of the spectrum (spectral absorbance).

ABSORBANCY. The common logarithm of the reciprocal of the **transmittancy.**

ABSORBED DOSE. The International Commission on Radiological Units (July, 1953) in its revised recommendations, established the "absorbed dose of any ionizing radiation as the amount of energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest. It is expressed in **rads.**"

ABSORBED DOSE, DETERMINATION OF. The International Commission on Radiological Units recommended (July, 1953): "Since the calorimetric methods of determining absorbed doses are not usually practicable, ionization methods are generally employed. The quantity which must be measured is the ionization produced in a gas by the same flow of corpuscular radiation as exists in the material under consideration. The energy, E_m, imparted to unit mass of the material is then essentially related to the ionization per unit mass of gas, J_m, by the equation

$$E_m = WsJ_m$$

where W is the average energy expended by the ionizing particles per ion-pair formed in the gas, and s is the ratio of the mass stopping power of the material to that of the gas. Since the calculation of the absorbed dose from measurements of ionization requires a knowledge of the parameters W and s as well as variables characterizing the radiation and the irradiated material, it is recommended that tables of the best available data be prepared and held under continual review."

ABSORBED DOSE, INTEGRAL. The integration of the energy absorbed throughout a given region of interest. The unit is the **gram-rad.**

ABSORBENT. A substance, material, or solution able to **imbibe,** or "attract into its mass," or trap liquids or gases, commonly to remove them from a given medium or region.

ABSORBER. In general, a medium, substance or functional part that takes up matter or energy. Specifically a body of material introduced between a source of radiation and a detector to (1) determine the energy or nature of the radiation; (2) to shield the detector from the radiation; or (3) to transmit selectively one or more components of the radiation, so that the radiation undergoes a change in its energy spectrum. Such an absorber may function through a combination of processes of true **absorption, scattering** and **slowing-down.**

ABSORPTANCE. The ratio of the **radiant flux** absorbed in a body of material to the radiant flux incident upon it. Commonly, the material is in the form of a parallel-sided plate and the radiation in the form of a parallel beam incident normally on the surface of the plate. Properly, transmission measurements should be corrected for reflection and scattering losses to determine the absorptance. The absorptance may be measured for any radiation, for visible light (optical absorptance) or as a function of the wavelength of the radiation (spectral absorptance).

ABSORPTIOMETER. A device equipped with a simple dispersing system or with filters by which a determination may be made of the concentration of substances by their absorption of nearly monochromatic radiation at a selected wavelength. Note that this is the third meaning given under **colorimeter.**

ABSORPTION. (1) The process whereby the total number of particles emerging from a body of matter is reduced relative to the number entering, as a result of interaction of the particles with the body. (2) The process whereby the kinetic energy of a particle is reduced while traversing a body of matter. This loss of kinetic energy of corpuscular radiation is also referred to as moderation, slowing, or stopping. (3) The process whereby some or all of the energy of **sound waves** or **electromagnetic radiations** is transferred to the substance on which they are incident or which they traverse. (4) The process of "attraction into the mass" of one substance by another so that the **absorbed substance** disappears physically.

ABSORPTION BAND. A region of the **absorption spectrum** in which the **absorptivity** passes through a maximum or inflection.

ABSORPTION CELL. A glass vessel used to hold liquids for the determination of their **absorption spectra.**

ABSORPTION COEFFICIENT. (1) For the absorption of one substance or phase in another, as in the absorption of a gas in a liquid, the absorption coefficient is the volume of gas dissolved by a specified volume of solvent; thus a widely-used coefficient is the quantity α in the expression $\alpha = V_0/Vp$, where V_0 is the volume of gas reduced to standard conditions, V is the volume of liquid and p is the partial pressure of the gas. (2) In the case of sound, the absorption coefficient (which is also called the acoustical absorptivity) is defined as the fraction of the incident **sound energy** absorbed by a surface or medium, the surface being considered part of an infinite area. (3) In the most general use of the term absorption coefficient, applied to electromagnetic radiation and atomic and sub-atomic particles, it is a measure of the rate of decrease in intensity of a beam of photons or particles in its passage through a particular substance. One complication in the statement of the absorption coefficient arises from the cause of the decrease in intensity When light, x-rays, or other electromagnetic radiation enters a body of matter, it experiences in general two types of attenuation. Part of it is subjected to **scattering,** being reflected in all directions, while another portion is absorbed by being converted into other forms of energy. The scattered radiation may still be effective in the same ways as the original, but the absorbed portion ceases to exist as radiation or is re-emitted as secondary radiation. Strictly therefore, we have to distinguish the true absorption coefficient from the **scattering coefficient**; but for practical purposes it is sometimes convenient to add them together as the total attenuation or **extinction coefficient.**

Accurate measurements upon radiation which has traversed various thicknesses of matter has established that any infinitely-thin layer perpendicular to the direction of propagation cuts down the flux density by a fraction of its value proportional to the thickness of the layer, whence by integration (when permissible) the flux density after having penetrated the medium to a distance x is

$$I = I_0 e^{-ax};$$

in which I_0 is the flux density just after entrance into the medium (i.e. for $x = 0$). (See the **Bouguer law.**) For true absorption, the constant a is the absorption coefficient. For scattering, which obeys the same law, a is the scattering coefficient. And for the total attenuation, including both, it is the **extinction coefficient,** which is the sum of the absorption and the scattering coefficients.

The absorption coefficient may be computed for total radiation which enters the absorbing material, for the visible luminous radiation or as a function of wavelength, being in that case, the **spectral absorption coefficient.** The absorption coefficient divided by the density of the absorbing medium is called the mass absorption coefficient. (See **absorption coefficient, mass** and other qualified terms.)

ABSORPTION COEFFICIENT, AMPLITUDE. The absolute value of the natural logarithm of the ratio of the peak sound pressure (see **sound pressure, peak**) or particle velocity (see **velocity, particle**) at two points (along the path of the sound beam) a unit distance apart. It is usually measured in nepers/cm. In a plane wave, if ξ_1 is the maximum particle velocity at x_1 and ξ_2 is that at x_2, measured in the direction of propagation of the wave, the amplitude absorption coefficient α is given by

$$\alpha = \frac{1}{x_2 - x_1} \ln \frac{\xi_1}{\xi_2}.$$

ABSORPTION COEFFICIENT, ATOMIC. The atomic absorption coefficient of an element is the fractional decrease in intensity, per number of atoms per unit area; it is equal to the linear absorption coefficient (see **absorption coefficient, linear**) divided by the number of atoms per unit volume, or to the mass absorption coefficient (see **absorption coefficient, mass**) divided by the number of atoms per unit mass. If the medium consists of only one nuclide, the atomic absorption coefficient μ_a is equivalent to the total **cross section** for the radiation in question.

ABSORPTION COEFFICIENT, LINEAR. The linear absorption coefficient μ_l is the fractional decrease in intensity per unit distance traversed, or $\mu_l = -dI/Idx$, where I is the intensity of the beam and x is the distance traversed.

ABSORPTION COEFFICIENT, MASS. The mass **absorption coefficient** μ_m is the fractional decrease in intensity per unit surface density. For a substance of density ρ, μ_m is equal to μ_l/ρ, and hence is independent of the density.

ABSORPTION CURVE. The graphical relationship between thickness of absorbing material and intensity of transmitted radiation.

ABSORPTION DISCONTINUITY. A discontinuity appearing in the **absorption coefficient** of a substance for a particular type of radiation when expressed as a function of the energy (or frequency or wavelength) of this radiation. An absorption discontinuity is often associated with anomalies in other variables such as the **refractive index.**

ABSORPTION EDGE. The wavelength corresponding to an abrupt discontinuity in the intensity of an absorption spectrum, notably an x-ray absorption spectrum, which gives the appearance of a sharp edge in the photograph of such a spectrum.

ABSORPTION, EXPONENTIAL. The removal of photons or particles from a beam, as it travels through matter, according to the exponential relationship:

$$I = I_0 e^{-\mu x}$$

where I is the intensity of the beam after traveling through a thickness of matter x, I_0 is the initial intensity of the beam, μ is the appropriate absorption coefficient, and e is the natural logarithmic base.

ABSORPTION FACTOR. In any absorbing system, especially in the case of absorption of **radiation,** the ratio of the total unabsorbed radiation to the total incident radiation, or to the total radiation transmitted in the absence of the absorbing substance. (Cf. **absorptivity.**)

ABSORPTION INDEX. In traversing perpendicularly a thin layer of absorbing material of thickness d, the amplitude of vibration of light of wavelength λ decreases in the ratio

$$1 : e^{-2\pi\kappa \frac{d}{\lambda}}$$

where κ is the absorption index. In consequence, the ratio of the intensities of the emerging and incident light is given by

$$I_1/I_0 = e^{-4\pi\kappa \frac{d}{\lambda}}.$$

For an absorbing layer of thickness λ this ratio becomes

$$I_1/I_0 = e^{-4\pi\kappa}.$$

The **absorption coefficient** "a" is given by

$$I_1/I_0 = e^{-ad}$$

hence

$$a = 4\pi\kappa/\lambda.$$

ABSORPTION LIMIT. See **absorption discontinuity.**

ABSORPTION LOSS, ACOUSTIC. That part of the **transmission loss** due to the dissipation or conversion of sound energy into other forms of energy (e.g., heat), either within the medium or attendant upon a reflection.

ABSORPTION MESH. A **filter element** used in a **waveguide** system to absorb spurious components of electromagnetic energy.

ABSORPTION MODULATION. See **modulation, absorption.**

ABSORPTION, SELECTIVE. **Absorption** which varies in amount with wavelength.

ABSORPTION SPECTRUM. See **spectrum, absorption.**

ABSORPTION TRAP. See **trap.**

ABSORPTIVE POWER, OPTICAL. The same as **absorptivity.**

ABSORPTIVITY, OPTICAL. The **transmissivity** subtracted from unity.

ABUNDANCE RATIO. The proportions of the various **isotopes** making up a particular specimen of an **element.**

ABVOLT. The **cgs electromagnetic unit** of **potential difference** and **electromotive** force. It is the potential difference that must exist between two points in order that one erg of work be done when one abcoulomb of charge is moved from one point to the other. One abvolt is 10^{-8} volt.

A-C. See **alternating current.**

A-C BRIDGES. See **bridges.**