

INDEX

IIT JAM BT: PHYSCIS

CHAPTER NO.	CHAPTER NAME	PAGE NO.
1	UNITS & MEASUREMENTS	1
2	KINEMATICS	9
3	LAWS OF MOTION	19
4	WORK ENERGY & POWER	30
5	ROTATIONAL MOTION	36
6	GRAVITATION	42
7	MECHANICAL PROPERTIES OF SOLID & LIQUID	48
8	THERMAL PROPERTIES OF MATTER	55
9	ELECTROSTATICS	72
10	MAGNETOSTATICS	83
11	ELECTROMAGNETIC INDUCTION	93
12	ELECTROMAGNETIC WAVE	99
13	RAY OPTICS	104
14	WAVE OPTICS	117
15	MODERN PHYSICS	123
16	SOLID & SEMICONDUCTOR DEVICES	133

UNITS & MEASUREMENTS

Physical Quantity

The quantities which can be measured by an instrument and by means of which we can describe the laws of physics are called physical quantities.

Type of physical quantities

1. Fundamental
2. Derived
3. Supplementary

1. Fundamental Quantities: Out of large number of physical quantities which exist in nature, there are only few quantities which are independent of all other quantities and do not require the help of any other physical quantity for their definition, therefore these are called absolute quantities. These quantities are also called fundamental or basic quantities, as all other quantities are based upon and can be expressed in terms of these quantities.

Table showing the seven (7) Fundamental Quantities of the International System of Units.

Fundamental Quantity		S.I. Unit	
Name	Symbol	Name	Symbol
Mass	M	Kilogram	kg
Length	l	Metre	m
Time	T	Second	S
Current	I	Ampere	A
Temperature	T	Kelvin	K
Amount of Substance	N	Mole	Mol
Luminous Intensity	I _v	Candela	cd

Note: These are also called as absolute or base quantities.

In mechanics, we treat length, mass and time as the three basic or fundamental quantities.

2. Derived: Physical quantities which can be expressed as combination of base quantities are called as derived quantities.

For example: Speed, velocity, acceleration, force, momentum, pressure, energy etc.

$$\text{EX. 1 } \text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{\text{length}}{\text{time}}$$

3. Supplementary: Beside the seven fundamental physical quantities two supplementary quantities are also defined, they are:

- (1) Plane angle
- (2) Solid angle.

Note: The supplementary quantities have only units but no dimensions.

UNIT:

Measurement of any physical quantity is expressed in terms of an internationally accepted certain basic reference standard called unit.

The units for the fundamental or base quantities are called fundamental or base unit. Other physical quantities are expressed as combination of these base units and hence, called derived units.

A complete set of units, both fundamental and derived is called a system of unit.

Principle Systems of Unit

There are various system in use over the world: CGS, FPS, SI (MKS) etc.

Table for Units of some physical quantities in different systems.

	Physical Quantity	System		
		CGS (Gaussian)	MKS (SI)	FPS (British)
Fundamental	Length	Centimetre	Meter	Foot
	Mass	Gram	Kilogram	Pound
	Time	Second	Second	Second
Derived	Force	dyne	newton → N	poundal
	Wok or Energy	erg	Joule → J	ft-poundal
	Power	erg/s	Watt → W	ft-poundal/s

Supplementary Units:

(1) Plane angle: radian (rad)

(2) Solid angle: steradian (sr)

Ex. Find the SI unit of speed, acceleration**Solution:**

$$\text{speed} = \frac{\text{distance}}{\text{time}} = \frac{\text{meter}(m)}{\text{second}(s)}$$

$$= m/s \quad (\text{called as meter per second})$$

$$\text{acceleration} = \frac{\text{velocity}}{\text{time}} = \frac{\text{displacement}/\text{time}}{\text{time}}$$

$$= \frac{\text{displacement}}{(\text{time})^2} = \frac{\text{meter}}{\text{second}^2} = m/s^2$$

 s^2 (called as meter per second square)**Prefixes**

The magnitudes of physical quantities vary over a wide range.

The CGPM recommended standard prefixes for magnitude too large or too small to be expressed more compactly for certain power of 10.

Multiple	Prefix	Symbol
10	deca	D
10^2	hecto	H
10^3	kilo	K
10^4	mega	M
10^9	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{16}	exa	E
Submultiple	Prefix	Symbol
10^{-1}	deci	D
10^{-2}	centi	C
10^{-3}	milli	M
10^{-4}	micro	μ
10^{-9}	nano	N
10^{-12}	pico	P
10^{-15}	femto	F
10^{-16}	atto	A

Some Special Types of Units:

1.	1 Micron (1μ)	$= 10^{-4}$ cm	$= 10^{-6}$ m	(length)
2.	1 Angstrom ($1\text{\AA}$)	$= 10^{-8}$ cm	$= 10^{-10}$ m	(length)
3.	1 fermi ($1f$)	$= 10^{-13}$ cm	$= 10^{-15}$ m	(length)
4.	1 inch	$= 2.54$ cm		(length)
5.	1 mile	$= 5280$ feet	$= 1.609$ km	(length)
6.	1 atmosphere	$= 10^5$ N/m ²	$= 76$ torr $= 76$ mm of Hg pressure	(pressure)
7.	1 litre	$= 10^{-3}$ m ³	$= 1000$ cm ³	(volume)
8.	1 carat	$= 0.0002$ kg		(weight)
9.	1 pound (lb)	$= 0.4536$ kg		(weight)

Dimensions

Dimensions of a physical quantity are the power to which the fundamental quantities must be raised to represent the given physical quantity.

$$\text{For example, density} = \frac{\text{mass}}{\text{volume}} = \frac{\text{mass}}{(\text{length})^3}$$

$$\text{Or density} = (\text{mass}) (\text{length})^{-3}$$

Thus, the dimensions of density are 1 in mass and -3 in length.

The dimensions of all other fundamental quantities are zero.

For convenience, the fundamental quantities are represented by one letter symbols. Generally, mass is denoted by M, length by L, time by T and electric current by A.

DIMENSIONAL FORMULA

It is an expression which shows how and which of the fundamental units are required to represent the unit of physical quantity.

Different quantities with units symbol and dimensional formula.

Quantity	Symbol	Formula	S.I. Unit	D.F.
Displacement	S	l	Metre or m	$M^0 L T^0$
Area	A	$l \times b$	$(\text{metre})^2$ or m^2	$M^0 L^2 T^0$
Volume	V	$l \times b \times h$	$(\text{metre})^3$ or m^3	$M^0 L^3 T^0$
Velocity	V	$v = \frac{\Delta s}{\Delta t}$	m/s	$M^0 L T^{-1}$
Acceleration	A	$a = \frac{\Delta v}{\Delta t}$	m/s^2	$M^0 L T^{-2}$
Force	F	$f = ma$	Newton or N	$M L T^{-2}$

Momentum	P	$p = mv$	Kgm/s	MLT^{-1}
Impulse	I	$F \times t$	N.sec	MLT^{-1}
Work	W	$F \cdot d$	N.m	ML^2T^{-2}
Energy	KE or P.E. = mgh	$K.E = \frac{1}{2}mv^2$	Joule or J	ML^2T^{-2}
Power	P	$p = \frac{W}{t}$	watt W	ML^2T^{-3}
Angular displacement	θ	$\theta = \frac{\text{arc}}{\text{radius}}$	radian or rad	$M^0L^0T^0$
Angular velocity	ω	$\omega = \frac{\theta}{t}$	rad/sec	$M^0L^0T^{-1}$
Angular acceleration	α	$\alpha = \frac{\Delta\omega}{\Delta t}$	rad/	$M^0L^0T^{-2}$
Moment of Inertia	I	$I = mr^2$	$kg - m^2$	ML^2T^0
Density	d	$d = \frac{M}{V}$	kg/m^3	$ML^{-3}T^0$
pressure	p	$p = F/A$	Pascal or Pa	$ML^{-1}T^{-2}$
Torque	t	$T = r * f$	N.m.	ML^2T^{-2}
Frequency	v or f	$f = \frac{1}{T}$	hertz or Hz	$M^0L^0T^{-1}$
Stress	-	F/A	N/m^2	$ML^{-1}T^{-2}$
Strain	-	$\frac{\Delta l}{l}; \frac{\Delta A}{A}; \frac{\text{inc}V}{V}$	-	$M^0L^0T^0$
Youngs modulus (Bulk modulus of rigidity)	Y	$Y = \frac{F/A}{\Delta l/l}$	N/m^2	$ML^{-1}T^{-2}$
Surface tension	T	$\frac{F}{l} \text{ or } \frac{W}{A}$	$\frac{N}{m}; \frac{J}{m^2}$	ML^0T^{-2}
Force constant (spring)	K	$F = kx$	N/m	ML^0T^{-2}
Coefficient of viscosity	η	$F = \eta \left(\frac{dv}{dx} \right) A$	Kg/ms(poise in C.G.S)	$ML^{-1}T^{-1}$
Gravitation constant	G	$F = \frac{Gm_1m_2}{r^2}$	$\frac{N - m^2}{kg^2}$	$M^{-1}L^3T^{-2}$
Gravitational potential	V_g	$V_g = \frac{PE}{m}$	$\frac{J}{kg}$	$M^0L^2T^{-2}$
Temperature Heat	θ	-	Kelvin or K	$M^0L^0T^0\theta^1$
	Q	$Q = m \times s \times \Delta t$	Joule of Calorie	ML^2T^{-2}
Specific heat	S	$Q = m \times s \times \Delta t$	$\frac{\text{Joule}}{kg.Kelvin}$	$M^0L^2T^{-2}\theta^{-1}$
Latent heat	L	$Q = mL$	$\frac{\text{Joule}}{kg}$	$M^0L^2T^{-2}$
Coefficient of thermal conductivity	K	$Q = \frac{KA(\theta_1 - \theta_2)t}{d}$	$\frac{\text{Joule}}{m \text{ sec } K}$	$MLT^{-3}\theta^{-1}$
Universal gas constant	R	$PV = nRT$	$\frac{\text{Joule}}{\text{Mol. } K}$	$ML^2T^{-2}\theta^{-1}$
Mechanical equivalent of heat	J	$W = JH$	-	$M^0L^0T^0$
Charge	Q or q	$I = \frac{Q}{t}$	Coulomb or C	M^0L^0TA
Current	I	-	Ampere or A	$M^0L^0T^0A$

Electric permittivity	ϵ_0	$\epsilon_0 = \frac{1}{4\pi F} \cdot \frac{q_1 q_2}{r^2}$	$\frac{(\text{coul.})^2}{N \cdot m^2} \text{ or } \frac{C^2}{B - m^2}$	$M^{-1}L^{-3}T^4A^2$
Electric potential	V	$V = \frac{\Delta W}{q}$	Joule/coul	$ML^2T^{-3}A^{-1}$
Intensity of electric field	E	$E = \frac{F}{q}$	N/coul.	$MLT^{-3}A^{-1}$
Capacitance	C	$Q = CV$	Farad	$M^{-1}L^{-2}T^4A^2$
Dielectric constant	ϵ_r	$\epsilon_r = \frac{\epsilon}{\epsilon_0}$	-	$M^0L^0T^0$
Or relative permittivity	R	$V = IR$	Ohm	$ML^2T^{-3}A^{-2}$
Resistance				
Conductance	S	$S = \frac{1}{R}$	Mho	$M^{-1}L^{-2}T^{-3}A^2$
Specific resistance or resistivity	ρ	$\rho = \frac{RA}{l}$	Ohm x meter	$ML^3T^{-3}A^{-2}$
Conductivity or	S	$\sigma = \frac{1}{\rho}$	Mho/meter	$M^{-1}L^{-3}T^3A^2$
Specific conductance	B	$F = qvB \sin \theta$ Or $F = BIL$	Tesla or weber/ m^2	$MT^{-2}A^{-1}$
magnetic induction				
Magnetic flux	ϕ	$e = \frac{d\phi}{dt}$	Weber	$ML^2T^{-2}A^{-1}$
Magnetic intensity	H	$B = \mu H$	A/m	$M^0L^{-1}T^0A$
Magnetic permeability	μ_0	$B = \frac{\mu_0 Idl \sin \theta}{4\pi r^2}$	$\frac{N}{amp^2}$	$MLT^{-2}A^{-2}$
Coefficient of self or Mutual inductance	L	$e = L \cdot \frac{dl}{dt}$	Henry	$ML^2T^{-2}A^{-2}$
Electric dipole moment	P	$p = q \times 2l$	C.m.	M^0LTA
Magnetic dipole moment	M	$m = NIA$	amp. m^2	$M^0L^2AT^0$

Quantities having same Dimensions

Dimension	Quantity
$[M^0L^0T^{-1}]$	Frequency, angular frequency, angular velocity, velocity gradient and decay constant
$[ML^2T^{-2}]$	Work, internal energy, potential energy, kinetic energy, torque, moment of force
$[ML^{-1}T^{-2}]$	Pressure, stress, Young's modulus, bulk modulus, modulus of rigidity, energy density
$[ML^1T^{-1}]$	Momentum, impulse
$[M^0L^1T^{-2}]$	Acceleration due to gravity, gravitational field intensity
$[ML^1T^{-2}]$	Thrust, force, weight, energy gradient
$[ML^2T^{-1}]$	Angular momentum and Planck's constant

Application of Dimensional Analysis

1. To find dimensions of physical constant or coefficients: As dimensions of a physical quantity are unique, we write any formula or equation incorporating the given constant and then by substituting the dimensional formulae of all other quantities, we can find the dimensions of the required constant or coefficient.

- (i) Gravitational constant: According to Newton's law of gravitation

$$F = G \frac{m_1 m_2}{r^2} \text{ or } G = \frac{Fr^2}{m_1 m_2}$$

Substituting the dimensions of all physical quantities

$$[G] = \frac{[ML^{-2}][L^2]}{[M][M]} = [M^{-1}L^3T^{-2}]$$

- (ii) Plank constant: According to Planck $E = h\nu$ or $h = \frac{E}{\nu}$

Substituting the dimension of all physical quantities

$$[h] = \frac{[ML^2T^{-1}]}{[T^{-1}]} = [ML^2T^{-1}]$$

- (iii) Coefficient of viscosity: According to Poiseuille's formula

$$\frac{dV}{dt} = \frac{\pi pr^2}{8\eta l} \text{ or } \eta = \frac{\pi pr^4}{8l(dV/dt)}$$

Substituting the dimensions of all physical quantities

$$[\eta] = \frac{[ML^{-1}T^{-2}][L^4]}{[L][L^3/T]} = [ML^{-1}T^{-1}]$$

Significant Figures

Significant figures in the measured value of a physical quantity tell the number of digits in which we have confidence. Larger the number of significant figures obtained in a measurement, greater is the accuracy of the measurement. The reverse is also true.

The following rules are observed in counting the number of significant figures in a given measured quantity.

- All non-zero digits are significant.
Example: 42.3 has three significant figures.
243.4 has four significant figures.
24.123 has five significant figures.
- A zero becomes significant figure if it appears between two non-zero digits.
Example: 5.03 has three significant figures.
5.604 has four significant figures.
4.004 has four significant figures.
- Leading zeros or the zeros placed to the left of the number are never significant.
Example: 0.543 has three significant figures.
0.045 has two significant figures.
0.006 has one significant figure.
- Trailing zeros or the zeros placed to the right of the number are significant.
Example: 4.330 has four significant figures.
433.00 has five significant figures.
343.000 has six significant figures.
- In exponential notation, the numerical portion gives the number of significant figures.
Example: 1.32×10 has three significant figures.
 132×10 has three significant figures.

Rounding Off

While rounding off measurements, we use the following rules by convention:

- If the digit to be dropped is less than 5. Then the preceding digit is left unchanged.
Example: $x = 7.82$ is rounded off to 7.8,
again $X = 3.94$ is rounded off to 3.9.

- If the digit to be dropped is more than 5, then the preceding digit is raised by one.

Example: $x = 6.87$ is rounded off to 6.9.

again $x = 12.78$ is rounded off to 12.8.

- If the digit to be dropped is 5 followed by digits other than zero, then the preceding digit is raised by one.

Example: $x = 16.351$ is rounded off to 16.4.

again $x = 6.758$ is rounded off to 6.8.

- If digit to be dropped is 5 or 5 followed by zeros, then preceding digit is left unchanged, if it is even.

Example: $x = 3.250$ becomes 3.2 on rounding off,

again $x = 12.650$ becomes 12.6 on rounding off.

- If digit to be dropped is 5 or 5 followed by zeros, then the preceding digit is raised by one, if it is odd.

Example: $x = 3.750$ is rounded off to 3.8,

again $x = 16.150$ is rounded off to

Errors of Measurement

The measuring process is essentially a process of comparison. In spite of our best efforts, the measured value of a quantity is always somewhat different from its actual value, or true value. This difference in the true value and measured value of a quantity is called error of measurement.

(1) Absolute error: Absolute error in the measurement of a physical quantity is the magnitude of the difference between the true value and the measured value of the quantity.

Let a physical quantity be measured n times. Let the measured value be $a, a, a, \dots a$. The arithmetic mean of these value is

$$a_m = \frac{a_1 + a_2 + \dots + a_n}{n}$$

Usually, a is taken as the true value of the quantity, if the same is unknown otherwise.

By definition, absolute errors in the measured values of the quantity are

$$\Delta a_1 = a_m - a_1$$

$$\Delta a_2 = a_m - a_2$$

... ..

$$\Delta a_n = a_m - a_n$$

The absolute errors may be positive in certain cases and negative in certain other cases.

(2) Mean absolute error: It is the arithmetic mean of the magnitudes of absolute errors in all the measurements of the quantity. It is represented by $\underline{\Delta a}$. Thus

$$\underline{\Delta a} = \frac{|\Delta a_1| + |\Delta a_2| + \dots + |\Delta a_n|}{n}$$

Hence the final result of measurement may be written as $a = a_m \pm \underline{\Delta a}$

This implies that any measurement of the quantity is likely to lie between $(a_m + \underline{\Delta a})$ and $(a_m - \underline{\Delta a})$.

(3) Relative error or Fractional error: The relative error or fractional error of measurement is defined as the ratio of mean absolute error to the mean value of the quantity measured. Thus

$$\text{Relative error or Fractional error} = \frac{\text{Mean absolute error}}{\text{Mean val}} = \frac{\Delta a}{a_m}$$

(4) Percentage error: When the relative/fractional error is expressed in percentage, we call it percentage error. Thus

$$\text{Percentage error} = \frac{\Delta a}{a_m} \times 100\%$$

Propagation of Errors

(1) Error in sum of the quantities:

Suppose $x = a + b$

Let Δa = absolute error in measurement of a

Δb = absolute error in measurement of b

Δx = absolute error in calculation of x i.e. sum of a and b .

The maximum absolute error in x is $\Delta x = \pm \frac{(\Delta a + \Delta b)}{a+b} \times 100\%$

(2) Error in difference of the quantities:

Suppose $x = a - b$

Let Δa = absolute error in measurement of a

Δb = absolute error in measurement of b

Δx = absolute error in calculation of x i.e. difference of a and b .

The maximum absolute error in x is $\Delta x = \pm(\Delta a + \Delta b)$

Percentage error in the value of $X = \frac{(\Delta a + \Delta b)}{a-b} \times 100\%$

(3) Error in product of quantities:

Suppose $x = a \times b$

Let Δa = absolute error in measurement of a ,

Δb = absolute error in measurement of b ,

Δx = absolute error in calculation of x i.e. product of a and b .

The maximum fractional error in x is $\frac{\Delta x}{x} = \pm \left(\frac{\Delta a}{a} + \frac{\Delta b}{b} \right)$

Percentage error in the value of x

= (% error in value of a) + (% error in value of b)

(4) Error in division of quantities:

Suppose $X = \frac{a}{b}$

Let Δa = absolute error in measurement of a ,

Δb = absolute error in measurement of b ,

Δx = absolute error in calculation of x i.e. product of a and b .

The maximum fractional error in x is $\frac{\Delta x}{x} = \pm \left(\frac{\Delta a}{a} + \frac{\Delta b}{b} \right)$

Percentage error in the value of x

= (% error in value of a) + (% error in value of b)

(5) Error in quantity raised to some power:

Suppose $X = \frac{a^n}{b^m}$

Let Δa = absolute error in measurement of a ,

Δb = absolute error in measurement of b ,

Δx = absolute error in calculation of x i.e. product of a and b .

The maximum fractional error in x is $\frac{\Delta x}{x} = \pm \left(n \frac{\Delta a}{a} + m \frac{\Delta b}{b} \right)$

Percentage error in the value of x

= n (% error in value of a) + m (% error in value of b)

BASIC MATHEMATICS

Mensuration Formulas:

r : radius ;

d = diameter ;

V = Volume

$S.A$ = surface area

(a) Circle

Parameter : $2\pi r = \pi d$, Area : $\pi r^2 = \frac{1}{4}\pi d^2$

(b) Sphere

Surface area = $4\pi r^2 = \pi d^2$, Volume $\frac{4}{3}\pi r^3 = \frac{1}{6}\pi d^3$

(c) Spherical Shell (Hollow sphere)

Surface area = $4\pi r^2 = \pi d^2$

Volume of material used = $(4\pi r^2)(dr)$,

dr = thickness

(d) Cylinder

Lateral area = $2\pi rh$

$V = \pi r^2 h$

Total area = $2\pi rh + 2\pi r^2$

= $2\pi r(h + r)$

(e) Cone

Lateral area = $\pi r \sqrt{r^2 + h^2}$

h = height

Total area = $\pi r(\sqrt{r^2 + h^2} + r)$

$V = \frac{1}{3}\pi r^2 h$

ANGLE CONVERSION FORMULAS $\approx$

1 degree = $\frac{\pi}{180^\circ}$ (≈ 0.02) radian Degrees to radians:

multiply by $\frac{\pi}{180^\circ}$

1 radian ≈ 57 degrees

Radians to degrees : multiply by $\frac{180^\circ}{\pi}$

Ex. 15 Covert 45° to radians :

$$45 \times \frac{\pi}{180} = \frac{\pi}{4} \text{ rad}$$

Convert $\frac{\pi}{6}$ rad to degrees:

$$\frac{\pi}{6} \times \frac{180}{\pi} = 30^\circ$$

Ex.16 Convert 30° to radians:

$$\text{Solution: } 30^\circ \times \frac{\pi}{180^\circ} = \frac{\pi}{6} \text{ rad}$$

Ex. 17 Convert $\frac{\pi}{3}$ rad to degrees.

$$\text{Solution: } \frac{\pi}{3} \times \frac{180}{\pi} = 60$$

Standard values

- (1) $30^\circ = \frac{\pi}{6} \text{ rad}$
 (2) $45^\circ = \frac{\pi}{4} \text{ rad}$
 (3) $60^\circ = \frac{\pi}{3} \text{ rad}$
 (4) $90^\circ = \frac{\pi}{2} \text{ rad}$

- (5) $120^\circ = \frac{2\pi}{3} \text{ rad}$
 (6) $135^\circ = \frac{3\pi}{4} \text{ rad}$
 (7) $150^\circ = \frac{5\pi}{6} \text{ rad}$
 (8) $180^\circ = \pi \text{ rad}$
 (9) $360^\circ = 2\pi \text{ rad}$

Trigonometric Value Table								
Angles (in degrees)	0	35	45	60	90	180	270	360
Angles (in Radians)	0	$\pi/6$	$\pi/4$	$\pi/3$	$\pi/2$	π	$3\pi/2$	2π
Sin	0	1/2	$1/\sqrt{2}$	$\sqrt{3}/2$	1	0	-1	0
Cos	1	$\sqrt{3}/2$	$1/\sqrt{2}$	1/2	0	-1	0	1
Tan	0	$1/\sqrt{3}$	1	$\sqrt{3}$	∞	0	∞	0
Cot	∞	$\sqrt{3}$	1	$1/\sqrt{3}$	0	∞	0	∞
Cosec	∞	2	$\sqrt{2}$	$2\sqrt{3}$	1	∞	-1	∞
Sec	1	$2/\sqrt{3}$	$\sqrt{2}$	2	∞	-1	∞	1

SOLVED EXAMPLES:

1. Find the dimensions of resistivity, thermal conductivity and coefficient of viscosity.

Solution:

(i) $R = \rho \frac{l}{A}$
 $\rho = \frac{RA}{l} = [ML^2T^{-3}A^{-2}]$

- (ii) Thermal conductivity, k

$$\frac{d\theta}{dt} = \frac{kl}{A\Delta\theta} = \frac{ML^tT^{-3}L}{L^2K}$$

$$= ML^{-3}K^{-1}$$

- (iii) Coefficient of viscosity

$$\therefore F = \eta A \frac{dv}{dx}$$

$$\eta = \frac{Fdx}{Adv} = \frac{(ML^{-2})(L)}{(L^2)(LT^{-1})} = ML^{-1}T^{-1}$$

2. If density ρ acceleration due to gravity g and frequency f are the basic quantities, find the dimensions of force.

Solution:

$$\text{We have } \rho = ML^{-3} \quad g = LT^{-2} \quad f = T^{-1}$$

Solving for M, L and T in terms of ρ , g and f we get

$$M = \rho^2 g^3 f^{-6} \quad L = g t^{-2} \quad \& \quad T = f^{-1}$$

$$\text{Force} = [MLT^{-2}] = [\rho g^3 f^{-6} \cdot g f^{-2} \cdot f^2] = [\rho g^4 f^{-6}]$$

3. The dimensions of the Rydberg constant are

- (a) $M^\circ L^{-1}T$ (b) MLT^{-1}
 (c) $M^\circ L^{-1}T^\circ$ (d) $ML^\circ T^2$

Solution: (c)

$$\text{From the relation } \frac{1}{\lambda} = R \left[\frac{1}{n_1^2} - \frac{1}{n_2^2} \right]$$

$$R = \frac{1}{L} = L^{-1} = M^\circ L^{-1}T^0$$

$\therefore$ (C)

4. An athlete's coach told his team that muscle times speed power. What dimensions does he view for "muscle"?

- (a) MLT^2 (b) ML^2T^{-2}
 (c) MLT^{-2} (d) L

Solution: (c)

$$\text{power} = \text{force} \times \text{velocity}$$

$$= \text{muscle times speed}$$

$$\therefore \text{Muscle represents force}$$

$$\text{muscle} = [ML^{-2}]$$

$\therefore$ (C)

5. Dimensions of ohm are same as (h is Planck's constant and e is charge)

- (a) $\frac{h}{e}$ (b) $\frac{h^2}{e}$
 (c) $\frac{h}{e^2}$ (d) $\frac{h^2}{e^2}$

Solution: (c)

$$\frac{h}{e^2} = \frac{[ML^2T^{-1}]}{[AT]^2} = [ML^2T^{-3}A^{-2}] = \text{resistance}$$

6. An experiment measures quantities a , b , c and x is calculated from $x = ab^2/c^3$. If the maximum percentage error in a , b and c are 1% 3% and 2% respectively, the maximum percentage error in x will be

- (a) 13 % (b) 17 %
 (c) 14 % (d) 11 %

Solution: (a)

Maximum percentage error in x

$$\text{As } x = \frac{ab^2}{c^3}$$

$$\frac{\Delta x}{x} = \frac{\Delta a}{a} + 2 \frac{\Delta b}{b} + 3 \frac{\Delta c}{c}$$

$$\frac{\Delta x}{x} = 1\% + 2 \times 3\% + 3 \times 2\%$$

$$= (1 + 6 + 6)\% = 13\%$$

7. The error in the measurement of the radius of a sphere is 1%. Then error in the measurement of volume is

- (a) 1 % (b) 5 %
(c) 3 % (d) 8 %

Solution:

$$V = \frac{4}{3} \pi r^3$$

$$\frac{\Delta V}{V} \times 100 = 3 \left(\frac{\Delta r}{r} \right) \times 100 = 3 \times 1 = 3 \%$$

$\therefore$ (C)

PREVIOUS YEAR QUESTIONS:

(IIT JAM BT 2021)

1. The moment of force in terms of fundamental dimensions is

- (1) MLT^{-1} (2) ML^2T^{-2}
(3) $ML^{-1}T^{-1}$ (4) MLT^{-2}

(IIT JAM BT 2020)

2. Consider a spherical particle of mass m and radius r moving in a medium. Its velocity at any time t is given by $v = v_0 \exp\left(\frac{-6\pi \eta r t}{m}\right)$, where v_0 is initial velocity of the particle. The dimensions of X are

- (1) MLT^{-1} (2) $M^{-1}LT$
(3) $ML^{-1}T^{-1}$ (4) Dimensionless

(IIT JAM BT 2019)

3. The dimensions of coefficient of viscosity are _____.

- (1) $ML^{-1}T^{-1}$ (2) $ML^{-1}T^{-2}$
(3) $ML^{-2}T^{-2}$ (4) $ML^{-2}T^{-1}$

(IIT JAM BT 2018)

4. Three vectors are as follows

$$\vec{a} = 3\hat{i} - 10\hat{j} + 7\hat{k}$$

$$\vec{b} = -9\hat{i} + 6\hat{j} - 47\hat{k}$$

$$\vec{c} = 11\hat{i} - 17\hat{k}$$

The value of $(\vec{a} + \vec{b}) \cdot \vec{c}$ is

- (1) 614 (2) 746
(3) 2 (4) 134

(GAT-B 2020)

5. Which of the following is a dimensionless quantity?

- (1) magnetic flux
(2) specific heat at constant volume
(3) amplification factor in electronics
(4) Young's modulus

(JNU BT 2017)

6. If $\vec{a}$ and $\vec{b}$ are two vectors of equal magnitude, such that the angle between them is 60° , and $\vec{a} \cdot \vec{b} = 8$. Find the length $|\vec{a}|$

- (1) 2 (2) 4
(3) 6 (4) 8

(TIFR 2020)

7. Pick the odd one out:

- (1) Speed of light in vacuum
(2) Charge of the electron
(3) Diameter of the Earth
(4) Gravitational constant

(TIFR 2014)

8. The dimensional representation of Planck's constant is same as that of

- (1) Angular momentum (2) Momentum
(3) Torque (4) Energy

Answer Key

1	2	3	4	5	6	7	8
(2)	(3)	(1)	(1)	(3)	(2)	(3)	(1)

:: Solution ::

1. **Solution:**

Moment of force = Torque

$$T = rF \sin \theta$$

$$= [L] [MLT^{-2}]$$

$$= [ML^2T^{-2}]$$

2. **Solution:**

Power of exponential has to be dimensionless

$$\therefore \exp\left(\frac{-6\pi \eta r t}{m}\right) =$$

$$X = \frac{M}{rt} = [ML^{-1}T^{-1}]$$

3. **Solution:**

$$F = \eta \frac{u}{y} A \text{ here } \eta: \text{coefficient of viscosity}$$

$$\eta = \frac{Fy}{uA} = \frac{[MLT^{-2}][L]}{[LT^{-1}][L^2]}$$

$$= [ML^{-1}T^{-1}]$$

4. **Solution:** $(\vec{a} + \vec{b}) \cdot \vec{c} = (-6\hat{i} + (-4\hat{j}) - 40\hat{k}) \cdot \vec{c}$

$$= -66 + 680$$

$$= 614$$

5. **Solution:**

Amplification factor is dimensionless because it's a ratio of the output voltage by input voltage

6. **Solution:**

$$a \cdot b = ab \cos \theta = a^2 \cos 60 = \frac{a^2}{2} = 8$$

$$a = 4$$

7. **Solution:**

Diameter of earth is not universal constant

At equator & pole the diameter of earth is different

8. **Solution:**

Dimension of Angular momentum is

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

$$\text{Planck constant} = [ML^2T^{-1}]$$

KINEMATICS

Introduction

The branch of physics in which motion and the forces causing motion are studied is called mechanics. As a first step in studying mechanics, we describe the motion of particles and bodies in terms of space and time without studying the cause of motion. This part of mechanics is called kinematics. We first define displacement, velocity and acceleration. Then, using these concepts, we study the motion of the objects moving under different conditions.

One dimensional	Two dimensional	Three dimensional
Motion of body in a straight line is called one dimensional motion.	Motion of body in a plane is called two dimensional motion.	Motion of body in a space is called three dimensional motion
When only one coordinate of the position of a body changes with time then it is said to be moving one dimensionally.	When two coordinates of the position of a body changes with time then it is said to be moving two dimensionally.	When all three coordinates of the position of a body changes with time then it is said to be moving three dimensionally
Ex. (i) Motion of car on a straight road. (ii) Motion of freely falling body.	Ex. (i) motion of car on a circular turn. (ii) Motion of billiards ball.	Ex. (i) motion of flying kite. (ii) motion of flying insect.

Motion in a Straight Line

When a particle moves along a straight line (assuming along the x-axis of the reference frame), we need only one coordinate (here the x-coordinate) to specify its position. This is also known as motion in one dimension or one-dimensional motion or rectilinear motion of the particle.

Distance	Displacement
(i) Length of actual path covered between the initial and final positions/points (ii) Scalar quantity (iii) Can have only +ve values	(i) Length of the shortest path between initial and final points. (ii) Vector quantity (iii) Can have -ve, 0,+ve values.

Both distance and displacement are measured in metres or kilometre. Their dimension is $[L]$.

Speed	Velocity
(i) The rate at which distance is covered. (ii) Scalar quantity (iii) Can have only +ve values	(i) The rate at which displacement takes place. (ii) Vector quantity (iii) Can have -ve, 0,+ve values.

(a) Uniform Speed: When a particle covers equal distances in equal intervals of time, (no matter how small the intervals are) then it is said to be moving with uniform speed.

(b) Non-uniform (variable) Speed: In non-uniform speed particle covers unequal distances in equal intervals of time.

(c) Average Speed: The average speed of a particle for a given 'Interval of time' is defined as the ration of distance travelled to the time taken.

$$\text{Average speed} = \frac{\text{Distance travelled}}{\text{Time taken}}; v_{av} = \frac{\Delta S}{\Delta t}$$

Time Average Speed: When particle moves with different uniform speed $v_1, v_2, v_3 \dots$ etc in different time intervals $t_1, t_2, t_3 \dots$ etc respectively, its average speed over the total time of journey is given as

$$v_{av} = \frac{\text{Total distance covered}}{\text{Total time elapsed}} = \frac{d_1 + d_2 + d_3 + \dots}{t_1 + t_2 + t_3 + \dots} = \frac{v_1 t_1 + v_2 t_2 + v_3 t_3 + \dots}{t_1 + t_2 + t_3 + \dots}$$

Special case: When particle moves with speed v_1 upto half time of its total motion and in rest time it is moving with speed v_2 then $v_{av} = \frac{v_1 + v_2}{2}$

Distance Averaged Speed: When a particle describes different distances $d_1, d_2, d_3, \dots$ with different time intervals $t_1, t_2, t_3, \dots$ with speeds $v_1, v_2, v_3, \dots$ respectively then the speed of particle averaged over the total distance can be given as

$$u_{av} = \frac{\text{Total distance covered}}{\text{Total time elapsed}} = \frac{d_1 + d_2 + d_3 + \dots}{t_1 + t_2 + t_3 + \dots} = \frac{d_1 + d_2 + d_3 + \dots}{\frac{d_1}{v_1} + \frac{d_2}{v_2} + \frac{d_3}{v_3} + \dots}$$

When particle moves the first half of a distance at a speed of v_1 and second half of the distance at speed v_2 then

$$v_{av} = \frac{2v_1v_2}{v_1 + v_2}$$

When particle covers one-third distance at speed v_1 next one third at speed v_2 and last one third at speed v_3 then

$$v_{av} = \frac{3v_1v_2v_3}{v_1v_2 + v_2v_3 + v_3v_1}$$

(d) Instantaneous Speed: It is the speed of a particle at particular instant. When we say "speed", it usually means instantaneous speed.

The instantaneous speed is average speed for infinitesimally small time interval (i.e., $\Delta t \rightarrow 0$). Thus Instantaneous speed

$$v = \frac{\Delta s}{\Delta t} = \frac{ds}{dt}$$

Velocity:

Rate of change of position i.e. rate of displacement with time is called velocity.

- (i) It is a scalar quantity having symbol v .
- (ii) Dimension: $[M^0 L^1 T^{-1}]$
- (iii) Unit: metre/second (S.I.), cm/second (C.G.S)
- (iv) Types

(a) Uniform Velocity: A particle is said to have uniform velocity, if magnitudes as well as direction of its velocity remains same and this is possible only when the particles moves in same straight line without reversing its direction.

(b) Non-uniform Velocity: A particle is said to have non-uniform velocity, if either of magnitude or direction of velocity changes (or both changes).

(c) Average Velocity: It is defined as the ratio of displacement to time taken by the body

$$\text{Average velocity} = \frac{\text{Displacement}}{\text{Time taken}}; \vec{v}_{av} = \frac{\Delta \vec{r}}{\Delta t}$$

(d) Instantaneous Velocity: Instantaneous velocity is defined as rate of change of position vector of particles with time at a certain instant of time.

$$\text{Instantaneous velocity } \vec{v} = \frac{\Delta \vec{r}}{\Delta t} = \frac{d\vec{r}}{dt}$$

Acceleration

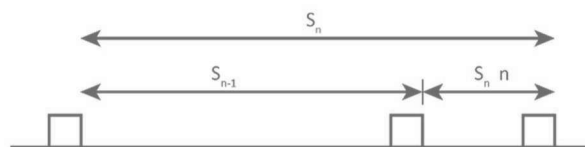
The time rate of change of velocity of an object is called acceleration of the object.

It is a vector quantity. It's direction is same as that of change in velocity (Not of the velocity)

Table for Possible ways of velocity change

When only direction of velocity changes	When only magnitude of velocity changes	When both magnitude and direction of velocity changes
Acceleration perpendicular to velocity	Acceleration parallel or anti-parallel to velocity	Acceleration has two components one is perpendicular to velocity and another parallel or anti-parallel to velocity
Ex. Uniform circular motion	Ex. Motion under gravity	Ex. Projectile motion

Displacement in n^{th} second



Displacement in n^{th} second = Displacement in n sec. – Displacement in $(n - 1)$ sec.

$$S_{nth} = S_n - S_{n-1} = \left[u(n) + \frac{1}{2}an^2 \right] - \left[u(n-1) + \frac{1}{2}a(n-1)^2 \right]$$

$$\therefore S_{nth} = u + \frac{a}{2}(2n-1)$$

EQUATION MOTION IN A STRAIGHT LINE WITH UNIFORM ACCELERATION

Consider the motion of a particle moving along the x-axis with uniform acceleration.

Let u = Initial velocity (at time $t = 0$)

V = Final velocity (at time t) and

x = Net displacement in the time interval $t = 0$ to $t = t$

The equations describing such uniformly accelerated motion are

$$v = u + at$$

$$x = ut + \frac{1}{2}at^2$$

$$v^2 = u^2 + 2ax$$