UNIT 1

Physical World and Measurement

SCOPE AND EXCITEMENT OF PHYSICS

The scope of physics is very wide. It covers an immense range of natural phenomena.

- Distances extend from small dimensions of subatomic particles to the very large separation between galaxies of the universe. e.g. the radius of atomic nucleus is about 10^{-14} m while radius of universe is about 10^{25} m.
- Time intervals encountered in physical world vary over a large range. e.g. time taken by light to cross nuclear dimension is about 10^{-22} sec while the life of sun is about 10^{18} sec.
- Mass of an electron is 10^{-30} kg whereas mass of the universe is about 10^{55} kg.

Physics provides answers to exciting questions such as, why is sky blue? Why is glass transparent? etc.

PHYSICS, TECHNOLOGY AND SOCIETY

Physics is the knowledge of material universe for its own sake, whereas technology transfers the knowledge of physics into practical shape for the well being of human race. For example,

- Faraday's law of electromagnetic induction enabled the development of electric generator, electric motor, transformer etc.
- Discovery of nuclear fission led to development of nuclear power plants.
- Laws of thermodynamics led to development of heat engines.
- Physics has made both positive and negative impacts on the society. On the one hand we use aeroplanes, television, computers etc. but on the other hand we blame technologies for widespread pollution, resource depletion etc.

NATURE OF PHYSICAL LAWS

Physics is the study of nature and natural phenomena. The observations and experiments lead the physicists to certain facts. A remarkable fact is that some special physical quantities remain constant in time. These are called the conserved quantities of nature. In classical physics, we deal with following conservation laws :

- Law of conservation of energy
- Law of conservation of linear momentum
- Law of conservation of angular momentum
- Law of conservation of charge

PHYSICAL QUANTITIES

The quantities by means of which we describe the laws of physics are called physical quantities. A physical quantity is completely specified if it has –

Numerical value only	or	Magnitude only	or	Magnitude of direction
Ratio		Scalar		Vector
e.g. refractive index, dielectric constant etc.		e.g. mass, charge, current.		e.g. displacement, torque.

In general, expressing the magnitude of a physical quantity we choose a unit and then find how many times that unit is contained in the given physical quantity, i.e.

magnitude of physical quantity = numerical value × unit

Hence for a given physical quantity

(a) As the unit will change, numerical value will also change, e.g. density of water = 1 g/cc = 10^3 kg/m^3 and not 1 kg/m^3.

(b) Larger the unit smaller will be the numerical value and vice-versa, e.g. if 1 ampere = $\left(\frac{1}{10}\right)$ emu of current then as 1 is greater than $\left(\frac{1}{10}\right)$, ampere is a smaller unit than emu of current.

Types of Physical Quantities

There are two types of physical quantities

- Fundamental quantities
- Derived quantities

- **Fundamental quantities :** The quantities which do not depend upon other quantities for their complete definition are known as fundamental or base quantities.
- There are seven fundamental or base quantities in SI system. They are length, mass, time, electric current, thermodynamic temperature, amount of substance, luminous intensity.
- **Derived quantities :** Those physical quantities which are derived from the fundamental quantities are known as derived quantities.

e.g. speed $\left(=\frac{\text{distance}}{\text{time}}\right)$, volume, acceleration, force, pressure etc.

Illustration 1

Find the fundamental quantities in term of which density can be expressed.

Soln. : We know $\text{density} = \frac{\text{mass}}{\text{volume}}$

Also, volume = $(\text{length})^3$

$\therefore\ \text{density} = \frac{\text{mass}}{(\text{length})^3}$

Hence density is a derived quantity which depends on base quantities mass and length.

UNITS

- The chosen reference standard of measurement in multiples of which, a physical quantity is expressed is called the unit of that quantity. e.g., when we say that length of a rod is 3 metres, then metre is unit to measure the length of the rod.
- The result of measurement of a physical quantity is expressed by a number (or numerical measure) accompanied by a unit. In general,

  Measure of a physical quantity = numerical value (n) × unit (u).

Characteristics of a Standard Unit

A unit selected for measuring a physical quantity should fulfill the following requirements :

- It should be of convenient size.
- It should be well defined.
- It should be easily available so that as many laboratories as possible can duplicate it.
- It should not change with time and place.
- It should not change with the change in physical conditions e.g. temperature, pressure etc.
- It should be universally agreed upon so that results obtained in different countries are comparable.

FUNDAMENTAL AND DERIVED UNITS

- **Fundamental units :** The units chosen for measuring fundamental quantities are known as fundamental units e.g. kilogram, metre, second are the fundamental units for mass, length and time respectively.
- **Derived units :** The units of derived quantities or the units that can be expressed in terms of the base units are called derived units.

  e.g. unit of speed $= \frac{\text{unit of distance}}{\text{unit of time}} = \frac{\text{metre}}{\text{second}} = \text{m s}^{-1}$

  Some derived units are named in honour of great scientists e.g. unit of force – newton (N), unit of frequency – hertz (Hz) etc.

SYSTEM OF UNITS

A complete set of units, both fundamental and derived for all kinds of physical quantities, is called a system of units. A few common systems are given below :

- **CGS system or Gaussian system**

S.No.	Physical quantity	Name of the unit	Symbol
1.	Length	centimetre	cm
2.	Mass	gram	g
3.	Time	second	s

- **FPS system**

S.No.	Physical quantity	Name of the unit	Symbol
1.	Length	foot	ft
2.	Mass	pound	lb
3.	Time	second	s

- **MKS system**

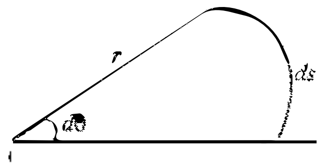
S.No.	Physical quantity	Name of the unit	Symbol
1.	Length	metre	m
2.	Mass	kilogram	kg
3.	Time	second	s

- **International system of units (SI) :** The system of units, which is at present internationally accepted for measurement is abbreviated as SI. The SI is based on the following seven fundamental units and two supplementary units as shown in the table.

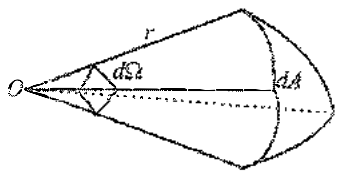
S. No.	Physical quantity	Name of the unit	Symbol
1.	Length	metre	m
2.	Mass	kilogram	kg
3.	Time	second	s
4.	Electric current	ampere	A
5.	Temperature	kelvin	K
6.	Amount of substance	mole	mol
7.	Luminous intensity	candela	cd
	Supplementary quantities		
8.	Plane angle	radian	rad
9.	Solid angle	steradian	sr

- **Metre :** One metre is the length of the path travelled by light in vacuum during a time interval of 1/299,792,458 of a second.
- **Kilogram :** One kilogram is equal to the mass of the international prototype of the kilogram (a platinum-iridium alloy cylinder) kept at International Bureau of Weights and Measures, at Sevres, near Paris, France.
- **Second :** One second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.
- **Ampere :** One ampere is that constant current, which when maintained in each of the two straight parallel conductors of infinite length and negligible circular cross-section, held one metre apart in vacuum, shall produce a force per unit length of 2×10^{-7} N/m between them.
- **Kelvin :** One kelvin, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.
- **Mole :** One mole is the amount of substance of a system, which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12.
- **Candela :** One candela is the luminous intensity, in a given direction, of a source that emits mono-chromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian.
- **Radian :** One radian is the angle subtended at the centre of a circle by an arc equal in length to the radius of the circle.
- If an arc of length ds subtends an angle $d\theta$ at the centre O of a circle of radius r as shown in the figure, then

$$d\theta = \frac{ds}{r} \text{ radian}$$



- **Steradian :** One steradian is the solid angle subtended at the centre of a sphere, by that surface of the sphere, which is equal in area, to the square of radius of the sphere.
- If an area dA of a spherical surface subtends a solid angle $d\Omega$ at the centre of the sphere O of radius r as shown in the figure, then



$d\Omega = \frac{dA}{r^2}$ steradian

- **Advantages of SI**
  - SI is a coherent system of units.
  - SI is a rational system of units.
  - SI is an absolute system of units.
  - SI is a metric system.
- **Practical units of length :**

S.No.	Practical units
1.	1 astronomical unit = 1 AU $= 1.496 \times 10^{11}$ m (average distance of the sun from the earth)
2.	1 light year = 1 ly = 9.46×10^{15} m (distance that light travels with velocity of 3×10^8 m s^{-1} in 1 year)
3.	1 parsec = 3.08×10^{16} m (parsec is the distance at which average radius of earth's orbit subtends an angle of 1 arc second)
4.	1 micron = 1 μm = 10^{-6} m
5.	1 angstrom = 1 Å = 10^{-10} m
6.	1 fermi = 1 f = 10^{-15} m

- **Practical units of mass:**

S.No.	Practical units
1.	1 tonne or 1 metric ton = 10^3 kg
2.	1 quintal = 10^2 kg
3.	1 pound = 0.4536 kg
4.	1 atomic mass unit = 1 amu or 1 u $= 1.66 \times 10^{-27}$ kg

- **Practical units of time:**

S.No.	Practical units
1.	**Solar day :** It is the time taken by earth to complete one rotation about its axis w.r.t. the sun. 1 year = $365\frac{1}{4}$ solar days.
2.	**Lunar month :** It is the time taken by moon to complete one revolution around the earth in its orbit. 1 lunar month = 27.3 days
3.	**Solar year :** It is the time taken by the earth to complete one revolution around the sun in its orbit.
4.	**Tropical year :** It is that year in which solar eclipse occurs.
5.	**Leap year :** It is that year in which the month of February is of 29 days.
6.	1 solar day = 86400 s
7.	1 shake = 10^{-8} s.

SI PREFIXES

- The prefixes, their symbols and their values expressed as powers of 10 are as shown in table.

Power of 10	Prefix	Symbol
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a
10^{-21}	zepto	z
10^{-24}	yocto	y
10^{1}	deca	da
10^{2}	hecto	h
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E
10^{21}	zetta	Z
10^{24}	yotta	Y

CONVERSION FACTORS

- To convert a physical quantity from one set of units to the other, the required multiplication factor is called conversion factor.
- Magnitude of a physical quantity = numerical value (n) × unit (u) while conversion from one set of units to the other the magnitude of the quantity must remain same. Therefore

$$n_1u_1 = n_2u_2 \text{ or } nu = \text{constant or } n \propto \frac{1}{u}$$

- It means that the numeric value of a physical quantity is inversely proportional to the base unit.

e.g. 1 m = 100 cm = 3.28 ft = 39.4 inch
(SI) (CGS) (FPS)