MATSCIENCE REPORT 58

INTERNATIONAL SYSTEM OF UNITS

By

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THE INSTITUTE OF MATHEMATICAL SCIENCES, MADRAS-20. (INDIA).

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INTERNATIONAL SYSTEM OF UNITS

1. Rationalization of Units.
2. The Force: 'NEWTON' in Electricity and Magnetism.
3. Units of Time.
4. Units of Energy.

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RATIONALIZATION OF UNITS

V.V.L. Rao

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I. Systems of Units

1. Mechanics: 7 Systems.

1) F.P.S.
2) C.G.S. Absolute Systems
3) M.K.S.

C.G.S., M.K.S., M.T.S. are all forms of the 'Metric System.'

4) F.P.S.
5) C.G.S. Gravitational Systems
6) M.K.S.

7) M.T.S. (Tonne) = 10^3 kg. = 10^6 gr.

2. Electricity and Magnetism.

1. e.su: The CGS absolute electrostatic system.
2. e.mu: The CGS absolute electromagnetic system.
3. Prac: The practical system.
4. Internat.: The International system.
5. G. : The Gaussian system
6. hls : Heaviside-Lorentz system.
7. MIE : The 'MIE' unrationalised system (German)

8. MIE : The 'MIE' Rationalised system (German)

9. MKSA : The MKSA unrationalised

10. MKSA : The MKSA Rationalised (now known as 'SI' - the practical, absolute system).

11. CGS-Franklin: Unrationalised.

12. CGS-Biot : Unrationalised.

13. Definitive (Campbell-1933)

14. Ampere-Ohm(Karapetoff) 1941.

15. <u>The SI: System International</u>

(Accepted in 1960 at the XI General Conference of Weights and Measures with six basic units:

Quality	Unit	Symbol
Length	Metre	m
Mass	Kilogramme	kg
Time	Second	s
Electric Current	Ampere	A
Temperature	Degree (Kelvin)	^{o}K
Luminous Intensity	Candele	cd

The 'SI' system is the metric system of tomorrow for Science, Engineering and Technology. It unifies the 2 CGS systems and the Practical system.

Rationalised MKSA System (RMKSA)

What India adopted in December 1956 is the MKSA. This is evident from the definition of 'Ampere' in the Government of India Act. IEC addopted MKSA system in 1950 and thus the 'Battle of Units' required for over 150 years seemed to be at an end.

What is rationalisation?

Rationalisation means the transferring of the ubiquitous factors π, 2π, 4π from some of the basic equations in electrostatics and electromagnetics. Any system of units can be 'rationalised'. Maxwell and Oliver Heaviside suggested in 19th century that the system of units then in vogue were 'irrational' and hence needs rationalisation. (Quote Oliver-Heaviside)

Table

Equation describing	In C.G.S. Units	In R.M.K.S. Units
1. M.M.F. of a coil of N turns	$\frac{4\pi NI}{10}$ Amp. turns	NI Amp. turns
2. Inductance of a solenoid	$4\pi \frac{N^2A}{1} \frac{dB}{dH}$ 10^{-9}H	$\frac{N^2A}{1}$ $\frac{dB}{dH}$ Henry
3. Capacity of parallel plates	$\frac{1A}{4\pi d}$ x10^9F	$\frac{kA}{d}$ F
4. Capacity of concentive cylinders	$\frac{kl}{\log(R/r)}$ x 10^9 F	$\frac{2\pi\ kl}{\log(R/r)}$ Farads

$\frac{B}{H} = \mu = \mu_r \mu_0$, where

μ = absolute permeability;

μ_0 = permeability of free space = $4\pi/10^7 = 1.257 \times 10^{-6}$ H/m;

μ_r = relative permeability of the medium (dimensionless)

$$\mu = \left\{ \frac{\text{Flux density product in the medium}}{\text{Flux density product in free space.}} \right\}$$

Similarly, $\epsilon = \epsilon_r = \epsilon_0$, where

ϵ = absolute permittivity

ϵ_0 = permittivity of free space $= \frac{10^{-9}}{9 \times 4\pi} \doteq \frac{10^{-9}}{31\pi}$

$= 8.854 \times 10^{-12}$ F/m

ϵ_r = Relative permittivity of the medium (dimensionless)

$$= \left\{ \frac{\text{Permittivity of a medium}}{\text{Permittivity of free space.}} \right\}$$

Note; $\mu_r = 1$, $\epsilon_r = 1$ for vacuum or air.

Values of Permeability and Permittivity in different systems

Table

	C.G.S. Systems		M.K.S. Systems		
	e.s.u	e.m.u	MKS	RMKSA	
μ	$\frac{1}{c^2} = \frac{1}{9 \times 10^{20}}$ sec^2/cm^2	1(unity)	10^{-7}	$4\pi \times 10^{-7}$ $\doteq 1.257 \times 10^{-6}$ H/m	Permeability of free space
ϵ_0	1(unity)	$\frac{1}{c^2} = \frac{1}{9 \times 10^{20}}$ sec^2/cm^2	$\frac{10^{-9}}{9}$	$\frac{10^{-9}}{3677}$ $\doteq 8.854 \times 10^{-12}$ F/m	Permittivity of free space.

The new definition of Ampere (from January 1948)

'The Ampere is the strength of the constant current which, flowing through two parallel, rectilinear conductors of negligible circular cross-section and placed in vacuo at a distance of one meter from each other, produces between these two conductors a force of 2×10^{-7} newtons per meter of their length'.

The mechanical force per meter length of each conductor ; 1 m long.

$$F = \mu_0 \frac{I_1 I_2}{2\pi d} \quad \text{(Ampere's equation)} \quad \underline{(d \ll 1)}$$

$I_1 = I_2 = 1$ amp.

$d = 1$ meter ; $\mu_0 = 4\pi \times 10^{-7}$ H/m

$$F \text{ (in Newtons)} = \frac{4\pi \times 10^{-7}}{2\pi} \times 1 \times 1 = 2 \times 10^{-7} \text{ N/m}$$

The advantages of the Rationalised System

1. A single, coherent, absolute system.
2. Draws a clear-cut distinction between the unit of mass and unit of force.
3. Supplies the units formerly missing in the former 'Practical' System of units.
4. In the R.M.K.S., possible to draw simple anologies. e.g. with heat flow; transmission of sound energy.
5. Puts 2π and 4π where they belong.
6. Informative nature of 'BH' = 4π times energy (in ergs.)/cu.cm.

   In M.K.S. =Joules/cu m.

   Displacement D in coulombs/m^2

   Flux ϕ in Volt-seconds (Webers)
7. Treatment of electricity first and then magnetism more rational because all magnetism is electrical in origin.
8. It meets the requirements of electrical and radio engineers in their every day life far better than any alternative.
9. Using LMTI or LMTQ dimensional system, will avoid fractional indices.
10. Scope for new ideas in the development of experiments to determine the magnitudes of μ_0 and ϵ_0.
11. Brings out that, in vacuo, B and H are different (both numerically and in nature); also are D and ϵ in electrostatics)

CHAPTER I

The Force: 'NEWTON' IN ELECTRICITY AND MAGNETISM

Contents

CHAPTER 1

The Force: 'NEWTON' IN ELECTRICITY AND MAGNETISM

1. The 'Newton' and the 'Coulomb'. Coulomb is the unit of electric charge—(Symbol: C). It is most easily specified in terms of the force of repulsion on an identical charge.

Coulomb's Law states that $F_{elec.} = k\,\dfrac{q_1\,q_2}{d^2}$, (1)

where, k = a constant of proportionality = $9 \times 10^9\ \dfrac{\text{newton-metres}^2}{\text{coulomb}^2}$, q_1 and q_2 are in coulombs and d in metres. Then $F_{elec.}$ is in 'newtons'.

Thus, if q_1 is a point charge of 1 C and q_2 is also a point charge of 1 C and d equals 1 meter, then

$$F_{elec} = 9(10^9)\ \frac{(1) \times (1)}{(1)^2} = 9 \times 10^9\ \text{N}. \tag{2}$$

9000 million Newtons is a tremendous force! We get an idea of the very large magnitude of the charge; Coulomb, if we compare the electrical and gravitational forces between two one kg masses that carry a charge of one Coulomb each and are one meter apart.

$$F_{grav.} = G\,\frac{m_1\,m_2}{d^2} \tag{3}$$

where G = 6.670×10^{-11} Newtons-metre

$$F_{grav.} = 6.67 \times 10^{-11}\ \frac{1^2}{1^2} = 6.67\ \underline{\times 10^{-11}}\ \text{newton} \tag{4}$$

Thus, the electrical forces are very much greater than the gravitational forces at the same distance.

$\dfrac{F_{elec.}}{F_{grav.}} = \dfrac{9 \times 10^9}{6.67 \times 10^{-11}}$. This ratio is of the order of $\underline{10^{20}}$ times.

Therefore, we must conclude that a coulomb is a very,very large charge. Most static electric charges met with in electrical work are of the order of micro-coulombs=(10^{-6}C). Actually, many static charges are much smaller. The charge of a proton, which is the smallest possible charge, is only 1.6×10^{-19}C.

2. The 'Newton' and the 'Ampere'. The definition of 'Ampere', the unit of electric current in the 'SI' system involves the force, 'Newton'. This is quite a novel feature as the force is: 2×10^{-7} N/m. This is derived as follows:

In the 'SI' system, the force between two parallel conductors is

$$F = \mu \frac{I_1 I_2 l}{2\pi d} \qquad (5)$$

where $\mu = \mu_0 = 4\pi \times 10^{-7} \frac{\text{newton}}{\text{ampere}^2}$ or $\frac{\text{heury}}{\text{meter}}$

(vide appendix)

(in the RMKSA System)

(Note. $\mu = \mu_r \mu_0$, where μ_r is the relative permeability and μ_0 = permeability of free space) for air or vacuum

$\mu_r = 1 \therefore \mu = \mu_0$.

If, $I_1 = I_2 = 1$ amp. and $l = 1$ meter, d = 1 meter

$$\text{Then, } F = \overset{2}{\cancel{4\pi}} \times 10^{-7} \frac{\text{Newton}}{\text{ampere}^2} \times \frac{1A \times 1A \times 1m}{2\pi \times m} \qquad (6)$$

$$= 2 \times 10^{-7} \text{ Newton}$$

Thus, the ampere is expressed in terms of the 'meter' and the 'newton'. In practice, the ampere can be established with the aid of a meter-stick and a spring balance.

3. The 'Newton and the 'Volt' The unit of potential difference is the volt-(abbreviated; V). By definition, the p.d. between two points is given by : $(V_2 - V_1) = Ed$

$$[\text{Volt}] = \left[\frac{\text{Newton}}{\text{Coulomb}}\right] [\text{meter}]$$

$$= \left[\frac{\text{Newton. meter}}{\text{Coulomb}}\right] = \left[\frac{\text{Joul}}{\text{Coulomb}}\right]$$

$$(\therefore \quad \text{IJ} = \quad \text{N-m}) \tag{7}$$

Thus, a volt is a "Joule per coulomb".

Since, $E = \dfrac{V_2 - V_1}{d}$, the unit of electric field intensity could be expressed as a 'volt per meter'.

This means that

$$\left[\frac{\text{newton}}{\text{coulomb}}\right] = \left[\frac{\text{Volt}}{\text{meter}}\right] \tag{8}$$

Thus, a different unit of 'electric field intensity' is derived. The above dimensional equation does not really state a new fact, for by cross-multiplying by (meter), we get,

$$\text{Volt} = \frac{\text{Newton. meter}}{\text{Coulomb}} \tag{9}$$

In many cases, it is preferable to express an 'electric field intensity' in terms of 'volt per meter'.

For example, if the p.d. between two parallel plates is 100 volts and their separation is 10 cm (0.1 meter), than we atonce say that the electric field intensity is:

$$E = \frac{V_2 - V_1}{d} = \frac{100}{0.1} = 1000 \text{ volts/meter.}$$

or, we can say that the electric field intensity is 1000 newtons/coulomb.

4. The 'Newton' and the 'electric field. The electric field intensity(E) at any point is measured as the force experienced per unit charge placed at that point.

$$\therefore \quad E = \frac{F}{q} \tag{10}$$

In the 'SI' system, since a newton is the unit of force and a coulomb the unit of electrostatic charge, the unit of electric field intensity is a 'newton per coulomb'.
The electric fieldstrength in any direction is also defined as the potential gradient in the direction

$$E = -\frac{dv}{dx} \tag{11}$$

The unit of electric field will be one volt per meter. From the above two equations, 1 newton/coulomb = 1 volt/meter. Electric field intensity can be expressed either way.

5. 'Newton' and the 'electron volt': A unit of energy, frequently used in Physics and Electronics, is the 'electron-volt' (abbreviated: 'ev'). In this case, the unit of charge is the charge of an electron = 1.6×10^{-19} coulomb disregarding the minus sign before it, the unit of potential is the volt. An electron volt can be expressed in terms of a joule.

$$\begin{aligned}[eV] &= [1.6\ (10^{19})\ c]\ [V] \\ &= 1.6\ (10^{-19})\ [CV] \\ &= 1.6\ (10^{-19})\ [J] \end{aligned}$$

$$(\because \ 1 \text{ Joul} = 1 \text{ coulomb} \times \text{volt}) \tag{12}$$

Thus, an 'electron volt' = 1.6×10^{-19} joule, and a 'joule is nothing but a 'newton-meter'.

6. <u>The 'Newton' and 'Magnetic Induction'</u>: B, the magnetic induction, a vector quantity, characterises the magnetic field. The magnitude of B is given by the equation:

$$B = \frac{F}{q^{v} \sin} , \qquad (13)$$

where q is the magnitude of the charge, v its velocity, the angle between v and the direction of the magnetic field, and F, the force acting on a moving charge at the point. When F is expressed in newtons, q in coulombs, and v in meters/sec. B will be in '<u>Webers per square meter</u>', now called a '<u>Tesla</u>'. Thus, one 'Tesla' is the magnetic induction of a magnetic field in which one coulomb of charge, moving with a component of velocity perpendicular to the field (v sin) equal to one meter/sec., is acted on by a force of one newton.

$$1 \text{ Tesla} = \frac{1 \text{ newton}}{\text{coulomb} \times \text{meter/sec.}} = 10^4 \text{gauss} \qquad (14)$$

In the 'SI' system, 'Tesla' (symbol: 'T') is the unit of magnetic induction.

7. <u>The 'Newton' and the 'magnetic pole'</u>: In the SI system, coulomb's law of force between two magnetic poles is given by:

$$F = \frac{k.m_1 \, m_2}{d^2}$$, (compare this with the coulomb's law for electric charges)

where

$$k = \frac{1}{(4\pi \times \quad \frac{\text{newton}}{\text{ampere}^2}} \qquad (15)$$

where = permeability of free space = $4\pi \times 10^{-7}$ N/A²

$$\therefore F \text{ (in newtons)} = \frac{m_1 \, m_2}{16 \, \pi^2 \times 10^{-7} d^2} \qquad (16)$$

The odd value of $\frac{1}{16\pi^2 \times 10^{-7}}$ newton, got into the equation in the 'SI' system because of the value assigned to μ_0, the magnetic space constant

$$=(4\pi \times 10^{-7} \ \frac{N}{A^2} \ \text{or Henry/meter}) \tag{17}$$

In eqn. 16, by putting $m_1 = m_2 = 1$ and $r = 1$, we can define a '<u>Weber</u>' as that pole, which repels an equal pole of the same polarity with a force of $\left(\frac{1}{16\pi^2 \times 10^{-7}}\right)$ newtons, when the poles are one meter apart in vacuum. 1 weber=10^8 maxwells, in the <u>electro-magnetic system</u> of units, the coulomb's law is usually stated as follows:-

$$F(\text{in dynes}) = \frac{m_1 m_2}{\mu d^2} \tag{18}$$

where μ = 1, when $m_1 = m_2 = 1$, and d = 1 cm. Then F = 1 dyne.

Eventhough the method of radial magnetic field due to an isolated pole is to be replaced in the RMKSA system by the uniform magnetic field produced by a solenoid in the study of magnetism, yet the concept of a magnetic pole is useful for an understanding of this subject.

APPENDIX

To prove that $\left[\frac{\text{Henry}}{\text{meter}}\right] = \left[\frac{\text{Newton}}{\text{Ampere}^2}\right]$

$$\left[\frac{\text{Henry}}{\text{meter}}\right] = \left[\frac{\text{Weber}}{\text{Ampere}}\right] \times \left[\frac{1}{\text{meter}}\right]$$

$$= \frac{\text{Volt.second}}{\text{Ampere}} \times \frac{1}{\text{meter}} \quad (\because \text{ 1 Weber=1volt.sec.})$$

$$= \frac{\text{Volt.(second x Ampere)}}{\text{Ampere}^2 \text{ . meter}}$$

$$= \frac{\text{(Volt.cowlomb)}}{\text{Ampere}^2 \text{ meter}} = \frac{\text{Joule/meter}}{\text{amplere}^2} \quad (\because \text{ 1 joule: Valt.Cowlomb})$$

$$= \frac{\text{meter . Newton}}{\text{meter . ampere}^2} \quad (\because \text{ 1 Joule: meter-newton})$$

$$\therefore \left[\frac{\text{Henry}}{\text{meter}}\right] = \left[\frac{\text{Newton}}{\text{Ampere}^2}\right]$$

TIME

TIME

(Units and Scales from microcosmos to macrocosmos)

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1. Introduction

'Time is the independent variable in the laws of machanics'. Though this is the best definition that can be given of 'time', yet it does not define the idea completely. In truth, we know of no way of defining time 'absolutely'. Time will simply be what it is for all men, viz., an uninterrupted series of successive moments, each of which corresponds to a number.* The division of time into years, months, days, hours, minutes and seconds, a division consecrated by long usage, corresponds to a numerical system, which is, in reality, rather complicated, but appears to us as simple only on account of long-established habit. The astronomer no longer explores a world of 'space' alone but a four-dimensional structure, which he calls the 'space-time continuum'. To the mathematician, this presents no difficulty but to most of us these ideas appear abstruse because we live in a world of passing time in which the past is gone, and the future is yet to come. We are content with this, because we are just living in the present.+

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* Aristotle (384-322 BC) spoke of time as the 'number of motion'.

\+ Leibnitz (1646-1714) said: 'Time is the abstract of all relations, of sequence; space is the abstract of all relations of coexistence.

2. UNITS OF TIME

Though the ultimate unit of time in science and engineering is the 'second', most prominent among the natural time units are: the 'year' and the 'day'. Even though their meaning rarely challenges the judgement of a practical person, these simple units, nevertheless, prove troublesome to the scientist. 'Natural standards' of time are few in number but difficult to certify.

2.1 The Year

Roughly speaking, the year is the period of revolution of the earth about the Sun, but its length depends upon what is chosen as the reference for the period in question, and events are illdefined in a universe, in which all bodies move. There are at least five different 'years'. Thus, if one specifies the year to be the interval between one apparent passage of the Sun through a point in the sky, fixed with respect to the stars, and another such passage, he obtains what is called the SIDEREAL YEAR.

Its length is 365 days, 6 hours, 9 months, 9 seconds - the days, months, hours , minutes and seconds involved here are mean 'solar units' - (defined below). The TROPICAL YEAR is the interval between two successive vernal equinoxes. Its length is 365 days, 5 hours, 48 minutes and 46 seconds. This is an important unit in our daily life, because it is in unison with the seasons in nature. The difference between the 'Sidereal Year' and the 'tropical year' was discovered by Hipparchus, the Greek, in 130 B.C.

If the period of the earth's revolution is measured from the moment at which the earth is closest to the Sun (perihelion) to the next similar moment, the interval thus obtained is the <u>NODAL YEAR</u> of length: 346 d. 7 h. 53 m. Though this differs widely from others, it has a significance as a basis for predicting SOLAR and LUNAR eclipses. Then, which is the 'true year'?

The life of any people is governed to a great extent by the calendar and the calendar, in order to be useful, should match with the seasons. The most accurate calendar, as established by the scientists recently, corresponds to that of the MAYAS of Central America. Though their time of reckoning was based on lines other than ours, they determined the duration of the year more accurately than other peoples.

The following table gives the duration of the length of the year according to different calendars:

<u>Table 1</u>

1. Julian calendar	- 365,250,000 days
2. Gregorian calendar	- 365,242,500 days
3. Mayan calendar	- 365,242,129 days
4. Exact astronomical year	- 365,242,195 days
5. Tropical year of the modern astronomers	- 365,242,195 days
6. Civil year	- 365 days (ordinarily) 366 days (for a leap year)
7. Sidereal year	- 365 days, 6 hrs. 9 minutes, 9 secs. (a few minutes longer than the average civil year)

2.2 The Day

A day is the period of rotation of the earth about its own axis. The basic requirement of a standard of time is a repetitive process, in which a uniform pattern of recurring features may be recognised. Standards are therefore based on:

1. the rotation of the earth;
2. the oscillation of a free pendulum or a flat spiral spring;
3. the vibration of a molecule or a quarts crystal.

For all these, the main assumption is constancy of recurrence in interval.

Any time based on the rotation of the earth will only be uniform if the rate of rotation is uniform and it is now known that this condition is not exactly fulfilled. Therefore, the astronomers have adopted a new standard called 'EPHEMERIS TIME' (E.T.).

Ephemeris Time: The orbital motions of the moon and planets are used for ephemeris time. It is free from the irregularities in mean solar time caused by the variation in the rate of rotation of the earth, and is determined in practice as a correction to Greenwich mean time, which will bring observations of the right ascension and declination of the moon into agreement with the theoretically calculated values. Clocks are not actually regulated to ephemeris time; it is sufficient to keep a record of the corrections necessary. Mean solar time at Greenwich is called G.M.T.

2.3 The Second

The unit of time is the second. It is defined as the fraction

$$\frac{1}{31,556,925,9747} \text{ of the tropical year for 1900.}$$

January 0 at 12 h.E.T. This new unit of time is, by definition, invariable being a fixed fraction of an unambiguous interval of time. This is almost what the I.S.I. had adopted in the 'standards of weight and Measures Act' 1956, while adopting the metric system in India. The Act actually defined as follows:-

'A second means $\frac{1}{31,556,925,975}$ of the length of the tropical year for 1900.0, the year commencing at 12.00 hours universal time on the first day of January, 1900'.

By a resolution of the International Committee of Weights and Measures in 1956, the second of 'ephemeris time' becomes the 'SECOND'. A scale of time, based on an alternative natural standard is provided by a continuously running quartz clock, calibrated with reference to an atomic or molecular resonator. The frequency of a selected caesium resonance has been provisionally determined as 9,192,631,770 cycles per ephemeris second. The caesium standard thus provides an accurate and accessible time-scale approximate to ephemeris second. (see sec.11).

2.4 Different 'Days'

It is imperative to state what recurring event is to mark the end of the period called a day. If we take it as the time between two successive culminations of a fixed star, we get the 'SIDEREAL DAY'. If we measure from solar noon to the next solar noon by noting the length of the stylus on a sun dial, we get the 'SOLAR DAY'. Because the earth, while revolving about the Sun, also revolves about its own axis, our observer on earth sees one less culmination of the Sun than he sees culmination of a fixed star. Therefore, a year is about 365 solar days but 366 sidereal days. More accurately, the sidereal day is shorter by 3m 56s than a solar day. 'Solar time' is more useful than a 'sidereal time' but unfortunately the solar day fluctuates through the year. The chief cause of these fluctuations is the eccentricity of the earth's orbit. To correct for these fluctuations, the astronomer introduces a fictitious 'mean sun', which passes through the vernal equinox at the same time as the actual Sun but moves with uniform angular velocity along the celestial equator. All times referred to this fictitious Sun are called 'MEAN SOLAR TIMES'. The difference between the 'mean' and 'true' solar time is known as the 'time equation'. It is zero thrice a year - in mid April, mid June and early September but reaches a maximum of about 15 min. on certain months (in mid February more than 14 min. behind the clock and early in November when it is more than 16 min. ahead of the clock)

Thus, years and days are the intervals of duration, which science has woven into the thread of time. There are no simple natural rhythms of convenient period in terms of which the day can be calibrated, the human heart beat being too irregular.

In the F.P.S., C.G.S. and M.K.S. systems of units - (both absolute and gravitational) - the unit of time is the 'SECOND'. It is the interval of time equal to $\frac{1}{86,400}$ of a 'mean solar day' — (defined already). The International Astronomical Union gives the following definition: the (ephemeris) second is equal to $\frac{1}{31,556,925,975}$ of the tropical year, for 1900.0 January 0 d,12 h, ephemeris time.

3. SCALES OF TIME

Time has different meanings on different scales. This is an important aspect of the cosmoses of which there are at least SEVEN.

Table 2: A Table of Cosmoses

1. Protocosmos: the ultimate unmanifest cosmos of the Absolute.
2. Ayocosmos: the first manifestations of all possible systems of the worlds.
3. Macrocosmos: the cosmos of the individual systems within the Ayocosmos. In relation to Man, this is the galaxy-(the Milky way) - which contains the solar system.
4. Deuterocosmos: The cosmos of solar system.
5. Mesocosmos: The cosmos of planets, to which our earth belongs.
6. Tritocosmos: The cosmos of organic life.
7. Microcosmos: The cosmos of MAN

The following table gives the times for the 7 cosmoses listed above and also for: (1) cell, (2) atom, (3) electron and (4) proton. An essential feature of the cosmoses is that they are all discontinuous. There are four significant times, which determines the character of any cosmos, viz:-

1) the time of the quickest noticeable impression;
2) the time for breathing;
3) the period of waking and sleeping;
4) the life span.

Table 3

The Times of the Cosmoses

No.	Cosmos	Quickest impression	Breath	Waking and sleeping	Life
1.	Protocosmos	3×10^{15} yrs.	9×10^{19} yrs.	3×10^{23} yrs.	9×10^{2}[illegible]
2.	Ayocosmos (all possible worlds)	9×10^{10} ,,	3×10^{15} ,,	9×10^{19} ,,	3×10^{23} ,,
3.	Macrocosmos (the starry galaxy)	3×10^{6} ,,	9×10^{10} ,,	3×10^{15} ,,	9×10^{1}[illegible] ,,
4.	Deuterocosmos (Sun)	80 ,,	3×10^{6} ,,	9×10^{10} ,,	3×10^{15} ,,
5.	Mesocosmos (Earth)	24 hrs.	80 ,,	3×10^{6} ,,	9×10^{10} ,,
6.	Tritocosmos (organic life)	3 secs.	24 hrs.	80 ,,	3×10^{6} ,,
7.	Microcosmos (Man)	10^{-4} ,,	3 secs.	24 hrs.	80 ,,
8.	Cell		10^{-4} ,,	3 secs.	24 hrs.
9.	Atom			10^{-4} secs.	3 secs.
10.	Electron				10 secs.
11.	Proton				3×10^{-8} ,,

The following table summarises the above listed 4 characteristics for: (1) organic life, (2) man and (3) Cell.

Table 4

	Cosmos	Quickest impression	Breath	Waking and sleeping	Life
1.	Organic life	3 secs.	24 hrs.	80 years	3 million years
2.	Man	$\frac{1}{10,000}$ secs.	3 secs.	24 hrs.	80 years
3.	Cell	$\frac{1}{300,000,000}$,,	$\frac{1}{10,000}$,,	3 secs.	24 hrs.

In the case of man, these four significant times are, on an average, related to each other by a factor = 30,000 (approximately).

$$\text{e.g}\left(\frac{3 \text{ sec}}{\frac{1}{10,000}}\right) = 30,000; \left(\frac{24 \times 60 \times 60}{3}\right) = 28,8000 \ (\simeq 30,000);$$

$$\left(\frac{80 \times 365 \times 24}{24}\right) = 29,200 \simeq 30,000.$$

From the above table, we note that the organic life, as a whole, breathes once a day, whereas in the cosmos of cells a day represents its complete life span. Therefore, one infers that the time scales of the different cosmoses are also related by a factor of 30,000 - (see Table 5). In the cosmos of man, the times are in accordance with ordinary everyday experience. We breath in and out, on an average, once in 3 secons. Day and night follow every 24 hours and the average life of man is of the order of 80 years-(Biblical span of life: 70 years). The time of quickest impression is perhaps unfamiliar, but we find that the eye can be aware of a flash of light lasting for about $\frac{1}{10,000}$ sec.; if the duration is shorter than this no impression is received by the ratina. In the cosmos of cells, it is a physiological fact that the ordinary cells in living matter do have a life-time measured in days; they are continually dying and being replaced and some of the cells of the body live for hardly 24 hours!

The time-scale of organic life is again consistent with what we can appreciate. Though the individual cells have their own breath, the major processes of organic life, like the PHOTO SYNTHESIS in plants or the intake of food and excretion of waste in animals, have a rhythm connected to the earth's diurnal period of rotation.

At the other end of the scale (Table No.3), we have a life of only 3 secons for an atom and $\frac{1}{10,000}$ sec. for an electron. The electron is elusive. We can never say that an electron exists at any moment or place but only that there is some evidence that it was there a moment ago. Supposed life of some of the particle of nucleus is very much less than a millionth of a second -- e.g.

for a Muon: $(2.212 \pm 0.001) \times 10^{-6}$ sec.
Hyperon: $(2.205 \pm 0.086) \times 10^{-10}$ sec.

The seven cosmoses (4 to 10 in Table 3) form an integrated system. At one end of the scale, we have the Sun, the primary source of energy for all the succeeding cosmoses. This very energy is derived from the formation of atoms by the integration of electrons at the other end of the scale. There is a similar correspondence between the earth and the atoms; and between organic life and cell.

This relationship can be expressed in terms of 'Relative Time Scales'. The time scale of the sun is $(30,000)^3$ times <u>longer</u> than that of man, while the time scale of the electron is $(30,000)^3$ times <u>shorter</u>, so that the two combined equal to the time scale of man. Similarly, with the other cosmoses in the period, as shown in the Table 5, below.

Table 5

Cosmos	Relative Time Scale
1. Sun	$(30,000)^3$
2. Earth	$(30,000)^2$
3. Organic Life	(30,000)
4. Man	1 (unity)
5. Cell	1/30,000
6. Atom	$1/(30,000)^2$
7. Electron	$\frac{1}{(30,000)^3}$

This is only another way of saying that man's understanding is limited by his 'scale'. Therefore, it is clear that 'time' has different meanings in different cosmoses, which have different relative time scales.

4. OCCURRENCE OF TIME IN PHYSICAL QUANTITIES

Time occurs in the measurement of a number of physical quantities: This is readily seen from the following dimensional equations:-

Dimensional value

(1) <u>Velocity</u>: (linear) $[v] = [LT^{-1}]$

(angular) $[\omega] = [T^{-1}]$

(2) <u>Accln</u>: (linear) $[a] = [LT^{-2}]$

(angular) $\frac{\omega}{t} = [\alpha] = [T^{-2}]$

(3) Momentum: $(m \times v) = [MLT^{-1}]$

Angular momentum: $[L] = I\omega = [L^2MT^{-1}]$ (when I = the moment of inertia)

(4) Force $[F] = [MLT^{-2}]$

(5) Impuse $[F \times t] = [MLT^{-1}]$

(6) Work of energy $[W] = [ML^2T^{-2}]$

(7) Power $[P] = [ML^2T^{-3}]$

(8) Frequency $[f] = [T^{-1}]$.

Thus, the 'time' is one of the three physical quantities length, mass and time arbitrarily chosen as three basic quantities in any system of units but, as a dimension, pervades in a number of important quantities in physics and engineering like: velocity, acceleration, momentum, force, work or energy.

5. COSMOLOGICAL CONSIDERATIONS

'In relation to time standards, the physicist's criterion is that the use of an acceptable standard along with other standards of measurements, enables intuitively recognized irregularities of the external world to be described in terms of simple quantitative laws. Such a body of laws, when it becomes sufficiently all embracing, qualifies for recognition as a 'cosmology'.' Lack of precisely defined standards did not, however, prevent the ancients from elaborating their fanciful pre-scientific cosmologies, and, in later times, the slow process of refinement of definition of a standard proceeded in parallel with the gradual simplification of the world picture of the astronomer'.

Actually, the procession of the equinoxes was discovered by HIPPARCHUS in 130 B.C. while our modern cosmology starts from 16th century A.D. The cosmological beliefs of our age are:

1) The sun differs from any one of the stars only in that it is much nearer the earth (by a factor of 10^5 than the nearest of them).

2) It is enormously larger than the earth, which seen from the sun revolves in a plane orbit around it, at a distance which varies continuously within a range of 3.3% of the mean during each revolution, the mean distance remaining constant.

3) The earth rotates about an axis which is inclined to the plane of its orbit (the angle between this axis and the normal to the orbit being about $23^{\circ}27'$), the sense of its rotation being the same as the sense of its revolution about the sun.
4) The rotational axis itself rotates very slowly about a direction normal to the earth's orbit, in the sense opposite to that in which the normal orbit is described. The basic assumption for our scientific time standard is that the sidereal day is repeated indefinitely as a constant interval. This is seen in its true context as the assumption in cosmology that the period of rotation of the earth about its axis is constant. The apparently complete success of Newtonian mechanics, for two centuries after his death, in describing the phenomena of the external world on the basis of this assumption, is ample proof of its close approximation to 'truth'. Now there are two questions to be considered:-
1) whether there is any recent evidence that the above assumption is not strictly valid?
2) whether its acceptance involves any logical inconsistencies?
The answers to these questions can be summed up as follows:
The rate of the earth's rotation is, in fact, slowly decreasing, though by no more than 1 part in 10^8 per century (corresponding to an increase of period of rotation of less than 0.001 second per 100 years). The various influences, which might produce changes in our standard time-keeper, at this stage in its evolution very nearly cancel one another out.

6. THE GEOLOGIC TIME SCALE

Geologists 'read' the earth's history in sufficient detail that they can locate the major events of the last 4 billion years (4 x 10^9 years) and fit them into the sequence of 'geologic time scale'. In this time scale, as in the human time scales, the historical record is less accurate the farther back in time we go. Reliable dating in years has been available only since the 1930's. The named intervals of geological time are of unequal duration, because the original division of time was based on the relative time of geological events and not absolute years. Archeologists speak of the 'Bronze Age' or the 'Stone Age', without referring to a specific date in years.

The major division of geological time are called '<u>ERAS</u>'. Eras are divided into 'periods'. Division of periods are called '<u>EPOCHS</u>'. Epochs are portions og geological time, generally comprising only a 'few million years'.

6.1 Development of the Geologic Time Scale.

The geologic time scale is the end-product of a thought - sequence extending over two centuries. Classification of geologic time into portions comparable to 'ERAS', can be dated from the late 18th century. The use of formal geologic time scale on an international basis was introduced only in 1893. The modern classification scheme is now considered an arbitrary division of continuous geologic time into named segments corresponding to rock exposures at classical localities.

The following table gives the geologic time scale. Oldest rocks: 4.0 billion years old = 4×10^9 years. Age of elements (maximum possible age of earth) = 5.6 billion years. Age of stony meteorites: 4.5 billion years.

Table 6

The Geologic Time Scale

Millions of years age	Era	Period	Epoch
1		Quarternary	Pleistocene
10			Pliocene
23	Cenozoic	Tertiary	Miocene
34			Oligocene
			Eocene
70			Paleocene
135		Cretaceous	
180	Mesozoic	Jurassic	
200		Triassic	
270		Permian	
320	Paleozoic	Pennsylvania	
350		Mississipian	
400		Devonian	
430		Silurian	
490		Ordovician	
540		Cambian	
600			
1900	Late Precambian		
4000	Early Precambian		

(Taken from p.472 and 473 of 'Concepts in Physical Sciences' by Sidney Rosen Robert Siegfried John M. Dennison, Harper and Row, N.Y.)

Dates based on work by J.L. KULP, 1960.

6.1 Determining Dates in years

The concept of half-life in a radioactivity decay series provides a key to developing 'Radio active dating' methods.

A half-life is defined as the time required for half of the initial radio active atoms in a sample of radioactive substances to disintegrate to daughter products of radio active transformation. Age of a mineral crystal containing uranium

$$= \frac{\text{no. of uranium atoms}}{\text{no. of atoms of } U + Pb}$$

This was suggested by Bertram Boltwood at Yale in 1907.

The half-life of $_{92}U^{238}$ is 4.5 billion years.

The age of the crystal is: half-life in years multiplied by age of crystal expressed in half lives.

Table 7

Half lives of the Uranium Series

U^{238}	: 4.5×10^4 year	P_b^{214}	: 26.8 min.
Th^{234}	: 24.1 day	B_i^{214}	: 19.7 ,,
P_a^{234}	: 1.18 min	P_o^{214}	: 1.64×10^{-4} sec.
U^{234}	: 2.48×10^5 year	P_b^{210}	: 19.4 year
Th^{230}	: 8×10^4 ,,	B_i^{210}	: 5 days
R_a^{226}	: 1,620 ,,	P_o^{210}	: 188.4 days
R_n^{222}	: 382 ,,	P_b^{216}	: stable
P_o^{218}	: 3.05 min.		

6.2 Units of Measurement of Quantities of Radio Active Decay.

When the nuclei of radio active matter decay, three types of radiation are emitted: (1) alpha, (2) beta and (3) gamma radiation. Radio active decay is described by the following quantities:

1. The decay constant
2. Half-life period
3. Radio activity
4. Specific Radioactivity
5. Concentration of radio active matter in media like air, water, etc.

6.3 Units of measurement of these quantities.

1. Decay Constant. The decay constant is a quantity equal to the proportion of radioactive atoms decaying in one second. The unit of measurement of decay constant λ can be determined from:

$$dN = -\lambda N \cdot dt$$

where N = no. of atoms in the radioactive substance at the beginning of the time interval dt, and

dN = no. of atoms, which decay over the time (dt).

From the above equation, we find that

$$\lambda = -\left(\frac{dN}{N \cdot dt}\right)$$

is a dimensionless quantity. Therefore, the decay constant is measured in (sec^{-1}).

2. <u>Half-life</u>: The half-life (T) is the time in which half the nuclei of a radioactive material decay. The half life is measured in time units: seconds, minutes, hours, days or years. (see sec.6.1).

3. <u>Radioactivity</u>: The radioactivity of a substance is the number of atoms which decay per second in a given radioactive preparation. Radioactivity = $\alpha = \frac{dN}{dt} = \lambda N$

i.e. radioactivity is proportional to the amount of radioactive matter in the given preparation. Hence measuring the radio-activity is actually the same as measuring the amount of radio active matter (the two quantities being directly proportional).

The radioactivity of a preparation, in terms of α and β decay, is measured in units called: 'Curies' or 'Rutherfords'

1. <u>The Curie</u>:- It is the amount of radioactive substance which undergoes exactly 3.7×10^{10} <u>decays a second</u>. The Curie is used to form the fractional units: Millicurie and μ curie.

2. <u>The Rutherford</u>: It is the amount of radioactive matter which undergoes 10^6 <u>decays a second</u>.

The 'Curie' and 'rutherford' are related as follows:-

$$1 \text{ curie} = 3.7 \times 10^4 \text{ rutherfords}$$

$$1 \text{ rutherford} = 2.7 \times 10^{-5} \text{ curie}$$

(The activity of a preparation in terms of gamma rays is measured in gram-equivalents of radium).

7. MEASUREMENT OF TIME

Time measurement consists in counting the repetitions of any recurring phenomenon, and if the interval between successive recurrences is appreciable, in further subdivision. The phenomenon most often used is the rotation of the earth, where the counting is done by 'days'. Days are measured by observing the passages of the meridian by stars, and are subdivided into hours, minutes and seconds by precision clocks. However, as discussed already, the day is subject to variation in duration. Therefore, when the utmost precision is required, years are measured and subdivided. Broadly, a time-interval may be measured in 2 ways:-

1) as the duration or interval between two known epochs;

2) simply by counting from an arbitrary starting point, as is done with the aid of a stop watch.

7.1 Time Interval Measurement.

For the measurement of elapsed periods of time, there are two classes of times:

i) clocks, watches, etc., which measure the time of the day;

ii) stop-watches, which measure time intervals.

The smallest measurable time interval is 10^{-10}sec.

A large number of devices and methods are available for measuring time-intervals-(short or long). These devices are based on the following principles:-

1. <u>Timers controlled by the acceleration due to gravity</u>:

These include pendulum and water clocks and glasses.

2. <u>Mechanical vibrations depending upon the constancy of the elastic properties of materials</u>: e.g. vibrating reeds, tuning forks, quartz crystals, balance wheel escapement units used in ordinary watches, clocks and stopwatches. Electric circuits are required to obtain time measurements with tuning forks and quartz and quartz crystals. (Clocks based on quartz crystals are called 'crystal clocks')

3. <u>Electrical oscillations depending upon the constancy of circuit elements</u>:- These include the rate of discharge of a capacitance and inductance-capacitance circuits. They are used in laboratories to measure short intervals of time.

4. <u>Vibration of atoms in the atomic clock</u>: This measures the time of day precisely.

5. <u>The rotation of the members of the solar system about their axes and about the sun</u>: They are used in measuring longer periods of time. The rotation of the earth about its own axis determines the length of the day; the rotation of the earth about the sun determines the year. Instruments for direct measurement include transit telescopes, sundials, etc.

6. <u>The velocity of light or of other electromagnetic radiation</u>:

This is used in time-interval measurement. Radiowaves, which have the same velocity as that of light may traverse cavity resonators, that is a fixed distance and if the traverse is repetitive, result in an electrical output of a particular frequency, which can be used to measure small time intervals. The difference in the velocity of light and of electricity flowing in wires (using the KERR cell as a valve), is utilised for measuring very ~~small~~ intervals of time.

7. Radioactivity decay: This can be used to measure both (i) long and ii) short intervals of geologic time. (see 6.1)

8. The measurable rate of mechanical rotation of a body:- This is used to measure time intervals as the rotating body can be made to give a periodic signal by a rotating mirror, e.g. the reflection of light focussed upon the mirror at one point of its rotation will give this signal.

8. Relativistic Time

Einstein's theory of Relativity deals with fundamental ideas concerning: space,time, mass, motion , gravitation, energy, etc. Some of these ideas are difficult to grasp because they appear to be opposed to our everyday experience. A few aspects of relativity in relation to time, will be mentioned below:

(i) The relationship between time and space: Three dimensions are necessary to locate a point on the earth. They correspond to (1), height, (2) length and (3) breadth. But, according to 'Relativity', we must use a fourth dimension, 'time', to pinpoint a certain event. For example, if we wish to meet some one inside a deep mine, we have to specify both: (1) when and (2) where. Here we make use of four dimensions of 'space-time'.

Thus in the development of the theory of relativity an attempt is made that 'time' on par with the dimensions of length. This attempt met with considerable success, though this led to the entering of the perplexing quantity into specification.

(ii) Space, motion and time are relative and depend upon the frame of reference that we choose.

Thus we live in a multi-dimensional space-time universe that may be finite or infinite in extent and whose beginning and ultimate destiny we do not know.

iii) It has been predicted by relativity, that passengers on a very high speed, space-ship would become 'aged' much more slowly on a long journey than their relations and friends upon the earth. This would result in thousands of years being elapsed as per the years measured on the earth, before the journey was completed, but this interval of time would be measured only in 'decades' by the passengers in the high speed space-ship. This is due to 'Time dilation'.

8.1. Time Dilation Formula

$$t' = t\sqrt{1 - \frac{v^2}{c^2}}$$

If on earth a time t elapses, then on a space-ship travelling with velocity, elapsed time is t', given by the formula, in which c is the velocity of light.

Time dilation becomes noticeable only when v is close to C. As long as $\left(\frac{v}{c}\right)$ is < 10, t' differs from t by less than 1/2 % only.

9. 'CHRONON' THE UNIT OF TIME FOR THE ATOMIC WORLD

One 'Chronon' is equivalent to 10^{-24} sec. This unit may prove to be the ultimate 'atom of time'. The unit of neuro-physiological time (which presumably controls our thought processes) is expected to be of the order of a millisecond (10^{-3} sec.) In recent years, speculations concerning a smallest interval of time have been revived, following the discovery that the electron and the proton have effective diameters of the order of 10^{-13}cm. It has been suggested that this may be the smallest length that can be determined. Correspondingly, the shortest interval of time may be obtained by dividing this length by the highest possible velocity (that of e.m. wave in vacuo = 3×10^{10} cm/sec.). On this basis, it follows that a 'chronon' is of the order of $\left(\frac{10^{-13}}{3 \times 10^{10}}\right) = 10^{-24}$ sec.

10. NANOSECOND COMPUTING

The computer industry is now on the verge of completing a most significant jump in computing speed - from microseconds to milli-microseconds or nano-seconds (10^{-9}) - having succeeded in translating fast physical phenomena into fast computing techniques in which the operations occur in the time light travels one foot. Speed of light in vacuum is 11.8 in/n sec or 1 ft/n sec. Nano second techniques are now in a state of consolidation.

11. THE LATEST INTERNATIONAL UNIT OF TIME

'The 12th CGPM: General conference on Weights and Measures, considering that, in spite of the results obtained in the use of Cesium as an atomic frequency standard, the time has not yet come for the general conference to adopt a new definition of the 'second', a fundamental unit of the International System of units - (abbreviation 'SI'), because of the new and important progress, which may arise from current researches, and considering also that it is not possible to wait any longer to base physical measurements of time on atomic or molecular frequency standards, empowered the international committee on Weights and Measures to designate the atomic or molecular standards of frequency to be used temporarily.

The International Committee then acquainted the CGPM with the following declaration:

The standard to be used is the transition between the hyperfine levels F = 4, M = 0 and F = 3, M = 0 of the fundamental state $^2S_{\frac{1}{2}}$ of the Cesium 133 atom unperturbed by external fields. The value: 9,192,631,770 hertz is assigned to the frequency of this transition' (Resolution translated from the original French, passed in 1964)

12. TIME ZONES OF THE WORLD

12.1 Zone and Standard Times:

In order to avoid the inconvenience of the continuous change of mean solar time with longitude, 'zone time' or '<u>civil time</u>' is the time generally used. Earth is divided into 24 time-zones, each approximately 15^o wide and centred on standard longitudes 0^o, 15^o, 30^o, 45^o and so on. With each of these zones, the time kept is the mean solar time of the standard meridian. All civilized nations use 'zone time'. Zone time is reckoned from 0 and 24 hour for the most official purposes, the time in hours and minutes being expressed by a four figure group followed by zone designation.

12.2 International Date Line:

Persons going westward around the earth must advance their time by one day, and these going eastward must retard their time by one day, in order to be in agreement with their neighbours, when they return home from their voyage. The International Date Line is the name given to a line following approximately the 180^{o}th meridian but avoiding inhabited islands, where the change of date is made conveniently.

Some Measured Time Intervals

The table below shows the wide range of time intervals that can be measured:

	Seconds
Age of the earth	1.3×10^{17}
Age of the pyramid of cheops	1.5×10^{11}
Human life expectancy (USA)	2×10^{9}
Time of the earth's orbit around the sun (1 year)	3.1×10^{7}
Time of the earth's rotation about the axis(1 day)	8.6×10^{4}
Period of the Echo II Satellite	5.1×10^{3}
Half life of the free neutron	7.0×10^{2}
Time between the normal hearbeats	8.0×10^{-1}
Period of concert - A tuning fork	2.3×10^{-3}
Half life of the muon	2.2×10^{-6}
Period of oscillation of 3 cm microwave	1.0×10^{-10}
Typical period of rotation of a molecule	1×10^{-12}
Half life of the neutral pion	2.2×10^{-16}
Period of oscillation of a 1-Mev gamma ray (calculated)	4×10^{-21}
Time for a fast elementary particle to pass through a mediumized nucleus (calculated)	2×10^{-23}

(Extracted from Table 1-2, p.7 of 'PHYSICS' by David Halliday and Robert Resnick (John Wiley, New York, 1966)

ENERGY

(UNITS IN PHYSICS, ENGINEERING AND TECHNOLOGY)

ENERGY

(Units in Physics and Engineering)

1. Introduction.

1.1. What is energy? A definition:

The usual definition of energy is the 'capacity for doing work'. A broader definition is 'Capacity for producing effects', which may differ very widely -

e.g. i) changing the position of a body;
ii) deforming a body;
iii) raising the temperature of body.

1.2. Forms

Energy exists in several forms:-
1) Mechanical, 2) Thermal, 3) Chemical, 4) Acoustical,
5) Electrical, 6) Magnetic, 7) Gravitational, 8) Radiation,
9) Nuclear energy.

The object of this monograph is to review the various units of energy in Science, Engineering and Technology and also in Nuclear Physics.

2. UNITS (General)

Units of 'work' and 'energy' are the same.

2) Energy is always the product of 2 factors:-

(intensity factor) x (capacity factor)

Mechanical work (in ergs.) = Force (in dynes) x distance (in cm)
,, ,, = Pressure (dynes/cm^2) x Volume (in cm^3)

The usual units in mechanics:-

System	Absolute unit of	Gravitational unit of work
F.P.S.	1 foot-poundal	1 foot-pound = 32 ft. pdls.
C.G.S.	1 dyne-cm or erg.	1 cm. gr (wt) = 981 dynes
M.K.S. or S.I.	1 metre-newton = 10^7 ergs. or 1 Joule	1 metre-kg. (force) = 981 Joules

'Power' is 'energy' expended in unit time - therefore 'power' multiplied by 'time' gives the energy. In the field of mechanics, there is a common British unit of power called: the Horse Power (H.P.), which is 550 foot pounds of work done per second or 550 x 60 = 33,000 ft.lbs.per minute.

There is the corresponding metric horse power, 75 kgf metre/sec. which is slightly less than the British horse power.

Br. H.P. = 746 watts

metric ,, = 736 watts

To avoid this confusion, the use of 'horse power' itself has to be altogether discontinued and hence' '<u>Joule</u>' will be the only unit of energy for all branches of Science, Engineering and Technology, internationally. In electrical engineering, the kilowatthour will be the main unit of energy and for bigger energies, megawatthourse (Mwh) = 10^6 watthours, and gigawatt hours (Gwh) = 10^9 watthours will be used. Similarly, from the coherent unit: Wattsecond, Kilowattsecond (kws) and megawatt second (Mws) should be the derived units.

The following energy units are equal:-

1 Joule $\equiv$ 1 Newton-metre $\equiv$ 1 wattsecond $\equiv$ 1 Volt.Amp.Second $\equiv$ $kg.m^2/s^2$

While 'Joule' could be used for all branches, as the unit of energy,

'Newton-metre' is useful in <u>mechanics</u>,

'watt-second' (and its multiples) in <u>magnetism</u>.

'Kilowatthour' (,,) in <u>electricity</u>.

(i) In the case of heat,

heat (in calories) = Tempr. difference (in degrees) x heat capacity (cal/deg)

(ii) elec. energy or work (in Joules) = Potential difference (in Volts) x charge (in coulombs)

(iii) Magnetic energy (in ergs) = Mag. field strength (in Gauss x magnetisation)

(iv) Gravitational ,, (in ergs) = Force of gravity (in dynes) x height (in cm)

The relationship between them is shown by the following Table.

Table I

Unit	k.w.h.	kcal	kgfm	cal	w.s.
Kilowatt	1	860	3.67×10^5	$8.6. \times 10^6$	3.6×10^6
Kilocalorie	1.16×10^{-3}	1	427	10^3	4.18×10^3
Kilopondmetre	2.72×10^{-6}	2.36×10^{-3}	1	2.35	9.81
Caloric	1.16×10^{-6}	10^{-3}	0.427	1	4.18
Wattsecond	2.78×10^{-7}	2.39×10^{-4}	0.102	0.239	1

There are a large number of units particularly in English speaking countries as the heat energy units. They are:-

1. The British Thermal Unit (abb: B. Th. U): It is the heat required to raise the temperature of 1 lb of water through 1° Fahrenheit.
2. The centrigrade heat unit (abb: C.H.U.): It is the heat required to raise the temperature of 1 lb of water through 1° c.
3. A 'Therm' is a bigger unit than the B. Th. U.

$$1 \text{ Therm} = 10^5 \text{ B. Th. U.}$$

The relationship among mechanical, electrical and thermal units is as follows:

Conversion factors:-

Table 2.

1 ft. lb.	=	0.000000377 kwh
1 B.Th.U.	=	0.000293 kwh
1 J	=	4.2×10^7 ergs/calorie
1 J	=	778 ft. lbs/B.Th.U.
1 kwh.	=	1.341 h.p. hours
1 C.H.U.	=	1900 J.
1 lb.caloric	=	453.6 gr. calories
1 B.Th.U.	=	252 gr. Calories
1 Therm	=	100,000 B.Th.U.

Note: The electrical energy is measured in kilowatthours. One kwh is called 'B.O.T.' or 'B.T.U.' This has to be distinguished from British Thermal unit (B.Th.U.). A B.Th.U. is a very small unit compared to B.O.T. (1 B.Th.U. = 0.000293 kwh)

3. Work or energy units in the U.K. and the U.S.A.

As stated already, the horse power as the unit of power and the horse power hour, as the unit of energy, are widely used both in the U.K. and the U.S.A.

The following table gives the relationship among:-

1) ft lb, 2) hp. hr., 3) B.Th.U. and 4) k. cal.

Table 3

	ft. lb.	hp.hr.	B.Th.U.	K.Cal
Foot pound	1	5.05×10^{-7}	1.29×10^{-3}	3.25×10^{-4}
Horse power hour	1.98×10^{6}	1	2550	645
B.Th.U.	778	3.93×10^{-4}	1	0.253
Kilocalories				1

4. <u>The energy unit</u>: Q

In estimating the total power resources of the earth, a very large unit, symbol: Q, has been introduced.

$$
\begin{aligned}
1\ Q &= 10^{18}\ \text{B.Th.U.} \\
&= 2.52 \times 10^{17}\ \text{k. cal} \\
&= 2.93 \times 10^{14}\ \text{kwh} \\
&= 293{,}000\ \text{Twh}
\end{aligned}
$$

Because of the large amounts of energy involved in global consumption, this large unit of energy has been introduced. It is used for 'energy content', not 'electricity equivalent', of fuel reserves.

$$
\begin{aligned}
1\ Q \text{ is approximately } &= 300 \times 10^{12}\ \text{kwh} \\
&= 400 \times 10^{12}\ \text{h.p.hr.} \\
&= 0.25 \times 10^{18}\ \text{k. cal.}
\end{aligned}
$$

<u>Exact</u> conversion formulae are:-

$$1\ Q = 2.93 \times 10^{12}\ \text{kwh} = 393.0 \times 10^{12}\ \text{H.P.h.}$$
$$= 0.251996 \times 10^{18}\ \text{kcal} = 1.05518 \times 10^{21}\ \text{Joule}$$
$$= 1.07599 \times 10^{20}\ \text{k gm.}$$
$$= 7.7826 \times 10^{20}\ \text{ft. lb.}$$

6. <u>Sound Energy Units</u>

<u>'Sound energy' and 'Sound energy density'</u>:-

The particles of an elastic medium through which sound waves are propagated undergo an oscillating motion and therefore possess kinetic and potential energy. This energy is called the <u>'sound energy'</u>.

The amount of sound energy contained in a unit volume of elastic medium is called the sound energy density, given by the equation:-

$$\omega = k \frac{W}{V}$$

where w is the sound energy contained in the volume V.

In S.I. units, $\omega = \frac{\text{Joule}}{m^3}$. Thus, the unit of sound energy density in the Mks or 'S.I.' system is the energy density at which 1 Joule of energy is concentrated in $1m^3$ of the medium. Its dimensions are:-

$$[\omega] = \frac{[W]}{[V]} = \frac{m^2 . Kg . sec^{-2}}{m^3} = m^{-1} Kg . sec^{-2}$$

The sound energy density in the C.G.S. system is erg/cm^3, its dimensions being: cm^{-1}, g. sec^{-2}.

5.1 Sound Energy Flux:-

The sound energy flux through a surface is the amount of energy passing through the surface during one period, in a direction normal to the surface.

The sound energy flux ϕ is obtained from the equation:-

$$\phi = k \bar{\omega} T S v,$$

where $\bar{\omega}$ is the mean energy density for one period,

S is the area of the surface,

T is the period,

v is the speed in sound

Putting k = 1, $\bar{\omega} = 1\ j/m^3$, T = 1 sec, S = $1m^2$ and v = 1m/sec., we get the unit of energy flux in the MKS System:-

$$MKS(\phi) = 1 \cdot 1 \frac{J}{m^3} \cdot 1 sec \cdot 1 m^2 \, 1 \frac{m}{sec} = 1 \text{ joule}.$$

The sound energy flux is measured in the CGS system in ergs.

5.3 Mean sound energy flux:- The mean sound energy flux through a surface is the average amount of energy per period passing through a given surface per unit of time. The mean flux is determined from the equation:-

$$\bar{\phi} = \frac{K \phi}{T} = \frac{K \cdot \bar{\omega} \cdot T \cdot S v}{T} = K \bar{\omega} S v$$

Assuming that $k = 1$, $\bar{\omega} = 1.J/m^3$, $S = 1m^2$ and $V = 1m/sec$, the unit for the mean flux in the MKS System becomes:-

$$1 \, MKS(\varphi) = 1 \cdot \frac{J}{sec} \, (watt).$$

The unit of mean sound energy flux through a surface in the MKS System is the mean sound energy flux of the sound waves for which one joule of energy passes through the given surface is one second.

$$[\bar{\varphi}] = [\bar{\omega}][s][v] = m^{-1}. Kg. sec^{-2} m^2. m. sec^{-1}$$
$$= m^2. Kg. sec^{-3}$$

In the CGS System, the unit of mean mean energy flux is the (ergs/sec), its dimension being ($cm^2.g.sec^{-3}$).
As seen from the above, the mean sound energy flux is measured in units of power (watts).

5.4 SOUND INTENSITY (Sound Strength).

The sound intensity or strength is the mean sound energy flux through a unit area:

$$I = k \frac{\bar{\varphi}}{s},$$

where $\bar{\phi}$ is the mean sound energy flux through the surface S. Sound intensity can also be defined thus: 'The amount of sound energy, average per period, passing through a unit area per unit time'. Assuming that $k = 1$, $\bar{\varphi} = 1J/s$ and $S = 1m^2$, we get that the unit of sound intensity in the MKS system is:

$$1MKS(I) = 1 \cdot \frac{1\frac{J}{sec}}{1m^2} = 1\frac{J}{sec.m^2} = \frac{1\ watt}{m^2}$$

The unit of sound intensity in the MKS system is taken as the intensity at which 1 Joule of energy/period passes through $1m^2$ of a surface (perpendicular to the direction of propagation) in one second. The dimensions of this unit are:-

$$[I] = \frac{[\bar{\varphi}]}{[S]} = \frac{m^2 . kg . sec^{-3}}{m^2} = kg . sec^{-3}$$

Therefore, the sound intensity is measured in the CGS system (in $erg/sec\text{-}cm^2$), its dimension being ($g.sec.^{-3}$). These units of sound intensity are rarely used.

6. <u>Units of energy in Electromagnetic Radiation</u>.

The range of electromagnetic waves subjected to a scientific study so far are of wavelengths: 10^6 cm to x rays, (of a wavelength of 10^{-12}cm.) Although, these waves may differ in wave length as well as mode of excitation, most types of e.m. radiation have certain common physical properties, such as:
(1) volumetric density of the energy, (2) energy flux,
(3) Intensity of energy flux, (4) surface density of energy flux.

6.1 Units for the measurement of energy quantities in Electromagnetic Radiation.

The energy density is the amount of energy, contained in a unit volume. There are two radiation energy densities:-

(1) Integral energy density:- It is the total energy of the e.m. radiation for all wavelengths present in the unit volume. The integral energy density 'w' is determined from the equation.

$\omega = \frac{dw}{dV}$, where dw is the total energy for all wavelength present in the volume dV.

The unit of measurement of the integral energy density is:-

In the MKS System: J/m^3 (dimensions: m^{-1}. kg. sec^{-2})

In the CGS System: erg./cm^3 (,, cm^{-1}. g. sec^{-2})

2. Spectral energy density:-

If we isolate the e.m. radiation with wavelength: λ to λ_1 $(= \lambda + d\lambda)$ and determine the radiation energy in a unit volume of wavelength within the range $d\lambda$, then the ratio: $w_\lambda = \frac{(dw)}{(d\lambda)}$ is called the radiation energy density. Therefore, the spectral energy density is a quantity numerically equal to the energy concentrated in a unit volume and corresponding to a single interval of wave length near the wavelength λ. From the above equation, we find that the spectral energy is measured:-

In the MKS system: in $J/m^2.m$ (dimensions: m^{-2}. kg. sec.$^{-2}$)
In the CGS System: in erg./cm^2 c.m. (dimensions: cm^{-2}. g. sec.$^{-2}$)
These units are used for measuring the spectral energy density over the radio wave band. For e.m. waves of shorter wavelength (including the visible spectrum, we use the units. $J/(m^3.A)$ and erg/(cm^2.A), since the length of these waves are usually expressed in Angstrom units ($A^o = 10^{-8}$ cm).

The spectral density can also be determined with respect to the frequency interval. Then the spectral energy density of radiation ω , is taken as the energy concentrated in a unit volume and corresponding to a single interval of frequencies close to the frequency ν. The units of measurement of spectral density, with reference to the unit frequency interval, can be obtained from the equation:

$$\omega_\nu = \frac{d\omega}{d\nu}$$

From this equation, it follows that the spectral energy density is measured:
In the MKS system: in J/m^2. sec.$^{-1}$ (dimensions: m^{-1}. kg. sec^{-1})
In the CGS system: in erg/cm^3 sec^{-1} (dimensions: cm^{-2}. g. sec^{-1})

6.1.2 Radiant energy flux or Radiant flux:-

The energy flux of e.m. radiation over a surface is the energy transferred by e.m. waves through a given surface per unit time. The following kinds of energy flux are usually considered:-

1. <u>The Integral Radiant Flux</u> (ϕ):- This is the total energy transferred by an area S by waves of all wavelength per unit time. The integral flux is obtained from the equation.

$\phi = \frac{dW}{dt}$, where dW is the energy transferred over the surface in the time dt .

It follows that the integral flux is measured in units of 'power' i.e.

in the MKS system: in J/sec (watt) and

in the CGS system: in erg./sec.

2. <u>SPECTRAL RADIANT ENERGY FLUX</u>

This flux ϕ_λ (ϕ_ν) is the energy transfered by e.m. waves through an area S per unit time internal of wave length near a wavelength λ (or per unit interval of frequency near a frequency ν).

The spectral energy flux is determined from the equations:

$$\phi_\lambda = \left(\frac{d\phi}{d\lambda}\right)$$

$$\phi_\nu = \left(\frac{d\phi}{d\nu}\right)$$

From these equations, it follows that the spectral energy flux is:

in the MKS system, in watts/m (dimensions: m. kg. sec^{-3})

or in watts/sec^{-1} (dimensions: m^2 kg. sec^{-2})

in the CGS system, in erg/(sec.cm) (,, cm.g.sec^{-3})or

erg/sec.sec^{-1} (dimensions cm^2.gsec^{-2})

These units are useful in measuring the spectral radiant energy flux for electromagnetic wavelengths. (In the region of the shorter wavelength, we use the units: (watts/A°) and (erg/sec. A°).

3. ENERGY FLUX INTENSITY

The '<u>surface energy flux density</u>' or '<u>energy flux intensity</u>' is the energy flux through a unit of surface.

There are two energy flux intensities:-

1. <u>The integral energy flux intensity</u>: This is the total flux through a unit of surface.

The integral flux intensity I is determined from the equation:-

$$I = \frac{d\varphi}{ds}$$, where $d\varphi$ is the internal energy flux through the surface.

Therefore, it follows that the integral flux intensity is measured, In the MKS system, in watt/m^2 (dimensions: kg. sec.$^{-3}$) and in the CGS system, in erg./(sec.cm^2) (dimensions: g. sec^{-3}).

2. <u>The spectral energy flux intensity</u>:- The spectral radiant energy flux $I_\lambda (I_\gamma)$ is the spectral energy flux passing through a unit. The spectral flux intensity is determined by the equation:

$$I_\lambda = \frac{d\varphi_\lambda}{ds} \; ; \; I_\nu = \frac{d\varphi_\nu}{ds} ,$$

where $d\phi_\lambda$ $(d\phi_\nu)$ is the spectral energy flux through an area ds. Therefore the spectral flux intensity is measured.

In the MKS system, in watt/(m.m^2) (dimensions: m^{-1}. kg. sec^{-1}

or in watt/(sec^{-1}.m^2)(dimensions kg. sec^{-2})

In the CGS system in erg/(sec. c.m. cm^2)(dimensions cm^{-1}.g.sec^{-3})

in erg/(sec.sec^{-1}cm^2) (dimensions of g. sec^{-2})

The above units are used in measuring the spectral flux intensity of radio waves:

The spectral energy flux intensity of e.m. waves of shorter wave-length (x-rays, gamma rays) is usually measured in units: watt/(Å-m^2) or erg/(sec-Å-cm^2).

7. UNITS OF THERMAL RADIATION

7.1. Definition:- Thermal radiation is radiation issuing from a body heated by energy reaching it from an outside source. Radiating bodies are described by two quantities:-

1) Integral emissivity; and 2) spectral emissivity. When thermal radiation falls on the surface of a body, the body absorbs some of the energy. Different bodies are capable of absorbing radiant energy incident upon them, to different extents. This ability of a body is described as the 'absorption' of a body.

7.2 Units of measurement for thermal radiation and absorption.

1) Integral emissivity of a body (symbol: R): This equals the total, i.e. the energy of all wavelengths radiated from a unit surface of the body per unit time. Thus, the integral emissivity is the integral energy flux radiated from a unit surface of the body, $R = \frac{d\phi}{ds}$

where $d\varphi$ integral energy flux emitted from the surface ds of the radiating body:

This quantity R is measured:

In the MKS system, in watt/m^2 (dimensions: kg/sec^{-1})

In the CGS system, in erg/cm^2. sec (dimensions: g. sec^{-1})

In usual practice, R is measured in cal/(cm^2. sec) or watt/cm^2.

2. <u>Spectral emissivity of a body</u>: The spectral emissivity of a radiating body is the energy emitted from a unit surface of the body/unit time and per unit interval of wavelength, near the wavelength λ. The spectral emissivity is also defined as the spectral energy flux from a unit surface of the body.

The spectral emissivity $\gamma_\lambda (\gamma_\nu)$, is determined by the equations:

$$\gamma_\lambda = \frac{d\varphi_\lambda}{ds}$$

and

$$\gamma_\nu = \frac{d\varphi_\nu}{ds}$$

where $d\varphi_\lambda (d\varphi_\nu)$ is the spectral flux from the surface of the radiating body.

From the above equations, the spectral emissivity is measured:

In the MKS system, in watt/(m.m^2) (dimensions: m^{-1} kg. sec^{-3}

or in watt/m.sec^{-1} (,, kg.sec^{-2})

In the CGS system, in [erg/(cm.cm^2.sec)] (dimensions cm^{-1}.g.sec^{-3})

or in erg/cm^2 (cimensions: g.sec^{-2})

In usual practice, the spectral emissivity is also measured in the units: [watt/(cm^2,Å)] and [cal/(cm^2.Å).]

N.B.:- The spectral emissivity is also called '<u>RADIANCE</u>' and at a given temperature, is a function of wavelength (and hence of frequency).

3. <u>Absorptivity of a Body</u>: (Symbol: a_λ): This quantity equals the ratio of the radiation energy absorbed by the body to the radiation energy incident upon it. Since the proportion of the energy absorbed by the body differs according to the wavelength the absorptivity must be determined for a narrow waveband close to wavelength λ where dW'_λ is the radiation energy absorbed by the body and dw_λ is the radiation energy incident on the body (both corresponding to the waveband $d\lambda$ near the wavelength λ).

The ratio: $\left(\frac{dw'_\lambda}{dw_\lambda}\right)$ can be replaced by the ratio of energy fluxes: $\left(\frac{d\varphi'_\lambda}{d\varphi_\lambda}\right)$. Hence $a_\lambda = \frac{d\varphi'_\lambda}{d\varphi_\lambda}$, where $d\varphi'_\lambda$ is the spectral energy flux absorbed by the body

and $d\varphi_\lambda$ is the spectral energy flux incident upon it.

From the above equation, it is seen that the absorptivity of a body is a <u>dimensionless</u> quantity. Therefore, it does not have any unit of measurement.

8. UNITS OF PHOTOMETRIC ENERGY QUANTITIES

8.1 Introduction.

In contrast to the quantities of radiation considered so far, the measurement of photometric quantities is based on the physiological action of light. Hence,to some extent, it becomes a subjective assessment because radiations of different wavelengths give rise to different impression optically. On the one hand, this distinction is qualitative (i.e. different wavelength produce different colour sensations) and, on the other hand; it is quantitative (i.e.different wavelength produce optical sensations of widely varying intensity). The most powerful sensation due to light, at constant radiant energy flux is produced by the wavelength of 555 mμ. Radiant energy at the wavelength of the visible region of the spectrum, produces less impression. Radiant energy of $\lambda >$ 0.76μ or $<$ 0.4μ is not visible at all.

Owing to the subjective nature of the photometric quantities, people perceive different areas of the spectrum in different ways. Therefore, while measuring photometric quantities, we have to use the 'average' sensitivity of the eye. That average is established by comparison of the individual sensitivity of the eyes of a large number of people who do not have defects of vision.

The mean sensitivity of the eye is described by a quantity called:

'Visibility Factor'

8.2 Units of measurement of photometric quantities:-

1. The Candle Power: of a source is a quantity determining the energy radiated by the source per unit time, rated on the basis of its lighting effect.

The unit of candle power is the CANDLE (abb: C)

2. The Candle: (definition): It is the luminous, intensity of 1/60 sq.cm. of black body radiation at the temperature of solidi - fication of platinum.

This 'new candle' is related as follows to the previous standard, called the 'International Candle' (now obsolute):

1 New Candle: 0.995 international candle

3. Luminous Flux: The luminous flux emitted by a light source in a solid angle is the quantity numerically equal to the product of the candle power I of the source and of the solid angle, i.e. If we assume that I = 1 candle and $d\omega$ = 1 steradian in the above formula, we derive the unit of LUMINOUS FLUX, called the 'LUMEN.'

4. LUMEN (Ddefinition): It is the luminous flux which is emitted by an isotropic point source of 1 candle in a solid angle of 1 steradian. This Lumen is related to the 'International lumen thus:

1 International Lumen = 1.0005 new lumens.

1 New lumen = 0.995 international lumens.

The total luminous flux emitted by a source of candle power I is equal to: $F = 4\pi I$

The luminous flux is also defined thus: The luminous flux through a surface ds is the energy transferred through the surface by radiation per unit time, as evaluated by its optical impression.

5. VISIBILITY FACTOR (abbrn: V_λ) It is the ratio of the luminous flux F to the radiant energy flux ϕ_λ producing this luminous flux i.e.

$$V_\lambda = \frac{F}{\phi_\lambda}$$

In the above equation, the energy flux, describes light as a purely physical phenomenon, while the luminous flux F describes it as a psychological phenomenon.

The quantity ϕ_λ shows how much energy passes through a surface per unit of time, and F shows how much impression the light energy makes on the human eye.

Thus, the visibility factor is a quantity relating the characteristics of light both as (1) a physical and (2) a psycho-physical phenomenon. The visibility factor is a subjective quantity and therefore, the numerical value of this factor is a subjective quantity and therefore, the numerical value of this factor is different for different people, and even for the same eye, the visibility factor varies according to wavelength. For the average eye, the greatest visibility factor occurs at a wavelength $\lambda = 550\ m\mu$. For $\lambda > 760\ m\mu$ or $< 400\ m\mu$ the visibility factor is zero.

Units: The visibility factor is measured in (lumen/watt) or (lumen/(erg/sec)

6. Illumination of a source:- The illumination (I) is determined by the luminous flux incident on a unit area. It follows from definition that:

$$E = \frac{dF}{ds}$$

The units of measurement for illumination are:-

(I) lux = (lumen/m^2) and (2) phot = (lumen/cm^2)
(M.K.S. unit) (C.G.S.Unit)

(1) The LUX (Definition): It is the illumination produced by a luminous flux of 1 lumen uniformly distributed over an area of one square meter.

2) The PHOT (Definition): It is the illumination produced by a luminous flux distributed over an area of one square cm:

The LUX and the PHOT are inter-related thus:

$$1\, lux = \frac{1\, lm}{m^2} = 1 . \frac{lm}{10^4\, cm^2} = \frac{10^{-4}\, lm}{cm^2} = 10^{-4}\, phot$$

$$1 \text{ lux} = 10^{-4} \text{ Phot}$$

$$\text{or } 1 \text{ phot} = 10^4 \text{ lux.}$$

7. EMITTANCE (abb:R) It is the quantity of luminous flux emitted per unit area of a radiating surface,

$$R = \frac{dF}{ds}$$

where dF = total luminous flux emitted from the area ds. Comparing this equation with that in para 6 it is clear that 'emittance' should be measured in the same unit as illumination, i.e. in 'luxes' or 'phots'.

8. <u>BRIGHTNESS</u> (Abb: B):- This is a quantity describing the emittance of a body in a particular direction. The brightness is defined as the quantity of luminous flux radiated in a given direction by a unit illuminating surface in a solid angle of 1 steradian. Brightness can also be defined as the ratio of the candle power in a given direction to the projection of the illuminating surface onto a plane perpendicular to the given direction.

Brightness is calculated from the formula:-

$$B = \frac{dF}{S\cos\varphi\, d\omega}$$

where dF is the luminous flux emitted from an area S, $d\omega$ is the solid angle within which the flux is emitted, ϕ is the angle between normal to the area and the directions of emittance and $S\cos\phi$ is the projection of the area S onto the direction determined by the angle ϕ.

9. Units of Brightness

The names of the units are: 1) the 'STILB' and 2) 'NIT' .

1) The STILB: (abbreviation (C/cm). It is the brightness of the surface, one sq. cm. of which radiates one candle in a direction perpendicular to the surface.

2) The NIT (abbrn: (c/cm^2) It is the brightness of a surface, one square meter of which radiates one candle in a direction perpendicular to the surface.

Relationship between the 'STILB' and the 'NIT'

$$1 \text{ Stilb} = \frac{1c}{1cm^2} = \frac{1c}{(10^{-2} m)^2} = \frac{10^4 c}{m^2} = 10^4 \text{ nit.}$$

$$\text{stilb} = 10^4 \text{ nit}$$

9. UNITS FOR QUANTITIES CHARACTERISING THE INTERACTION BETWEEN RADIATION AND MATTER

When X-rays, gamma rays, corpuscular radiation (rays, neutrons) are passed through matter, ionization of the atoms in the matter occurs. During the process of ionization, part of the radiation energy is lost. This phenomenon is called 'absorption of radiation energy' by the matter. The degree of 'ionisation of a substance' and the amount of radiation energy absorbed by it are indicative of the interaction between the radiation and matter. They form the basis of the quantities introduced to describe this effect.

The units of the various quantities involved in the interaction between radiation and matter are given below:

1. Absorbed Dose (Abbn:D):- The 'absorbed dose' or merely 'dose' is the amount of radiation energy absorbed by 1 cm^3 (or 1g) of a medium through which radiation has passed.

While calculating the amount of radiation energy absorbed per unit of volume or area of a specific medium, the 'roentgen' is used as the unit. While calculating per unit mass of the medium the 'rad' is used as the unit.

2. Roentgen (abbn: r):- Definition: The roentgen is the dose of x-ray or gamma radiation such that an associated corpuscular emission per 0.001293 g of air produces, in air, ions carrying a charge of 1 e.s.u. of electricity, of either sign (+ or -).

The number: 0.001293 g is the mass of 1cm^3 of air at N.T.P. By the expression: 'associated corpuscular emission....produces, in air, ions....', the following is meant:-

'The passage of x-rays and gamma radiation through a substance, does not directly ionise the substance. Their action can be reduced to the creation of a corpuscular emission (high speed electron flow) inside the substance itself. The collision between the electrons and atoms cause the ionization, which is noticed in the substance when x-rays and gamma rays are passed through it.'

The coherent subunits of roentgen are: (1) milliroentgen (mr) and (2) microroentgen (μr) :

The roentgen and the smaller units mentioned above, are used only with regard to the dosage of x-rays and gamma rays, i.e. to determine the dosage of e.m. radiation.

2. CORPUSCULAR RADIATION:- Measurement of the dosage of the corpuscular radiation (α, β rays and neutrons, etc.) is made in units called 'reps' (roentgen, equivalent, physical). The 'rep' is the dose of ionizing radiation at which the energy absorbed by a substance equal to the loss in energy during ionization caused by 1r of x-rays or gamma radiation.

In physical reactions, 1 rep of corpuscular radiation

$\doteq$ 1r of e.m. radiation.

During the past few years, the 'rad', a new unit of dosage has come into common use..

The rad is a dose of ionised radiation at which 1 gram of irradiated material absorbs 100 ergs of energy.

Relationship between (1) the rad and (2) the roentgen.

To establish this relationship, we have to calculate the amount of energy which is absorbed by 1 g of a medium when the radiation dose is 1r. Comparing this energy with 100 ergs of energy yields the ratio between the rad and the roentgen.

From the definition of the roentgen, it follows that a dose of 1r corresponds to the energy required to produce, in 0.001293g of air, the exact number of pairs of ions such that the total (+ve or -ve) charge equals 1. statcoulomb.

The following 3 tables give the exposure and absorbed doses of radiation. Roentgen and milliroentgen are units which are used to measure the effect of electromagnetic radiation (x-rays, γ rays); they are units of exposure dose. The roentgen equivalent, physical (abbr. as 'rep') is used to measure the physical effect of corpuscular radiation (α, β , neutron-radiation).

The roentgen equivalent, man (abbr. as 'rem'), and the 'millirem' are used to specify the biological effect of corpuscular radiation especially on man. They are units of absorbed dose.

Table 4

Unit	R	mR
Roentgen	1	10^3
Millircentgen	10^{-3}	1

Table 5

	rep
Roentgen, equivalent (Physical)	1

Table 6

	rem	mrem
Roentgen equivalent, ma[illegible]	1	10^3
millirem......	10^{-3}	1

3. Biological effect of Radiation.

The unit of biological effect of radiation is the EBR (Equivalent Biological Roentgen). The EBR is the dose of radiation (of any type) which, when absorbed by human tissue, produces a biological effect equivalent to the action of 1r of x-rays or gamma rays. In order to find the value of this radiation, we must express the dosage in reps, multiplied by the coefficient of relative biological intensity k:

$$D(EBR) = k\,D(rep)$$

The coefficient k differs with the type of radiation, e.g.,

$k = 1$ for x-rays and gamma and beta radiation

$k = 20$ for α radiation

$k = 10$ for proton.

4. INTEGRAL ABSORBED DOSE. The integral absorbed dose or integral dose consideration. The integral dose W can be determined from the equation: $W = k m D$

where D is the radiation dose,

m is the mass of the substance for which we are determining the dose,

k is the proportionality factor.

If $k = 1$, $m = 1g$ and $D = 1$ rad, the unit of measurement of the integral dose is 1 g. rad.

Since 1 rad = 100 ergs/g, we get 1 g. rad. = 100ergs.

5. ABSORBED DOSE RATE:

The absorbed dose rate is a quantity equal to the dose absorbed per unit time., i.e., it is determined by the ratio:

$$P = \frac{D}{t}$$

where D is the dose and t is the time over which it is received. It follows that the dose rate is measured in units of r/sec, r/min, or r/hr. or also rad/sec, rad/min, rad/hr.

6. INTEGRAL ABSORBED RATE:

The integral absorbed dose rate is the radiation energy absorbed by the entire volume under investigation, per unit time. It is calculated from $N = \frac{W}{t}$. From this question, it is seen that the unit of integral absorbed dose rate is the (g.rad)/sec or erg/sec, and

$$1g \cdot \frac{rad}{sec} = \frac{100\ erg}{sec}$$

10. ENERGY UNITS IN ATOMIC FIELD

In the field of atomic energy, there are two more quantities involving energy:-

(1) Radiation energy (in ergs) = energy quantum $h\nu$ (ergs/photon) x no. of photons (N)

(2) Atomic energy (in ergs) = c^2 (ergs/gram) x Mass (in gr).

Apart from these, a unit of energy used in atomic and nuclear physics is the 'Electron Volt'.

Electron volt: (abbreviation ev): Definition)

The electron volt is the energy acquired by a particle with a charge equal to the elementary charge (electron charge) after passing through a potential difference of 1 Volt.

$$1\ ev = 1.60 \times 10^{-10}\ J = 1.60 \times 10^{-12}\ erg = 1.63 \times 10^{-20}\ kgf.m.$$

The relationship between the 'electron-volt' and the 'erg' can be derived as follows:

The work done by an electric field in displacing a charge is expressed by the equation: $W = Eq$, where W = word done

q = magnitude of the charge

and E = potential difference.

Substituting into this equation, the electron charge: $e = 4.80 \times 10^{-10}$ C.G.Se(q) and the voltage $E = 1V = \frac{1}{300}$ c.g.s.e.m.u. (v), we get:

$$1ev = 4.80 \times 10^{-10} \times \frac{1}{300} = 1.60 \times 10^{-12} \text{ erg.}$$

when we want a bigger unit than 'ev', we can use Megaelectron volt. (Mev) which is bigger unit of energy 10^6 e.v. and a still bigger unit Bev = 10^9 e.v.

1 Mev = 1.60×10^{-13} joules = 1.60×10^{-6} erg. = 1.63×10^{-14}kgf.m.

The units: ev, Mev and Bev, are widely used in atomic and nuclear physics. These three units of energy (ev, Mev and Bev), are used to define phenomena in a single atom. They can be converted into any other unit of energy. The atomic unit of mass is called, 'mass unit', abbreviated to: MU An important fundamental constant of physics is the number L, giving the ratio between the microscopic unit gamma and the mass unit MU

1 gramme = LMU

$L = 6.025 \times 10^{23}$

L is called the Loschmidt number or the Avogadro number. We obtain the weight of the atom of any element expressed in grammes by dividing its atomic wt., which is always given in MU, by the Loschmidt number $L = 6.025 \times 10^{23}$.

Since the atomic weight of hydrogen $\simeq 1$, the reciprocal of L gives approximately the mass m_H of the hydrogen atom, expressed in gramme.

$$\therefore m_H = 1.67 \times 10^{-24} \text{ gr.}$$

The hydrogen atom is the lightest among the atoms of all elements, but the electron, which can be considered as the atom of negative electricity, is much lighter still. Its mass m_e is given by:

$$= 0.0055 \text{ MU} = 0.91 \times 10^{-27} \text{ gr.}$$

11. ATOMIC ENERGY

11.1. What has been called 'atomic energy' during the past two decades is the energy released by nuclear processes, in which not only the electronic shells of the atom are affected, but also the internal structure of their nuclei. The energy turnover of nuclear processes is millions of times greater than that of the very 'tame' chemical reactions involving only the outer shells. The following example, a chemical reaction will amplify the above remarks. The process of burning coal, is shown by the formulae:- $C + O_2 \rightarrow CO_2$

releases 4.17 ev per carbon atoms, which corresponds to a heat value of 8050 kcal per kg. or 14,500 B. Th. U. per lb of pure carbon. Again, the process of combination of hydrogen and oxygen to form water releases 2.5 ev per molecule of H_2O, corresponding to a heat value of 29,000 kcal/kg = 52,200 B.Th.U. per lb of hydrogen.

11.2 <u>Mass and energy</u>: <u>Einstein's equation</u>:-

Einstein predicted in 1905 the mutual conversion of matter into energy and vice versa. This is stated by the simple formula:-

$$E = mc^2,$$

where m is the increase or decrease of the mass of a body, the energy of which is increased or decreased by the amount E. The mass 'm' is expressed in grammes, the energy E in ergs and 'c', the velocity of light in cm/sec ($=3 \times 10^{10}$ cm/sec).

The conversion factor $c^2 = 9 \times 10^{20}$ is so large that all the energy we can supply to a body by heating it or by other means will not suffice to obtain a measurable increase of its mass.

The converse side of the excessive exchange rate in the conversion between matter and energy is the result that any weighable charge of the mass of a body which is not simply caused by adding or taking away of a number of atoms or molecules must involve enormous nuclei from primary particles. Atomic energy is produced in two distinct ways: (1) Fission and (2) Fusion.

The fusion process is the more efficient, as is evident from the table below:-

Table 7

Imaginary fusion reaction forming:	kwh per kg.
Helium from protons and neutrons	190 million
Oxygen from helium	24.2 million
Neon from helium and oxygen	6.25 million

From the mass/energy relationship $E = mc^2$, the following table gives the conversion data among (1) e.v (2) kg and (3) atomic mass unit (a.m.u.)

Table 8

Unit	e.v.	kg.	a.m.u.
1 1 electron volt	1	1.783×10^{-36}	1.074×10^{-9}
2 1 kg	5.610×10^{35}	1	6.025×10^{26}
3 1 amu	9.31×10^{8}	1.600×10^{-27}	1

(1 atomic mass unit = 1.660149×10^{-24} g)

12. ENERGIES OF THE PARTICLE ACCELERATORS.

Particle accelerators are among the most useful tools in nuclear physics. Energies of several million electron volts have been available for many years-(during the last 35 years)- from the early accelerators (such as the voltage multipliers, the electrostatic generator, and the cyclotron).

Elementary particles have been classified as:-

1)	Low energy particles	below 10 Mev.
2)	High energy particles	greater than 10 Mev.
3)	Ultra high energy particles (Billion-Volt range)	,, 100 Mev or 1 Bev.

The following table gives the progress in the increase of energies achieved with accelerators:-

Table 9

Year	Accelerator	Mev
1932	Cascade generator	0.8
1932	Cyclotron	1.2
1936	Electrostatic generator	5.0
1936	Cyclotron	6
1939	,,	10
1942	,,	60
1947	,,	30.00
1948	Synchroton	38.00
1952	Proton ,, (Brookhaven cosmotron) raised in 1954 to	2800 or 2.8 Bev 3.0 Bev.
1955	Bevatron (Berkeley)	6000 or 6.0 ,,
1960	,,	26,000 or 26.0 ,,
1966	(at Geneva)	30,000 or 30.0 ,,

Cosmic ray particles have been observed, which are millions of times as energetic as those produced by the biggest accelerating machines. Particles with energies up to 30,000 million electron volts or 30 Bev are produced by the biggest machines, but particles of about 10^{14} million e.v. have been detected in cosmic rays. Therefore, the biggest machines (particle/accelerators) are still very far from being able to produce particles as energetic as the more energetic ones in the cosmic rays.

13. The Atomic System of Units - The Unit of Energy:-

In order to reduce the numerical computation work in problems of atomic physics, Hartree of England suggested this system of units in 1927. In this system, the unit of charge is 'e', the charge on the electron (1.6×10^{-19} coulomb); the unit of mass is the rest mass of an electron (9×10^{-31} kg.); and the unit of length 'a' is the radius of the first Bohr orbit in the 'hydrogen' atom (0.53×10^{-8} cm); the unit of time is the reciprocal of the angular velocity $1/4\,\pi RC$ = (2.4×10^{-17}sec), where R is the Rydberg's constant and c the velocity of light. The unit of action is $(h/2\pi)$, where h is the Planck's constant. The unit of energy is $(e^2/a^2) = 2$ Rhc. This is the potential energy of the unit charge situated at unit distance from a similar charge and which is also equal to twice the ionization energy of the hydrogen atoms. It was also suggested that since (e^2/a^2) can be written as $\left(\frac{4\pi^2 m e^4}{h^2}\right)$, the quantity $\left(\frac{me^4}{h^2}\right)$ should be used as a unit of <u>energy</u>, named after <u>HARTREE</u>.

In the Hartree system itself, the unit of energy is 2 Rhc, where R is the Rydberg constant for hydrogen, 2 Rc is the quantum frequency that has this energy as its quantum energy, and 2R is the quantum wave number of a quantum of unit energy.

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