UNITS AND MEASUREMENTS

PHYSICAL QUANTITY

Any quantity, which can be measured, is called physical quantity. For example, mass, length, time, velocity, force, acceleration etc. are all physical quantities.

Measurement - Measurement is the process which consists of the comparison of an unknown quantity with a known fixed unit quantity. Every measurement whether it be a distance or weight, time or velocity or any other physical quantity requires two things - first a number and second a unit or standard.

UNIT

The standard used to measure a quantity is called its unit.

For example, we say 5 metres. Here the numerical part is 5 and the unit of length is metre. Thus the numerical value and the unit both are needed to completely express a physical quantity.

$$q = nu$$

Here, q = physical quantity

n = numerical value

u = unit of the quantity.

PROPERTIES OF A UNIT

A unit selected to measure a physical quantity should possess the following properties :

i) It should be of suitable size – neither too large nor too small.

ii) It should be well defined.

iii) It should not be variable (i.e., its value should remain same under all the circumstances so that external factors like temperature, pressure etc. cannot affect its magnitude).

iv) It should be accepted internationally.

v) It should be easily reproducible.

vi) It should not vary from place to place.

CLASSIFICATION OF UNITS

Units can be classified into two types :

Units

Fundamental Unit

i) The units which cannot be expressed in terms of any other physical quantity are called fundamental units.

ii) They are independent of each other.

iii) e.g., Mass = kg, g, pound

Length = m, cm, feet

Time = sec.

Derived Unit

i) All other quantities which can be expressed in terms of other quantities are called derived units.

ii) They can be obtained by combining fundamental units.

iii) e.g., (1) Area = length x breadth

= m x m

(1) Velocity $= \frac{\text{distance}}{\text{time}} = \frac{\text{m}}{\text{sec.}}$

(3) Force = mass x acceleration

$= \text{mass x } \frac{\text{length}}{\text{time}^2} = \text{kgm/s}^2$

SYSTEM OF UNITS

There are following systems of measurements commonly in use :

i) **C.G.S. System.** It is a system of measurement in which the fundamental units of measurement of length, mass and time are in centimetre, gram and second respectively.

ii) **F.P.S. System.** It is a system of measurement in which the fundamental units of measurement of length mass and time are foot, pound and second respectively.

iii) **M.K.S. System.** It is a system of measurement in which the fundamental units of measurement of length, mass and time are metre, kilograms and second respectively.

Note. We are free to express any physical quantity in the above stated three system, but intemixing is not allowed.

e.g., **Force** - We can express force in either of the three systems. In M.K.S. unit kgm/sec^2, in C.G.S. unit of force will be gcm/sec^2 and in F.P.S. unit of force will be lb ft/sec^2 but we cannot express force as kg cm/sec^2 or gm/sec^2 since mixing of three systems is not allowed in Physics.

UNITS

The unit of mass, length and time can be used to obtain the units of physical quantities in mechanics only. These three fundamental units are not sufficient to obtain the units of the physical quantities from all branches of Physics like thermodynamics, optics, electricity etc. For example, *current* - current as stated is not a fundamental quantity and by no means it can be expressed in terms of mass, length or time. Hence it cannot be a derived quantity, so, which type of quantity is current then?

In the General Conference of Weights and Measures held in 1960, was introduced a new and logical system of units known as **System Internationale Units** whose abbreviated from is S.I. It consists of total nine units in which seven are basic or fundamental units and two supplementary units along with their symbols. The list of the units is given below :

A-Basic or Fundamental Quantities

S.No.	*Name of the 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.	Luminous intensity	candela	cd
7.	Quantity of matter	mole	mol.

B-Supplementary Quantities

1.	Plane Angle	Radian	rad
2.	Solid Angle	Steradian	sr

The above mentioned units are found to be sufficient to obtain the units of the physical quantities from all branches of physics.

DEFINITION OF BASE UNIT

1. **Metre (m).** It is the unit of length. The distance travelled by light in vacuum in $\frac{1}{299,792,458}$ sec. in called metre.

2. **Kilogram (kg).** I is the unit of mass. It is defined as mass of platinumiridium cylinder kept in the International Bureau of Weight and Measurement at Severes in France.

3. **Second (sec).** It is the unit of time. It is defined as time taken by cesium 133 (CS-133) to vibrate 9,192,631,770 times.

4. **Ampere (A).** It is the unit of current. The current generating a force of $2x10^{-7}$ newton per metre between two straight parallel conductors of infinite length and negligible cross-section when placed one metre apart in vacuum is one ampere.

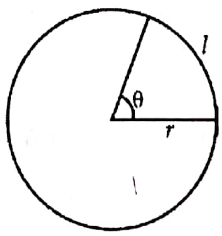
5. **Kelvin (K).** It is a unit of temperature. It is defined as $\frac{1}{273.16}$ of the thermodynamic temperature of the triple point of water.

6. **Candela (cd).** It is defined luminous intensity of a black body, in the direction perpendicular to the surface, having a surface area of $\frac{1}{600,000}m^2$ at the temperature of freezing platinum and at a pressure of 101,325 Nm^2.

7. **Mole (mol).** It is a unit of amount of substance. It is defined as the amount of substance which contains as many elementary constituents as there are atoms in 0.012 kg of carbon - 12.

Supplementary Units

1. **Radian (rad).** Radian in the angle subtended at the centre of circle by an arc equal to the radius of circle.



$$l = r\theta$$

If $\theta = 1$

Then $l = r$

2. **Steradian (sr).** Steradian is the solid angle subtended at the centre of sphere, by a surface area of the sphere whose magnitude is equal to the square of the radius of the sphere.

DIMENSIONS OF A PHYSICAL QUANTITY

The dimensions of a derived unit are the power to which the fundamental units of mass, length and time must be raised to represent it. Thus if a derived unit depends upon a^{th} power of mass, b^{th} power of length and c^{th} power of time then the dimension of that quantity will be $[M^a L^b T^c]$.

For example, area is independent of mass independent of time and is directly proportional to (length x breadth), square of length

$\therefore$ area = $[M^0 L^2 T^0]$

Power 0, 2, 0 of the fundamental units are called dimensions of area in mass, length and time respectively.

DIMENSIONAL FORMULA

The derived unit of all the physical quantities can be suitably expressed in terms of the fundamental unit of mass, length and time raised to some power.

e.g., if units of mass, length and time are denoted by capital letters in the bracket [M], [L] and [T] then dimensional formula may be defined as the expression $[M^a L^b T^c]$ which completely defines the physical quantity.

e.g., Velocity $= \dfrac{\text{Distance}}{\text{Time}} = \dfrac{[L]}{[T]} = [L^{+1}T^{-1}]$

$= [M^0 L^1 T^{-1}]$

$\therefore$ dimensions of velocity are

zero in mass

+1 in length

and -1 in time.

and $[M^0 L^{+1} T^{-1}]$ is the dimensional formula of velocity

DIMENSIONAL EQUATION

The equation obtained when a physical quantity is equated with its dimensional formula is known as dimensional equation.

If V denotes velocity then

$[V] = [M^0 L^1 T^{-1}]$ is the dimensional equation of velocity.

DIMENSIONAL FORMULA OF SOME PHYSICAL QUANTITIES

Important Points :

- Following points should be noted while obtained dimension of any physical quantity.

(a) dimensional formula is always enclosed inside the bracket e.g., $[M^aL^bT^c]$

(b) power are added in multiplication e.g., $L \times L = L^{1+1} = L^2$

(c) power are subtracted in division

e.g., $\frac{L^2}{L} = L^{2-1} = L^1$

(d) quantity in numerator has positive power.

(e) quantity in denominator has negative power.

e.g., $\frac{[L]}{[T]} = LT^{-1}$

- **Important Physical Quantities :**

1. Length (l) = $[M^0L^1T^0]$
2. Mass (m) = $[M^1L^0T^0]$
3. Time (t) = $[M^0L^0T^1]$
4. Height of Radius or Distance or Displacement = $[M^0L^1T^0]$
   (h) (r) (s) (d)
5. Area (a) = length x breadth
   = length x length
   = $[L^1] \times [L^1] = [L^{1+1}] = [M^0L^2T^0]$
6. Volume (V) = length x breadth x height
   = $[L] \times [L] \times [L] = [L]^{1+1+1} = [M^0L^3T^0]$
7. Density (ρ) = $\frac{\text{mass}}{\text{volume}} = \frac{[M^1L^0T^0]}{[M^0L^3T^0]}$
   = $[M^{1-0}L^{0-3}T^{0-0}] = [M^1L^{-3}T^0]$

8. Velocity or speed $= \dfrac{\text{displacement}}{\text{time}}$ or $\dfrac{\text{distance}}{\text{time}}$

$= \dfrac{\text{length}}{\text{time}} = \dfrac{M^0L^1T^0}{M^0L^0T^1} = [M^0L^1T^{-1}]$

9. Acceleration (a) $= \dfrac{\text{velocity}}{\text{time}} = \dfrac{M^0L^1T^{-1}}{M^0L^0T^1}$

$[M^0L^1T^{-1-1}] = [M^0L^1T^{-2}]$

10. Momentum (P) = Mass x Velocity

$= [M^1L^0T^0] \times [M^0L^1T^{-1}]$

$= [M^{1+0}L^{0+1}T^{0-1}] = [M^1L^1T^{-1}]$

11. Force (F) = Mass x Acceleration

$= [M^1L^0T^0] \times [M^0L^1T^{-2}]$

$= [M^{1+0}L^{0+1}T^{0-2}] = [M^1L^1T^{-2}]$

12. Impulse (I) = Force x time

$= [M^1L^1T^{-2}] \times [M^0L^0T^1]$

$= [M^{1+0}L^{1+0}T^{-2+1}] = [M^1L^1T^{-1}]$

13. Work (W) = Force x distance

$= [M^1L^1T^{-2}] \times [M^0L^1T^0]$

$= [M^{1+0}L^{1+1}T^{-2+0}] = [M^1L^2T^{-2}]$

14. Power (P) $= \dfrac{\text{Work done}}{\text{Time taken}} = \dfrac{[M^1L^2T^{-2}]}{[M^0L^0T^1]}$

$= [M^{1-0}L^{2-0}T^{-2-1}] = [M^1L^2T^{-3}]$

15. Energy (E)

a) Kinetic energy (K.E.) $= \dfrac{1}{2}mv^2$

$[M^0L^0T^0]\ [M^1L^0T^0]\ [M^0L^1T^{-1}]\ [M^0L^1T^{-1}]$

$\left[\because \dfrac{1}{2} \rightarrow \text{dimensionless constant}\right]$

$= [M^{0+1+0+0}L^{0+0+1+1}T^{0+0-1-1}]$

$= [M^1L^2T^{-2}]$

(b) Potential energy (P.E.) $= mgh$

$= [M^1L^0T^0]\,[M^0L^1T^{-2}]\,[M^0L^1T^0]$

[g → acceleration due to gravity

∴ dimension of acceleration

$= [M^{1+0+0}L^{0+1+1}T^{0-2+0}]$

$= [M^1L^2T^{-2}]$

16. Pressure $= \dfrac{\text{Force}}{\text{Area}} = \dfrac{[M^1L^1T^{-2}]}{[M^0L^2T^0]}$

$= [M^{1-0}L^{1-2}T^{-2-0}] = [M^1L^{-1}T^{-2}]$