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HOW TO COPE WITH DIFFERENT SYSTEMS OF UNITS

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Fundamental units in the International System of Units (SI) are explained. The natural units used in high energy physics are described. Different systems used in electromagnetism (SI, esu, emu, Gaussian) are also discussed as well as the interconversion of equations written in either SI or Gaussian system.

INTRODUCTION

Physics is a fundamental science concerned with natural phenomena that occur in our universe. It is a science of measurement, experiment, and of systemization of the results of experiment. The scientific method furnishes the fundamental basis of physics as well as of other sciences. The main objective of scientific approach is to develop physical theories based on model and on fundamental laws that will predict the results of some experiments. Physics is a quantitative science concerned with relations between careful measurements of well-defined quantities. In physics measurement comes first.

The definition of a physical quantity is the description of the operational behaviour for measuring the quantity. A definition of this type is an operational definition.

Let us consider the definition of a familiar physical quantity:average speed, e.g. the average speed of a motor car is 100 metres/hour. We define the average speed, a physical quantity, as the distance travelled (100 metres) divided by the time elapsed (3600 seconds).

$$\text{Average Speed} = \text{length/time} = (100 \text{ metres})/(3600 \text{ seconds})$$

$$= 2.78 \times 10^{-2} \text{ m/s}$$

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In the above calculation we divided two numbers to obtain the number 2.78 x 10^{-2}; we divided two units to obtain the new derived unit. The magnitude of the average speed is 2.78 x 10^{-2} m/s. The magnitude of a physical quantity is specified by a number and a unit.

Any physical quantity used in the formulation of laws and principles must be operationally defined by a specification of the procedure to be used for measuring the quantity. It is desirable to keep the number of arbitrary units employed in measurements as small as possible. Therefore, it is convenient to regard certain physical quantities as fundamental quantities. These are measured in terms of internationally accepted fundamental units or *basic units*.

Modern physics is a communal strŭcture built on measurement and dependent on repoducibility. And yet it is obvious that before the players can even begin any game but solitaire - there must be agreement on the rules.

Standardized measurement is a practical business that developed out of everyday needs of practical people - builders, merchants, and pedlers long before they became the instruments of science. Scales and rulers were measuring wheat and cloth. The basic notation of length, volume, weight (mass), and time were quantified in antiquity and simply carried over into physics.

THE INTERNATIONAL SYSTEM OF UNITS (SI)

In 1960 an international committee established rules to decide on a set of standards for the fundamental quantities. The *international sytem of units* is now almost universally employed in scientific measurement. The system is based on *metre* (m), *kilogramme* (kg), *second* (s), *ampere* (A), *kelvin* (K), *candela* (cd) and *mole* (mol).

For two centuries scientific measurement was based on *centimetre* (cm), *gramme* (g) and *second* (s) [the CGS system] rather than on *metre* (m), *kilogramme* (kg) and *second* (s) [the MKS system]. The principal difficulty with CGS units lay in electromagnetism. The electromagnetic units were generally either much too large or much too small. Thus in elecromagnetism a set of practical CGS units was adapted which differed from the basic units by factors which were generally multiples of ten. This meant a large number of conversion factors had to be memorised in order to convert basic to practical units and vice versa.

This difficulty is entirely removed in the MKS system in which *ampere* is adopted as a fundamental electrical unit. It so happens that if *metre*, *kilogramme*, *second* and *ampere* are taken as basic units, the unit of potential difference comes out to be *volt* - the old CGS practical unit. It follows immediately that *ohm*, *farad* and *henry* will be the electrical units in the MKSA system. It is possible only if the *ampere* (as defined in the MKSA system) must be equal to the older practical CGS unit of current (defined as one-tenth of an electromagnetic unit of current). This definition of unit of current - *ampere* - also explains why the permeability of vacuum must be exactly $4\pi \times 10^{-7}$ $H.m^{-1}$ in MKSA units.

Examples of further features of the SI system are the removal of *calorie* (as unit of heat energy), *mm of Hg* (as a unit of pressure) and a reduction in the plethara of sub-units which have been introduced through the years e.g. *gamma* (10^{-5} gauss), *angstrom* (10^{-10} m) and *micron* (10^{-6} m).

The SI system is still relatively young and further changes may be anticipated over the next few years. Recent changes have been the adoption of the *pascal* (Pa) as a named unit of pressure (1 Pa = 1 Nm^{-2}) and the *seimens* (S) as the unit of electrical conductance (1 S = 1 AV^{-1}).

Basic SI Units

(a) **Length** *metre* (m)

A *metre* is the length equal to 1 650 763.73 wavelengths in vacuum of the radiation corresponding to the transition between the levels $^2p_{10}$ and $^5d_5$ of krypton-86 atom.

(b) **Mass** *kilogramme* (kg)

A *kilogramme* is the unit of mass. It is the mass of the international prototype of the kilogramme.

(c) **Time** *second* (s)

A *second* is the duration of 9 192 631 770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of caesium-133 atom.

(d) **Electric Current** *ampere* (A)

Ampere is that current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length.

(e) **Thermodynamic Temperature** *kelvin* (K)

Kelvin, the unit of thermodynamic temperature, is $^1/_{273.16}$ of the thermodynamic temperature of the triple point of water.

(f) **Luminous Intensity** *candela* (cd)

Candela is the luminous intensity, in the perprendicular direction, of a surface of $^1/_{600000}$ square metre of a blackbody at the temperature of freezing platinum under a pressure of 101,325 newtons per square metre.

(g) **Amount of Substance** *mole* (m)

Mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogramme of carbon-12.

Conventions for the SI Units and Notation

The following conventins apply to the SI notations and units used in physics and other sciences:

- Full stops not to be used with abbreviations, e.g. kg <u>not</u> kg.; Js <u>not</u> J.s.
- Abbreviations to be given in singular form, e.g. cm <u>not</u> cms, etc.
- Although V/m could be used, a better way is to write Vm^{-1}, etc. Multiples or sub-multiples of simple or derived units may be used but the unit itself should not be altered, e.g. 3.5 kVm^{-1} <u>not</u> 3.5 Vmm^{-1}, etc.
- Multiples or sub-multiples should differ from the basic unit in steps of 10^3. The muliples 10^2, 10, 10^{-1} and 10^{-2} should not be used except in special circumstances.
- Commas should not be used in writing numbers, e.g. 2 997 950 <u>not</u> 2,997,950.

NATURAL UNITS

In high energy physics calculations are simplified by taking $c = h/2\pi = 1$. Therefore the equations do not contain c or $h/2\pi$. In this system

$$1\ sec = 2.998 \times 10^{10}\ cm\ (c = 1)$$
$$1\ sec^{-1} = 6.583 \times 10^{-22}\ MeV\ (h/2\pi = 1)$$
$$1\ eV = 5.068 \times 10^{4}\ cm^{-1} = 1.519 \times 10^{15}\ sec^{-1}$$
$$1\ year = 3.16 \times 10^{7}\ sec\ (\cong \pi \cdot \times 10^{7}\ sec)$$
$$1\ light\ yr = 0.946 \times 10^{18}\ cm$$
$$1\ parsec(pc) = 3.26\ light\ years$$

(*parsec* is a unit used in astronomy).

Further

$$G_N = 6.67 \times 10^{-8}\ cm^3 g^{-1} sec^{-2} = 7.43 \times 10^{-29}\ cm/g$$
$$m_p = 938\ MeV\ (1\ MeV = 1.78 \times 10^{-27}\ g)$$
$$m_e = 0.511\ MeV$$

The equation $E^2 = c^2p^2 + m^2c^4$ becomes in natural units

$$E^2 = p^2 + m^2$$

Therefore we see that natural units bring simplification in calculations and are widely used in advanced calculations even in areas other than high energy physics.

ELECTROMAGNETIC UNITS

The modern undergraduate texts for electromagnetism use SI system (e.g. Lorrain and Corson, 1970; Reitz and Milford, 1967); whereas advanced texts (e.g. Jackson, 1975) are based on Gaussian system. The student finds it very difficult to cope with a strange system without knowing how to properly convert equations written in one system to those mentioned in the other system. Further the manner whereby the velocity of light appears in Maxwell's wave equation has suffered either by omission from modern texts or from a coverage so brief as to be positively misleading.

Krumm and Scourfield (1986) have discussed the issue of how did Maxwell know that the velocity in his wave equation was that of light. Texts written in SI units usually derive $\varepsilon_0\mu_0 = 1/V^2$ and claim that it so happens that $V^2 = c^2$ misleading the reader since neither μ_0 ($=4\pi \times 10^{-7}$ H m^{-1} by definition of the ampere) nor ε_0 are constants of nature. They are just the conversion factors between different systems of units. Texts using the Gaussian system do no better job either. They obtain $V = c$ by multiplying the two $1/c$ coefficients in the $\nabla \times H$ and $\nabla \times E$ equations without proper explanation as to how these coefficients appeared in these equations in the first place.

Maxwell used the electrostatic and electromagnetic systems of units. He found out that these systems are not being consistent with each other. He proved that the conversion factor between these two systems has the dimensions of a velocity. His wave equation contains this conversion factor. By an earlier experiment Weber and Kohlrausch (1856) had determined an estimate for this factor. In their experiment a capacitor of known capacitance in electrostatic units was discharged through a deflection coil galvanometer which essentially measures the discharge current in electromagnetic units. They quote the result:

$$310\ 740\ 000\ m\ s^{-1}$$

Although, for experimental reasons, this value was somewhat high, Maxwell was amazed by the closeness of the conversion factor to the known velocity of light, e.g.

$$314\ 858\ 000\ m\ s^{-1}\ \text{(Fizeau, 1849)}$$
$$298\ 000\ 000\ m\ s^{-1}\ \text{(Foucault, 1862)}$$

Maxwell (1874) argued that, since this conversion factor was the phase velocity in his wave equation, the electromagnetic medium that sustains electromagnetic waves is identical to the luminiferous medium that sustains light waves, i.e. that light was an electromagnetic wave.

Maxwell (1873) in his Treatise list more than twelve experimental determinations of the conversion factor. Maxwell (1868) also designed an experiment to measure this conversion factor by balancing the attractive force between two capacitor plates against the repulsive force between two thin coils mounted on each plate. He obtained a value for the conversion factor of 284 200 000 $m\ s^{-1}$.

Let us look at these systems in some detail. The following discussion is based mainly on Wangness (1979). Consider two fundamental experimental results. The magnitude of force between two point charges is given by Coulomb's law

(1) $$F = C_e qq'/R^2$$

where C_e is a constant of proportionality whose numerical value will depend on the units used. Similarly, the magnitude of force acting on a unit length between two infinitely long current carrying parallel wires of negligible cross section can be written as

(2) $$dF/dz = 2C_m II'/p$$

where p is distance between the two wires, C_m is another constant of proportionality. Krumm and Scourfield (1986) also explain the origin of factor 2 in the above equation. All systems of units use the definition of current given by $I = dq/dt$.

If same set of mechanical units are used in (1) and (2), the two forces will have the same dimensions. This could be possible if the ratio C_e/C_m has the dimensions of (distance/time)^2. The value of this ratio has been measured many times and the current experimental result is

(3) $$(C_e/C_m)^{1/2} = c = 2.998 \times 10^8\ m\ s^{-1}$$

The various systems of units used in electromagnetism essentially differ in the way in which these constants are chosen. The system of units used in electromagnetism could be *rationalised* or *unrationalised*. For a rationalised system there are no numerical factors of 4π appearing in Maxwell's equations, whereas they do appear if an unrationalised system isused. It is of interest that use of a rationalized system does not make 4π disappear. It simply means that 4π's are found in results found from Maxwell's equations. Therefore, the choice of which type to use is somewhat a matter of taste.

The SI System

In the SI system C_e is taken as $1/4\pi\varepsilon_o$. This gives $C_m = \mu_o/4\pi$. This choice leads to $C_e/C_m = (9 \times 10^9)/(10^{-7}) = (3 \times 10^8\ m/s)^2$ in conformity with eq. (3). The Maxwell's equations in SI system are

(4a-d) $\nabla . D = \rho_f$; $\nabla \times E = - \partial B/\partial t$; $\nabla . B = 0$; $\nabla \times H = J_f + \partial D/\partial t$

(in this paper ∂ denotes partial differentiation). As we notice this is a rationalised system. The factor 4π appears in Coulomb's law instead of Maxwell's equations.

The Electrostatic and Electromagnetic Systems

If Coulomb's law is taken as a fundamental result to define a system of units for electromagnetism, we may take $C_e = 1$. Then eq. (3) gives $C_m = 1/c^2$ and eqs. (1) and (2) become

(5) $F = qq'/R^2$; $dF/dz = 2II'/c^2\rho$ (esu)

This procedure leads to *electrostatic system of units* (esu). In this system two equal unit charges a distance 1 *cm* apart repel each other with a force of 1 *dyne*. The unit of charge defined in this way is called a *statcoulomb* (from electrostatic). The unit of current will be 1 *statcoulomb/second* = 1 *statampere*, and that of potential difference 1 *erg/statcoulomb* = 1 *statvolt*. In the same way *statfarad*, *statohm*, and other units could be defined. The **B** field is related to the **E** field by writing Faraday's law as $\nabla \times E = - \partial B/\partial t$ or, equivalently, the Lorentz force as $F = q(E + v \times B)$. It is very common to find quantities measured in this system but not given in *statamperes*, *statfards* etc., but merely stated as being so many "electrostatic units" or "esu". In this form, however, this system is seldom used anymore.

If we are interested more in magnetostatics we could use eq. (2) as the starting point. To simplify it we may choose $C_m = 1$ so that $C_e = c^2$ and eqs. (1) and (2) become

(6) $F = c^2qq'/R^2$; $dF/dz = 2II'/\rho$ (emu)

Such a procedure leads to the *electromagnetic system of units* (emu). In this system two infinitely long parallel wrires carrying unit current placed 1 *cm* apart will attract each other with a force of 2 *dynes/cm*. Te unit of current defined in this way is called an *abampere* (from absolute). The unit charge will be 1 *abcoulomb* = 1 *abampere-second*. Similarly one can define *abvolt*, *abfarad* etc. The **E** and **B** fields are related by $\nabla \times E = - \partial B/\partial t$ or $F = q(E + v \times B)$. It is also very common to use simply the terminology of "electromagnetic units" or "emu". In this pure form, however, the electromagnetic system is never used. However, the system still in use in advanced texts is considred next.

The Gaussian System

This is an unrationalised CGS system. In this system the electrical quantities are measured in *elecrostatic units*, whereas the magnetic quantities are measured in *electromagnetic units*. Maxwell's equations in this system take the form

(7a,b) $\nabla . D = 4\pi\rho_f$; $\nabla . B = 0$

(7c,d) $\nabla \times \mathbf{E} = -(1/c)\partial\mathbf{B}/\partial t$; $\nabla \times \mathbf{H} = (4\pi/c)\mathbf{J}_f + (1/c)\partial\mathbf{D}/\partial t$

where the various field vectors are related by

(8) $$\mathbf{D} = \mathbf{E} + 4\pi\mathbf{P};\ \mathbf{H} = \mathbf{B} - 4\pi\mathbf{M}$$

and the Lorentz force is

(9) $$\mathbf{F} = q(\mathbf{E} + c^{-1}\ \mathbf{v} \times \mathbf{B})$$

The equation of continuity still has the form

(10) $$\nabla.\mathbf{J}_f + \partial\rho_f/\partial t = 0$$

The various constitutive equations are written as

(11a-c) $$\mathbf{D} = \varepsilon\mathbf{E};\ \mathbf{H} = \mathbf{B}/\mu;\ \mathbf{J}_f = \sigma\mathbf{E}$$

(11d,e) $$\mathbf{P} = \chi_e\mathbf{E};\ \mathbf{M} = \chi_m\mathbf{H}$$

so that

(12a,b) $$\varepsilon = 1 + 4\pi\chi_e;\ \mu = 1 + 4\pi\chi_m$$

Potential expressions, then, become

(13a,b) $$\mathbf{B} = \nabla \times \mathbf{A};\ \mathbf{E} = -\nabla\phi - (1/c)\partial\mathbf{A}/\partial t$$

The energy formulae of interest are

(14a,b) $$u = (1/8\pi)(\mathbf{E.D} + \mathbf{B.H});\ \mathbf{S} = (c/4\pi)(\mathbf{E} \times \mathbf{H})$$

where u is the energy density and **S** the Poynting vector. The first expression holds for linear media.

In the Gaussian system all the field vectors **E**, **D**, **B**, **H**, **P**, and **M** have the same dimensions. However, people gave different names to their units, e.g. **B** is measured in *gauss*, H in *oersted*, M in *oersted* (but see the next subsection), Φ in *maxwell* (= 1 *gauss-cm*^{2}). In vacuum **D** = **E** and **H** = **B**. The quantities ε, μ, χ_e, and χ_m are all dimensionless.

Sometimes a *modified Gaussian system* is used in which charge is measured in *statcoulombs (esu)*, but current is measured in *abamperes (emu)*. In this system, therefore, any symbol for current is replaced by c times that symbol (e.g. $\mathbf{J}_f \rightarrow c\mathbf{J}_f$). Ampere's law and equation of continuity take the form

(15a,b) $\nabla \times \mathbf{H} = 4\pi\mathbf{J}_f + (1/c)\partial\mathbf{D}/\partial t$; $\nabla.\mathbf{J}_f + (1/c)\partial\rho_f/\partial t = 0$

The other three Maxwell's equations remain unchanged.

In the *Heaviside-Lorentz system*, a rationalised Gaussian system, every 4π in the equations (7) through (12) is replaced by unity. For example, Maxwell's fiest equaton becomes $\nabla.\mathbf{D} = \rho_f$ where $\mathbf{D} = \mathbf{E} + \mathbf{P}$. The factors of c still remain in the different equations.

If the system of units used is not mentioned, one can find out by looking at the form of some familiar results like Maxwell's equations.

How to Cope with the Gaussian System

Any result in the Gaussian system can be obtained by starting with Maxwell's equations (7) and using the expressions (8) through (13) as required. This is not always convenient and we need to have a method that will enable us to transform a given result written the Gaussian system into the corresponding one in the SI system and vice versa. Table 1 provides a recipe for doing this. To use this table, replace a symbol in the column labeled by the system in which the formula is written by the symbol or combination listed for the other system. Symbols representing essentially mechanical quantities are unchanged. A few examples could be found after Table 2.

The use of Table 1 may occasionally lead to a wrong result when applied to a Gaussian equation which has been worked out for vacuum. This happens because $\mathbf{D} = \mathbf{E}$ and $\mathbf{B} = \mathbf{H}$ for free space, and there is a tendency to use these symbols intechangeably. This leads to ambiguities since conversion factors listed in Table 1 are different for the members of each of these pairs. For example, the equation connecting the field with the vector potential is often written as $\mathbf{H} = \nabla \times \mathbf{A}$. This will not transform directly back to the corresponding SI equation $\mathbf{B} = \nabla \times \mathbf{A}$, although it does lead to $\mu_0\mathbf{H} = \nabla \times \mathbf{A}$ which is valid for free space only.

Let us now look at the problem of converting the *numerical values* of a given physical quantity from one system to another. It may happen that the data are given numerically in the Gaussian units and it is necessary to insert their equivalent values into an SI formula, or conversely. Table 2 could be used for this purpose. The entry in each row gives the same amount of quantity expressed in different units. In other words, the terms in each row are equal.

Although **H** and **M** are both measured in *ampere/m* in the SI system, we note that conversion factors to *oersted* are different for each of them. This is because of the factor 4π in (8). Similar remarks apply to **D** and **P**. Sometimes magnetisation is stated in *gauss* rather than *oersted*. Most of the time the author really means "oersted". Then one can change the name and use the factor given in Table 2 for **M**. Ocassionally, the author really means "gauss" having in mind an SI definition of magnetic dipole moment equal to μ_0 times the usual expression. This would make the relation among magnetic vectors take the form $\mathbf{B} = \mu_0\mathbf{H} + \mathbf{M}$ rather than $\mathbf{B} = \mu_0(\mathbf{H} + \mathbf{M})$. In that case, it would be appropriate to measure **B** and **M** in the same units.

Table 1 Conversion of Symbols in Equations in SI System[1-3]

Quantity	*SI*	*Gaussian*
Capacitance	C	$4\pi\varepsilon_0 C$
Charge	q	$(4\pi\varepsilon_0)^{1/2}q$
Charge density		
line	λ	$(4\pi\varepsilon_0)^{1/2}\lambda$
surface	σ	$(4\pi\varepsilon_0)^{1/2}\lambda$
volume	ρ	$(4\pi\varepsilon_0)^{1/2}\rho$
Conductivity	σ	$4\pi\varepsilon_0\sigma$
Current	I	$(4\pi\varepsilon_0)^{1/2}I$
Current density		
line	K	$(4\pi\varepsilon_0)^{1/2}K$
surface	J	$(4\pi\varepsilon_0)^{1/2}J$
Dipole moment		
electric	$\mathbf{p}$	$(4\pi\varepsilon_0)^{1/2}\mathbf{p}$
magnetic	$\mathbf{m}$	$(4\pi/\mu_0)^{1/2}\mathbf{m}$
Electric displacement vector	$\mathbf{D}$	$(\varepsilon_0/4\pi)^{1/2}\mathbf{D}$
Electric field	E	$(4\pi\varepsilon_0)^{-1/2}E$
Inductance	L	$(4\pi\varepsilon_0)^{-1}L$
Magnetic field	H	$(4\pi\mu_0)^{-1/2}H$
Magnetic flux	Φ	$(\mu_0/4\pi)^{1/2}\Phi$
Magnetic induction	B	$(\mu_0/4\pi)^{1/2}B$
Magnetization	M	$(4\pi/\mu_0)^{1/2}M$
Permeability		
relative	K_m	μ
total	μ	$\mu\mu_0$
Permittivity		
relative (dielectric constant)	k_e	ε
total	ε	$\varepsilon\varepsilon_0$
Polarization	P	$(4\pi\varepsilon_0)^{1/2}P$
Resistance	R	$(4\pi\varepsilon_0)^{-1}R$
Resistivity	ρ	$(4\pi\varepsilon_0)^{-1}\rho$
Scalar potential	ϕ	$(4\pi\varepsilon_0)^{-1/2}\phi$
Speed of light in free space	$(\mu_0\varepsilon_0)^{-1/2}$	c
Susceptibility		
electric	χ_e	$4\pi\chi_e$
magnetic	χ_m	$4\pi\chi_m$
Magnetic vector potential	A	$(\mu_0/4\pi)^{1/2}A$

[1]Symbols representing essentially mechanical quantities (energy, force, length, mass, power, time, etc.) are unchanged. The same is true for the derivaties.

[2]To convert an equation written in SI system to the corresponding one in the Gaussian system, replace the symbol listed under the column labeled SI by that listed under Gaussian. Going from right to left in the table converts a Gaussian equation to an SI one.

[3]The use of Table 1 may sometimes lead to a wrong result when applied to a Gaussian system equation worked out for a vacuum.

Table 2 Conversion Table for Numerical Quantities[4]

Quantity	*Symbol*	*SI*	*Gaussian*
Capacitance	C	1 *m*	10^2 *cm*
Charge	q	1 *coulomb*	3×10^9 *statcoulomb*
Charge density	ρ	1 *coulomb/m*^{3}	3×10^3 *statcoulomb/cm*^{3}
Conductivity	σ	1 *(ohm-m)*$^{-1}$	9×10^9 *(statohm-cm)*$^{-1}$
Current	I	1 *ampere*	3×10^9 *statamperes* = 1×10^{-1} *abamperes*
Current density	J	1 *ampere/m*^{2}	3×10^5 *statampere/cm*^{2}
Electric displ.	D	1 *coulomb/m*^{2}	$12\pi \times 10^5$ *statvolt/cm*
Electric field	E	1 *volt/m*	$^1/_3 \times 10^{-4}$ *statvolt/cm*
Energy	ϵ	1 *joule*	1×10^7 *ergs*
Force	F	1 *newton*	1×10^5 *dynes*
Inductance	L	1 *henry*	$^1/_9 \times 10^{-11}$ *stathenrys*
Length	*l*	1 *metre(m)*	1×10^2 *centimetres(cm)*
Magnetic field	H	1 *ampere/m*	$4\pi \times 10^{-3}$ *oersted*
Magnetic flux	Φ	1 *weber*	1×10^8 *maxwells*
Magnetic induction	B	1 *weber/m*^{2} = 1 *tesla*	1×10^4 *gauss*
Magnetization	M	1 *ampere/m*	1×10^{-3} *oersted*
Mass	m	1 *kilogramme*	1×10^3 *grammes*
Polarization	P	1 *coulomb/m*^{2}	3×10^5 *statvolt/cm*
Potential	ϕ	1 *volt*	$^1/_{300}$ *statvolt*
Resistance	R	1 *ohm*	$^1/_9 \times 10^{-11}$ *statohms*
Time	t	1 *second*	1 *second*
Work	W	1 *joule*	1×10^7 ergs

Example 1

Let us transform Maxwell's third equation $\nabla \times \mathbf{E} = -\, \partial \mathbf{B}/\partial t$ into Gaussian system. From table 1

$$\mathbf{E} \rightarrow (4\pi\varepsilon_o)^{-1/2}\mathbf{E}; \quad \mathbf{B} \rightarrow (\mu_o/4\pi)^{1/2}\mathbf{B}; \quad \partial/\partial t \rightarrow \partial/\partial t$$

which gives $\nabla \times \mathbf{E} = -\, c^{-1}\, \partial \mathbf{B}/\partial t$ in the Gaussian system.

Example 2

To covert Lorentz force expression in SI system $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$ into an equivalent expression in the Gaussian system note that

$$\mathbf{F} \rightarrow \mathbf{F}; \quad \mathbf{v} \rightarrow \mathbf{v}; \quad q \rightarrow (4\pi\varepsilon_o)^{-1/2}q$$

from table 1. Using the expressions of **E** and **B** quoted in Ex. 1 we get $\mathbf{F} = q(\mathbf{E} + c^{-1}\mathbf{v} \times \mathbf{B})$ in the Gaussian system.

[4]Tables 1 and 2 are modified versions of Tables 23-1 and 23-2 of Wangness (1979).

The above discussion provides an overview of different systems used in electromagnetism and how to interpret different quantities in various systems. The quantity **A** appearing in (13) is the *magnetic vector potential*. Grough and Richards (1986) discuss the significance of magnetic vector potential in the process of electromagnetic induction from a long solenoid. The electric potential ϕ and the magnetic potential **A** form a four-vector in the context of relativity. A special kind of transformation, called *gauge transformation*, applied to these quantities uncouples the wave equation so that it could be easily solved. A gauge transformation was also used in the electroweak theory of Glashow, Weinberg and Salam which brought them the 1979 Nobel Prize in Physics.

CONCLUSION

The various system of units deviced to make calculations simple in different situatons are presented in this paper. The authors would like to make one more point before closing. A person working with physical quantities must have a clear idea about the order of magnitudes of the quantities one is dealing. In the Ph. D. examinations of University of California, Berkeley and Johns Hopkins University questions were asked to give the order of magnitude of common physical quantities, for example, the mass of proton. College teachers would have realised the significance of what we are talking about. They generally have to spend lot of time to instruct students how to choose proper range for the variables on the x- and y-axes so that their graphs donot lie just in one corner of the graph paper. Knowledge of the order of magnitudes of the quantities involved is also cruical for a researcher involved in experimental work. To illustrate how grave is the situation in this respect let us give one example. A university physics teacher went as an external examiner in a local college in Karachi. The student was performing photocell experiment. Two metre scales were present on his table. When asked if he had seen a metre scale scale, the answer was *no*. The teacher then asked, "How long is a *metre*?" The student pointed to the end of the laboratory and said this was the length of a *metre*.

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