A DICTIONARY OF Scientific Units

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and
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FIFTH EDITION

A DICTIONARY OF
Scientific Units

Including dimensionless numbers and scales

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Preface to the first edition

The intense specialization that occurs in science today has meant that scientists working in one field are often not familiar with the nomenclature used by their colleagues in other fields. This is particularly so in physics. This dictionary is designed to help overcome this difficulty by giving information about the units, dimensionless numbers and scales which have been used, or are still being used, throughout the world. Some four hundred entries are provided and these are supplemented by about five hundred references. The definition of each entry is given together with relevant historical facts. Where appropriate, some indication of the magnitude of each unit is included. Any scientific unit, which to the authors' knowledge has appeared in print, even if not universally adopted, has been listed. While it is too much to hope that there are no omissions, it is believed that there cannot be many and that this dictionary provides the most complete information of its kind available. The units are listed alphabetically and the references are numbered in sequence for each letter. In appendices are given a table of fundamental physical constants, details of standardization committees and conferences, a table of British and American weights and measures and conversion tables. The symbols and abbreviations used throughout the text are those recommended by the Institute of Physics and the Physical Society and by the British Standards Institution.

It is a pleasure to acknowledge the help given by numerous friends and colleagues and in particular that given by Dr J. R. Clarkson of the Royal South Hants Hospital; Mr C. H. Helmer of the Mechanical Engineering Department, Southampton University, Dr Peter Lane of the Iraq Petroleum Company; Miss D. M. Marshallsay of the Department of Economics, Southampton University; Mr R. E. Peroli of the Belfast Public Textile Testing House; Dr L. G. A. Sims, Professor of Electrical Engineering, Southampton University; Mr R. W. Watridge, the Southampton Borough analyst; Major H. W. H. West of the British Ceramic Research Association and by the Librarians and Staffs of the University and the Public Libraries at Southampton. Finally, we wish to thank Mrs H. G. Jerrard and Miss A. J. Tutte for typing the manuscript.

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1963

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Preface to the fifth edition

Since the publication of the fourth edition in 1980 advances in technology have led to more precise values of the fundamental physical constants and a movement towards definitions of the fundamental units of mass, length and time based on atomic parameters. More precise definitions of some other units such as the candela have been approved by the international committees. These changes, together with the definitions of several new units have been included in this edition, the text of which has been revised and which now contains over 850 units and dimensionless numbers.

The authors wish to thank all those who have helped in this latest compilation by suggestion and kindly criticism and Margaret Wainwright who has had the difficult and tedious task of typing, retyping and copying the fragmented parts that arise from a text revision. At the time of going to press we believe this book to provide the most complete and up-to-date information of its kind available.

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1985

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Introduction

All non-electrical physical quantities may be defined in terms of mass, length and time which are the three fundamental mechanical units. Electrical and magnetic quantities generally require four units of which three are mass, length and time and the fourth can be some electrical or magnetic quantity such as current, permeability or permittivity. It is sometimes convenient to introduce temperature as an independent unit ranking equally with length, time and mass but if it is recognized that heat is of the same nature as energy, temperature may be defined in terms of the three fundamental mechanical units. It would appear, then, that all physical quantities can be expressed in terms of four units. The measurement of mass, length and time dates back to the dawn of history, whereas electrical and magnetic phenomena were not considered quantitatively until the middle of the nineteenth century.

In principle, measurement is finding an expression for a quantity in terms of a ratio of the quantity concerned to a defined amount of the same quantity. The defined amount can be chosen in an arbitrary manner – e.g. the yard – or it can have its origin in some natural phenomenon, such as the metre, which can be defined in terms of the wavelength of a selected line of the krypton emission spectrum. The former type of units are called arbitrary, the latter natural. At present the fundamental units of length and time are natural units whereas that of mass is arbitrary. Natural units are, in theory at least, capable of being reproduced anywhere at any time, whereas arbitrary units require the presence of a prototype. Once an arbitrary unit is defined it does not alter and neither would a natural unit once its real value is known, but in practice natural units have to be changed in size every time a discrepancy is found in the natural measurement from which the unit is derived. An example of this is given by the kilogram which was originally intended to be a natural unit representing the mass of a cubic decimetre of water. More accurate measurement at a later date showed the volume of water used was 1·00028 cubic decimetre, so the kilogram is a little too heavy. This could have been remedied by altering the mass of the kilogram, but it was decided to keep the mass unchanged and to make the kilogram an arbitrary unit which is called the International Prototype Kilogram.

In general, units should be of such a size that the quantity being measured can be expressed in convenient figures. Thus the expenditure of a modern state may be given in units of millions of pounds but the cash in a child's money box is better counted in pence. It sometimes happens that the choice of a unit is not suitable to cover all applications in which case the original unit is multiplied by a suitable power of ten to give a derived unit. For example the unit of length is the metre but it is often better to give the distance between two towns in kilometres (10^3 m) and the size of bacteria in micrometers (10^{-6} m). A measurement should always be expressed as a number followed by the name of the unit concerned so that the magnitude and description of the physical quantity concerned are conveyed to all who require to know them. A number without a unit is meaningless unless it be a recognized dimensionless number or a ratio. A unit should always be called by its recognized name.

Systems of units

Any system of units defined in terms of the fundamental units of mass, length and time form an absolute system of units. The principle of absolute units was first proposed by K. F. Gauss (1777–1855) in 1832[1]. In 1851[2], he and Weber drew up a set of units based on the millimetre, the milligram and the second. This is known as the Gaussian system. Twenty-two years later[3] the British Association adopted the metric system but used the centimetre, the gram and the second as the fundamental units; these are often called the CGS units. The metric system recommended today is the International, or SI, system. This is based on the metre, kilogram and second. Engineers throughout the English speaking world generally use the foot, pound, second units. The history of the fundamental units is given briefly by Sir Richard Glazebrook in the 1931 Guthrie Lecture[4] and in some detail by R. W. Smith in the National Bureau of Standards Circular 593 entitled the Federal Basis for Weights and Measures[5]. The definitions of the seven SI base units are given in the National Physical Laboratory publication entitled *The International System of Units* (1977).

Electrical and magnetic quantities generally require a fourth term for their complete definition. In the CGS electromagnetic system, the units of which are also called e.m.u. or abunits, the fourth term is permeability and its value is taken as unity if the medium be a vacuum. In the CGS electrostatic system, in which the units are called e.s.u. or statunits, the fourth term is permittivity and this is considered to be unity in a vacuum. In the MKS system the fourth term is the permeability of free space and this has a value of $4\pi \times 10^{-7}$ henry metre^{-1} or 10^{-7} henry metre^{-1} according to whether a rationalized or unrationalized system is used. In SI units it is the ampere.

Atomic system of units

This system of units was suggested by Hartree in 1927[6] to reduce the numerical work in problems involving the atom. The unit of charge e is the charge on the electron (160×10^{-21} coulomb), the unit of mass m is the rest mass of an electron (900×10^{-33} kg) and the unit of length a is the radius of the first Bohr orbit in the hydrogen atom (53×10^{-12} m). The unit of time is the reciprocal of the angular frequency $1/4\pi Rc$ (24×10^{-18} second), where R is Rydberg's constant and c the speed of light. The unit of action is $h/2\pi$, where h is Planck's constant. The unit of energy is $e^2/a^2 = 2Rhc$, which is the potential energy of unit charge situated at unit distance from a similar charge and which is also equal to twice the ionization energy of the hydrogen atom. Shull and Hall[7] suggest that since e^2/a^2 can be written as $4\pi^2 me^4/h^2$, this quantity should be used as a unit of energy which they call the hartree. Other somewhat similar systems of atomic units have been developed in the past 60 years one of the most recent being by McWeeny[8] who used the electronic charge, the Bohr radius, the unit of action and the permeability of free space as his base units.

British Imperial Units

The majority of countries in the British Commonwealth have used imperial units which are based on the pound, the yard and the second. The standards for the first two are kept in London, the imperial standard pound being equal to about 0·453 592 43 kg and the imperial standard yard to approximately 0·914 399 m. The Weights and Measures Act of 1963 removed the independent status of these two quantities which are now based on the kilogram and the metre, the pound being defined as exactly 0·453 592 37 kg and the yard to 0·9144 m precisely. The unit of time, the second, has always been the same in both systems and was redefined by the 13th CGPM (1968) as the duration of 9 192 631 770 periods of radiation corresponding to the transitions between two hyperfine levels in the ground state of the caesium 133 atom.

CGS, e.m.u., e.s.u., system of electrical units

The force F between two magnetic poles of strength m_1 and m_2 placed a distance d apart in a medium of permeability μ is given by $F = m_1 m_2/\mu d^2$. If F, μ and d be each unity and if $m_1 = m_2 = m$, then m_1 and m_2 are poles of unit strength. Units based on this definition of m are known as electromagnetic units (e.m.u.). The quantities defined by these units are generally of an inconvenient size for practical work, so units known as practical units are used. The latter may be obtained by multiplying the e.m. unit by a suitable conversion factor. In 1903[9] the prefix ab was suggested to denote the unit concerned is a CGS electromagnetic unit, thus 1 abvolt $= 10^{-8}$ practical volts, 1 abampere $= 10$ practical amperes. The suggestion met with little response at first but in recent years some authors have started using this notation[10].

The force F between two charges q_1 and q_2, a distance d apart in a medium of permittivity ε, is given by $F = q_1 q_2/\varepsilon d^2$. If F, ε and d be unity and if $q_1 = q_2 = q$, then q_1 and q_2 are unit charges. Electrostatic units (e.s.u.) are based on this value of q. Like the e.m. units electrostatic units are not of convenient size for practical work and are generally replaced by practical units for everyday electrical measurements. In recent years the prefix stat has sometimes been used to denote electrostatic units, thus 1 stat volt = 300 practical volts, 1 stat ampere = $(1/3) \times 10^{-9}$ ampere. This prefix is an abbreviation for abstat which was proposed for electrostatic units at the same time as ab was suggested for electromagnetic units.

Ab units and stat units are connected by the relationship $\mu\varepsilon = 1/c^2$, where c is the velocity of light in centimetres second^{-1}. Thus the ratio (ab unit/stat unit) for the primary units is equal to the velocity of light, or its reciprocal, viz. abampere/statampere $= c$ and abvolt/statvolt $= 1/c$. The ratio ab/stat for secondary units is obtained by considering each of the primary units concerned thus

$$\frac{\text{ab farad}}{\text{stat farad}} = \frac{\text{ab coulomb}}{\text{ab volt}} = \frac{\text{stat volt}}{\text{stat coulomb}} = c^2$$

The inconvenience of having three systems of electrical units, ab units, stat units and practical units has been overcome by the introduction of the metre, kilogram, second, ampere units (MKS). In this system, the practical units have the same value as the theoretical ones, which themselves require no modification for use in either electromagnetic or electrostatic problems.

Gravitational system of units

In these units the three fundamental quantities are the unit of weight, the unit of length and the unit of time[11]. In the British system these are the pound weight, the foot and the second. In the metric system the units are either the gram weight, the centimetre and the second (CGS) or the kilogram weight, the metre and the second (MKS or SI). In both systems the unit of weight is the fundamental unit of mass when weighed in a standard gravitational field for which the value of g, the acceleration due to gravity, is known. The International Commission of Weights and Measures agreed in 1901 that for gravitational units g should have a value of 32·1740 ft sec^{-2} or 980·665 cm sec^{-2}. Some 70 years later the 61st CIPM (1972) recommended that, whenever precision measurements involving gravitational forces have to be made, the relevant local value of g used should be that obtained from the International Gravity Standardization Network (IGNS–71).

Heaviside–Lorentz system of units

These are CGS units in which the force between two magnetic poles m_1 and m_2, a distance d apart in a medium of permeability μ is given as $m_1 m_2/4\pi\mu d^2$. An analogous equation $q_1 q_2/4\pi\varepsilon d^2$ gives the force between two charges q_1

and q_2 in a medium of permittivity ε. The Heaviside–Lorentz units were the earliest rationalized units; they were proposed by Heaviside[12] in 1883 and used by him in a classical paper on electrical theory published nine years later[13].

International system of units

See **SI units**, p. 7.

Kalantaroff units

These were proposed by P. Kalantaroff in 1929[14]. The fundamental quantities on which they are based are the metre, second, weber and unit charge. Some advantages are claimed for the units in electrical and magnetic calculations but for most physical problems they are too cumbersome. Thus mass is expressed as:

$$\text{charge weber metre}^{-2}\ \text{second}^{-1}.$$

Ludovici system of units

A system of units proposed in 1956[15] in which the fundamental quantities are the free space values of the gravitational constant, permeability, permittivity and charge. These values give a unit of length equal to $4{\cdot}88 \times 10^{-36}$ m and a unit of time equivalent to $16{\cdot}3 \times 10^{-45}$ second.

MKS system of electrical units

The CGS electromagnetic and electrostatic units are somewhat inconveneint when calculating certain electrical properties such as inductance and capacitance as certain factors involving powers of ten or the figures 3 and 9 have to be introduced to derive practical units from those obtained from theoretical considerations. As early as 1873 Clerk Maxwell[16] showed that practical electromagnetic units could be substituted directly in the fundamental theoretical equations if the unit of length were taken as the earth's quadrant (10^7 m), the unit of mass as 10^{-11} gram, the permeability of a vacuum μ_0 as unity and the unit of time as the second. Thirty years later G. Giorgi[17] pointed out that if the unit of length be taken as the metre, the unit of mass as the kilogram, μ_0 as $4\pi \times 10^{-7}$ and the unit of time remain unchanged as the second, then the practical units could be used directly in both the electromagnetic and the electrostatic systems. Furthermore, the introduction of 4π into the value of μ_0 meant that most of the electrical units would be rationalized, i.e. the factor 2π would occur if the system were cylindrically symmetrical and 4π if spherically symmetrical. A disadvantage of the Giorgi system is that the difference between magnetic induction (B) and field strength (H) can no longer be ignored as it is in the CGS system in cases where the permeability is unity, such as when the medium is air. Similarly the difference between the electric field (E) and the electric displacement (D) cannot be neglected as it is when the permittivity is unity.

The Giorgi or MKS system attracted little attention until about 1935[18] but after this interest in them increased and in 1948[19] the 9th International Conference on Weights and Measures adopted the MKS definition as their definition of the ampere and recommended the fourth unit in the rationalized MKS system be $4\pi \times 10^{-7}$ henry metre^{-1}, a term which is known as the permeability of free space. The ampere is now defined as the steady current which, when maintained in two parallel conductors of infinite length and of negligible cross-section one metre apart in a vacuum, produces between the conductors a force equal to 2×10^{-7} MKS units of force per metre length.

OASM units

A system of units proposed in 1945[20] in which the ohm, ampere, second and metre are the fundamental quantities.

SI units

The Système International d'Unités (designated SI in all languages) is a *redefinition* of the MKS system. The seven base units are the ampere, candela, kelvin, kilogram, metre, mole and second[21]. These are of convenient size for normal practical work and may be used to give a rationalized coherent system of units in which the magnitude of any physical quantity may be expressed. The units have been evolved over the years from the rationalized MKS units; six were finally approved by the 11th CGPM (1960) and the seventh, the mole, by the 14th CGPM (1972). By the mid-1970s they had been adopted as the legal units for trade in over 30 countries and have been recommended for use by scientists throughout the world. The advantages of the system are numerous, thus the Joule – which is the unit of energy – may be expressed either as newton × metre or watt × second and, in electrical and magnetic work, there is now no necessity to use special electrostatic and electromagnetic units with the resulting confusion when it is necessary to change from one to the other. Older scientists will probably find it difficult to accommodate themselves to the new system for many of the old familiar values have gone, e.g. density of water is now 1000 kg m^{-3} and the acceleration due to gravity is 9·81 m sec^{-2}. They may find some solace, however, in the loophole left open to them by the National Bureau of Standards which, while recommending the use of the SI system, finishes its exhortation by stating 'except when the use of these units would obviously impair communication or reduce the usefulness of a report to the primary recipients'.

Stroud system of units

These were devised by Professor W. Stroud of Leeds about 1880[22] to give engineers a set of absolute units based on the pound, the foot and the second and in which the distinction between mass and weight was emphasized. Stroud used capital letters for forces and small letters for masses, thus one Pound could accelerate one pound by 32 feet per second per second.

TMS units

These are a metric system based on the tonne, metre and second.

A

Abampere (abcoulomb, abfarad, abohm, abvolt)
The prefix ab- denotes the CGS electromagnetic system of units, e.g. abampere is the unit of current in the CGS system. (*See* **CGS units**, page 4.)

Abbe
A name suggested in 1973 for an SI unit of linear spatial frequency[1]; it has the dimensions of Hz m^{-1} and is named after Ernst Abbe (1840–1901) an eminent authority on optical instruments.

Acoustic comfort index (ACI)
An arbitrary unit suggested in 1951[2] to indicate the noise in the passenger cabin of an aircraft. The figure +100 represented ideal conditions, −100 was intolerable and zero indicated the noise was just tolerable.

Acoustic ohm
The acoustic ohm is the unit of acoustic impedance[3]. The acoustic impedance of a surface is defined as the ratio of the effective sound pressure averaged over the surface (i.e. pressure/area) to the effective volume velocity through it. This ratio is a complex number. Volume velocity is defined as the rate of flow of the medium perpendicular to the surface. A surface has an acoustic impedance of one ohm when unit effective pressure produces unit velocity across it. The CGS acoustic ohm has dimensions of dyne second cm^{-5}, whereas the dimensions of the MKS unit, called the MKS acoustic ohm[4], are newton second $metre^{-5}$. The baffle of a loudspeaker has generally an acoustic impedance of the order of several hundred MKS acoustic ohms. The idea of applying Kirchhoff's electrical circuit procedures to solve acoustical problems was suggested by Webster[5] as early as 1919 but the acoustic ohm was first used by Stewart[6] in 1926.

Acre
A unit of area equal to 4840 square yards. It was first defined in England in

the reign of Edward I (1272–1307) and is reputed to be the area which a yoke of oxen could plough in a day.

At one time Ireland and Scotland used a different acre from that employed in England, thus one English (Imperial) acre = 0·82 Scottish acres, = 0·62 Irish acres, = 0·78 Cunningham or Plantation acres; the last mentioned was used mainly in North East Ireland whereas elsewhere in that country areas were measured in Irish acres[7]. One acre = 0·40467 hectares.

Alfvèn number (Al)

A dimensionless number characterizing steady fluid flow past an obstacle in a uniform magnetic field parallel to the direction of flow. It has a partial analogy to the Mach number. The Alfvèn number is given by $vl(\rho\mu)^{1/2} B^{-1/2}$ where v is the velocity of flow, l is length, ρ is density, μ is permeability and B is magnetic flux density. It is named after H. Alfvèn, the Swedish astrophysicist, who introduced the term magnetohydrodynamics.

Amagat units

These are units of volume and density used in the study of the behaviour of gases under pressure. The unit of volume is taken as being the volume occupied by a gram mole of the gas at unit pressure and 273·16 K and thus for an ideal gas the Amagat volume is 22·4 litres. The Amagat density unit expresses the density of gas in gram moles per litre, one density unit being equal to 0·0446 gram mole litre^{-1} at unit pressure. For both units, unit pressure is taken as one standard atmosphere. The units are named after E. H. Amagat (1841–1915) who studied the effect of high pressures on gases. Amagat units have been used extensively in Holland since the time of J. D. van der Waals (1837–1923) but were not used in England until 1939[8].

American run

A unit used in the textile industry for describing the length per unit mass of a yarn. (*See* **Yarn counts.**)

Ampere (A)

The 9th Meeting of the International Weights and Measures Congress[9] in 1948 defined the ampere as the intensity of the constant current which, when maintained in two parallel straight conductors of infinite length and of negligible cross-section placed one metre apart in a vacuum, produced between them a force equal to 2×10^{-7} MKS units of force per metre length. This unit, known as the absolute or SI ampere, replaced the international ampere which had been defined in 1908. The international unit, which was basically similar to the ampere introduced at the first meeting of IEC in 1881, was defined as the unvarying current which deposited 0·00111800 grams of silver by electrolysis from a silver nitrate solution in one second[10]. It was