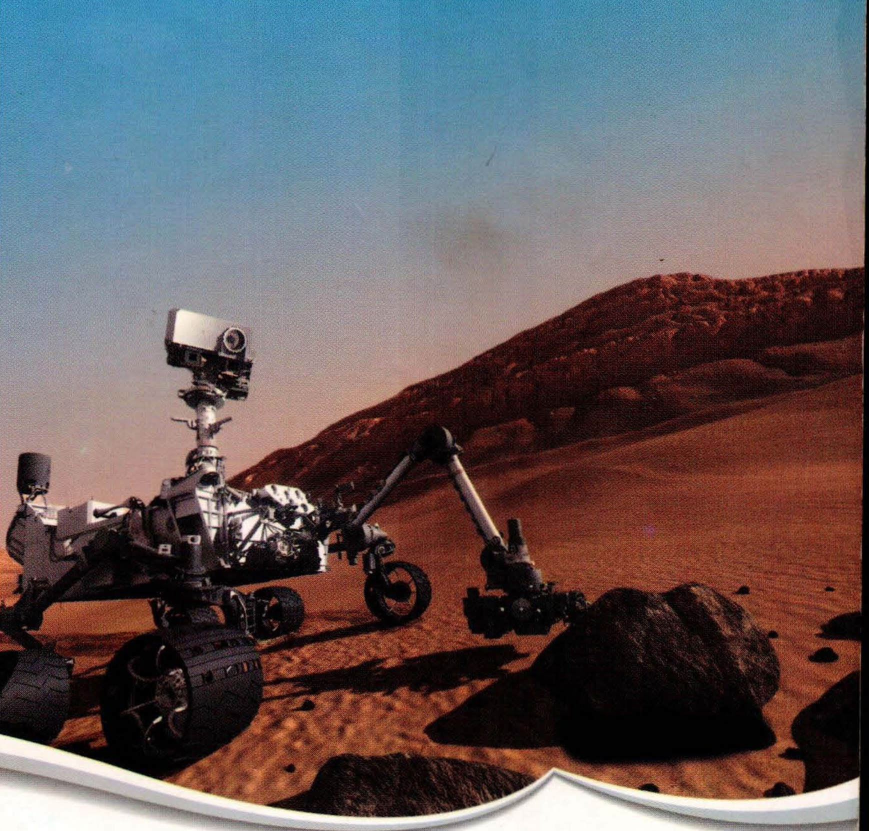
Physics
Handbook



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Contents

1 Basic Mathematics used in Physics

- **Quadratic equation**

Roots of $ax^2 + bx + c=0$ are $x = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Sum of roots $x_1 + x_2 = -\dfrac{b}{a}$; Product of roots $x_1 x_2 = \dfrac{c}{a}$

- **Binomial theorem**

$$(1+x)^n = 1 + nx + \frac{n(n-1)}{2}x^2 + \frac{n(n-1)(n-2)}{6}x^3 + \dots$$

$$(1-x)^n = 1 - nx + \frac{n(n-1)}{2}x^2 - \frac{n(n-1)(n-2)}{6}x^3 + \dots$$

If $x<<1$ then $(1+x)^n \approx 1 + nx$ & $(1-x)^n \approx 1-nx$

- **Logarithm**

$\log mn = \log m + \log n$

$\log \dfrac{m}{n} = \log m - \log n$

$\log m^n = n \log m$

$\log_e m = 2.303 \log_{10} m$

$\log 2 = 0.3010$

$\log 3 = 0.4771$

- **Componendo and dividendo theorem**

If $\dfrac{p}{q} = \dfrac{a}{b}$ then $\dfrac{p+q}{p-q} = \dfrac{a+b}{a-b}$

- **Arithmetic progression-AP**

$a, a+d, a+2d, a+3d, \dots a+(n-1)d$ here d = common difference

Sum of n terms $S_n = \dfrac{n}{2}[2a+(n-1)d]$

Note : (i) $1+2+3+4+5 \dots + n = \dfrac{n(n+1)}{2}$

(ii) $1^2+2^2+3^2+\dots+n^2 = \dfrac{n(n+1)(2n+1)}{6}$

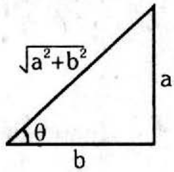
- **Geometrical progression-GP**

$a, ar, ar^2, ar^3, \dots$ here, r = common ratio

Sum of n terms $S_n = \dfrac{a(1-r^n)}{1-r}$ Sum of ∞ terms $S_\infty = \dfrac{a}{1-r}$

- **Trigonometry**

2π radian = 360° ⇒ 1 rad = 57.3°



$$\sin\theta = \frac{\text{perpendicular}}{\text{hypotenuse}} \qquad \cos\theta = \frac{\text{base}}{\text{hypotenuse}}$$

$$\tan\theta = \frac{\text{perpendicular}}{\text{base}} \qquad \cot\theta = \frac{\text{base}}{\text{perpendicular}}$$

$$\sec\theta = \frac{\text{hypotenuse}}{\text{base}} \qquad \text{cosec}\,\theta = \frac{\text{hypotenuse}}{\text{perpendicular}}$$

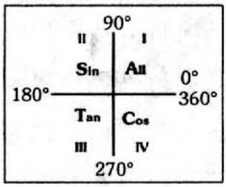
$$\sin\theta = \frac{a}{\sqrt{a^2+b^2}} \qquad \cos\theta = \frac{b}{\sqrt{a^2+b^2}} \qquad \tan\theta = \frac{a}{b}$$

$$\text{cosec}\theta = \frac{1}{\sin\theta} \qquad \sec\theta = \frac{1}{\cos\theta} \qquad \cot\theta = \frac{1}{\tan\theta}$$

$\sin^2\theta + \cos^2\theta = 1$ $\qquad 1 + \tan^2\theta = \sec^2\theta$ $\qquad 1 + \cot^2\theta = \text{cosec}^2\theta$

$\sin(A\pm B) = \sin A\cos B \pm \cos A\sin B$ $\qquad \cos(A\pm B) = \cos A\cos B \mp \sin A\sin B$

$$\tan(A\pm B) = \frac{\tan A \pm \tan B}{1 \mp \tan A \tan B}$$



$\sin 2A = 2\sin A\cos A$

$\cos 2A = \cos^2 A - \sin^2 A = 1 - 2\sin^2 A = 2\cos^2 A - 1$

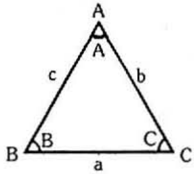
$$\tan 2A = \frac{2\tan A}{1-\tan^2 A}$$

$\sin(90°+\theta) = \cos\theta$	$\sin(180°-\theta) = \sin\theta$	$\sin(-\theta) = -\sin\theta$	$\sin(90°-\theta) = \cos\theta$
$\cos(90°+\theta) = -\sin\theta$	$\cos(180°-\theta) = -\cos\theta$	$\cos(-\theta) = \cos\theta$	$\cos(90°-\theta) = \sin\theta$
$\tan(90°+\theta) = -\cot\theta$	$\tan(180°-\theta) = -\tan\theta$	$\tan(-\theta) = -\tan\theta$	$\tan(90°-\theta) = \cot\theta$
$\sin(180°+\theta) = -\sin\theta$	$\sin(270°-\theta) = -\cos\theta$	$\sin(270°+\theta) = -\cos\theta$	$\sin(360°-\theta) = -\sin\theta$
$\cos(180°+\theta) = -\cos\theta$	$\cos(270°-\theta) = -\sin\theta$	$\cos(270°+\theta) = \sin\theta$	$\cos(360°-\theta) = \cos\theta$
$\tan(180°+\theta) = \tan\theta$	$\tan(270°-\theta) = \cot\theta$	$\tan(270°+\theta) = -\cot\theta$	$\tan(360°-\theta) = -\tan\theta$

$\theta \rightarrow$	0° (0)	30° $\left(\frac{\pi}{6}\right)$	45° $\left(\frac{\pi}{4}\right)$	60° $\left(\frac{\pi}{3}\right)$	90° $\left(\frac{\pi}{2}\right)$	120° $\left(\frac{2\pi}{3}\right)$	135° $\left(\frac{3\pi}{4}\right)$	150° $\left(\frac{5\pi}{6}\right)$	180° (π)	270° $\left(\frac{3\pi}{2}\right)$	360° (2π)
$\sin\theta$	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	–1	0
$\cos\theta$	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{1}{\sqrt{2}}$	$-\frac{\sqrt{3}}{2}$	–1	0	1
$\tan\theta$	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞	$-\sqrt{3}$	–1	$-\frac{1}{\sqrt{3}}$	0	∞	0

- **sine law**

$$\frac{\sin A}{a}=\frac{\sin B}{b}=\frac{\sin C}{c}$$



- **cosine law**

$$\cos A=\frac{b^2+c^2-a^2}{2bc},\ \cos B=\frac{c^2+a^2-b^2}{2ca},\ \cos C=\frac{a^2+b^2-c^2}{2ab}$$

- **For small θ**

$\sin\theta\approx\theta$ $\quad\cos\theta\approx 1\quad$ $\tan\theta\approx\theta\sin\theta\approx\tan\theta$

- **Differentiation**

- $y=x^n\rightarrow\frac{dy}{dx}=nx^{n-1}$
- $y=\ell nx\rightarrow\frac{dy}{dx}=\frac{1}{x}$
- $y=\sin x\rightarrow\frac{dy}{dx}=\cos x$
- $y=\cos x\rightarrow\frac{dy}{dx}=-\sin x$
- $y=e^{\alpha x+\beta}\rightarrow\frac{dy}{dx}=\alpha e^{\alpha x+\beta}$
- $y=uv\rightarrow\frac{dy}{dx}=u\frac{dv}{dx}+v\frac{du}{dx}$
- $y=f(g(x))\Rightarrow\frac{dy}{dx}=\frac{df(g(x))}{dg(x)}\times\frac{d(g(x))}{dx}$
- $y=k=$ constant $\Rightarrow\frac{dy}{dx}=0$
- $y=\frac{u}{v}\Rightarrow\frac{dy}{dx}=\frac{v\frac{du}{dx}-u\frac{dv}{dx}}{v^2}$

- **Integration**

- $\int x^n dx=\frac{x^{n+1}}{n+1}+C, n\neq-1$
- $\int\frac{1}{x}dx=\ell nx+C$
- $\int\sin x dx=-\cos x+C$
- $\int\cos x dx=\sin x+C$
- $\int e^{\alpha x+\beta}dx=\frac{1}{\alpha}e^{\alpha x+\beta}+C$
- $\int(\alpha x+\beta)^n dx=\frac{(\alpha x+\beta)^{n+1}}{\alpha(n+1)}+C$

- **Maxima & Minima of a function y = f(x)**

  - For maximum value $\frac{dy}{dx}=0$ & $\frac{d^2y}{dx^2}=-ve$

  - For minimum value $\frac{dy}{dx}=0$ & $\frac{d^2y}{dx^2}=+ve$

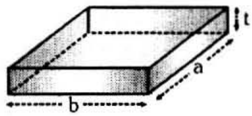
- **Average of a varying quantity**

If y = f(x) then $<y>=\bar{y}=\frac{\int_{x_1}^{x_2} y\,dx}{\int_{x_1}^{x_2} dx}=\frac{\int_{x_1}^{x_2} y\,dx}{x_2-x_1}$

Formulae for determination of area

- Area of a square = $(\text{side})^2$
- Area of rectangle = length $\times$ breadth
- Area of a triangle = $\frac{1}{2}\times$ base $\times$ height
- Area of a trapezoid = $\frac{1}{2}\times$ (distance between parallel sides) $\times$ (sum of parallel sides)
- Area enclosed by a circle = πr^2 (r = radius)
- Surface area of a sphere = $4\pi r^2$ (r = radius)
- Area of a parallelogram = base $\times$ height
- Area of curved surface of cylinder = $2\pi r\ell$ (r = radius and ℓ = length)
- Area of whole surface of cylinder = $2\pi r(r+\ell)$ (ℓ = length)
- Area of ellipse = πab (a & b are semi major and semi minor axis respectively)
- Surface area of a cube = $6(\text{side})^2$
- Total surface area of a cone = $\pi r^2+\pi r\ell$ where $\pi r\ell=\pi r\sqrt{r^2+h^2}$ = lateral area

Formulae for determination of volume :



- Volume of a rectangular slab = length × breadth × height = abt
- Volume of a cube = $(\text{side})^3$
- Volume of a sphere = $\frac{4}{3}\pi r^3$ (r = radius)
- Volume of a cylinder = $\pi r^2 \ell$ (r = radius and ℓ = length)
- Volume of a cone = $\frac{1}{3}\pi r^2 h$ (r = radius and h = height)

KEY POINTS:

- To convert an angle from degree to radian, we have to multiply it by $\frac{\pi}{180^\circ}$ and to convert an angle from radian to degree, we have to multiply it by $\frac{180^\circ}{\pi}$.
- By help of differentiation, if y is given, we can find $\frac{dy}{dx}$ and by help of integration, if $\frac{dy}{dx}$ is given, we can find y.
- The maximum and minimum values of function $A\cos\theta + B\sin\theta$ are $\sqrt{A^2+B^2}$ and $-\sqrt{A^2+B^2}$ respectively.
- $(a+b)^2 = a^2 + b^2 + 2ab$ $(a-b)^2 = a^2 + b^2 - 2ab$
  $(a+b)(a-b) = a^2 - b^2$ $(a+b)^3 = a^3 + b^3 + 3ab(a+b)$
  $(a-b)^3 = a^3 - b^3 - 3ab(a-b)$

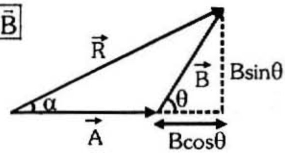
Important Notes

2 Vectors

- **Vector Quantities**

A physical quantity which requires magnitude and a particular direction, when it is expressed.

- **Triangle law of Vector addition** $\boxed{\vec{R}=\vec{A}+\vec{B}}$



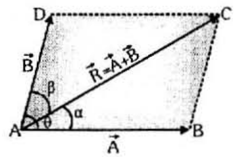
$R=\sqrt{A^2+B^2+2AB\cos\theta}$

$\tan\alpha=\dfrac{B\sin\theta}{A+B\cos\theta}$ If A = B then $R=2A\cos\dfrac{\theta}{2}$ & $\alpha=\dfrac{\theta}{2}$

R_{max} = A+B for θ=0° ; R_{min} = A–B for θ=180°

- **Parallelogram Law of Addition of Two Vectors**

If two vectors are represented by two adjacent sides of a parallelogram which are directed away from their common point then their sum (i.e. resultant vector) is given by the diagonal of the parallelogram passing away through that common point.

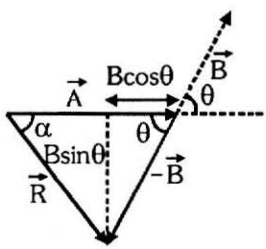


$$\overline{AB}+\overline{AD}=\overline{AC}=\vec{R} \text{ or } \vec{A}+\vec{B}=\vec{R}\Rightarrow R=\sqrt{A^2+B^2+2AB\cos\theta}$$

$$\tan\alpha=\frac{B\sin\theta}{A+B\cos\theta} \text{ and } \tan\beta=\frac{A\sin\theta}{B+A\cos\theta}$$

- **Vector subtraction**

$\boxed{\vec{R}=\vec{A}-\vec{B}}\Rightarrow\vec{R}=\vec{A}+(-\vec{B})$

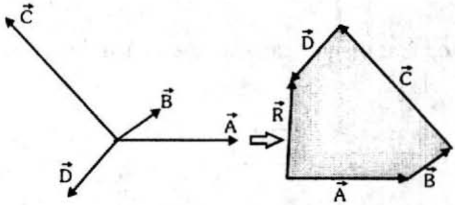


$R=\sqrt{A^2+B^2-2AB\cos\theta}$, $\tan\alpha=\dfrac{B\sin\theta}{A-B\cos\theta}$

If A = B then $R=2A\sin\dfrac{\theta}{2}$

- **Addition of More than Two Vectors (Law of Polygon)**

If some vectors are represented by sides of a polygon in same order, then their resultant vector is represented by the closing side of polygon in the opposite order.



$$\vec{R}=\vec{A}+\vec{B}+\vec{C}+\vec{D}$$

- **Rectangular component of a 3–D vector**

- $\vec{A}=A_x\hat{i}+A_y\hat{j}+A_z\hat{k}$

Angle made with x-axis $\quad \cos\alpha=\dfrac{A_x}{A}=\dfrac{A_x}{\sqrt{A_x^2+A_y^2+A_z^2}}=\ell$

Angle made with y-axis $\quad \cos\beta=\dfrac{A_y}{A}=\dfrac{A_y}{\sqrt{A_x^2+A_y^2+A_z^2}}=m$

Angle made with z-axis $\quad \cos\gamma=\dfrac{A_z}{A}=\dfrac{A_z}{\sqrt{A_x^2+A_y^2+A_z^2}}=n$

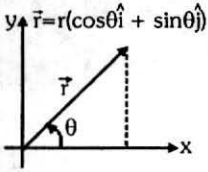
- ℓ, m, n are called direction cosines

$$\ell^2+m^2+n^2=\cos^2\alpha+\cos^2\beta+\cos^2\gamma=\frac{A_x^2+A_y^2+A_z^2}{\left(\sqrt{A_x^2+A_y^2+A_z^2}\right)^2}=1$$

or $\sin^2\alpha+\sin^2\beta+\sin^2\gamma=2$

- **General Vector in x-y plane**

$\vec{r}=x\hat{i}+y\hat{j}=r\left(\cos\theta\hat{i}+\sin\theta\hat{j}\right)$



Examples

1. Construct a vector of magnitude 6 units making an angle of 60° with x-axis.

Sol. $\vec{r} = r(\cos 60\hat{i} + \sin 60\hat{j}) = 6\left(\frac{1}{2}\hat{i} + \frac{\sqrt{3}}{2}\hat{j}\right) = 3\hat{i} + 3\sqrt{3}\hat{j}$

2. Construct an unit vector making an angle of 135° with x axis.

Sol. $\hat{r} = 1(\cos 135°\hat{i} + \sin 135°\hat{j}) = \frac{1}{\sqrt{2}}(-\hat{i} + \hat{j})$

- **Scalar product (Dot Product)**

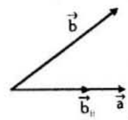
  - $\vec{A}.\vec{B} = AB\cos\theta \Rightarrow \boxed{\text{Angle between two vectors } \theta = \cos^{-1}\left(\frac{\vec{A}\cdot\vec{B}}{AB}\right)}$

  - If $\vec{A} = A_x\hat{i} + A_y\hat{j} + A_z\hat{k}$ & $\vec{B} = B_x\hat{i} + B_y\hat{j} + B_z\hat{k}$ then

    $\vec{A}.\vec{B} = A_xB_x + A_yB_y + A_zB_z$ and angle between $\vec{A}$ & $\vec{B}$ is given by

    $$\cos\theta = \frac{\vec{A}.\vec{B}}{AB} = \frac{A_xB_x + A_yB_y + A_zB_z}{\sqrt{A_x^2 + A_y^2 + A_z^2}\sqrt{B_x^2 + B_y^2 + B_z^2}}$$

  - $\hat{i}.\hat{i} = 1$, $\hat{j}.\hat{j} = 1$, $\hat{k}.\hat{k} = 1$, $\hat{i}.\hat{j} = 0$, $\hat{i}.\hat{k} = 0$, $\hat{j}.\hat{k} = 0$

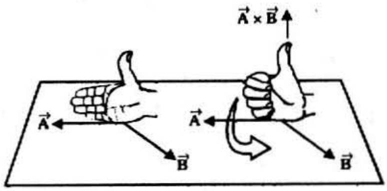


  - Component of vector $\vec{b}$ along vector $\vec{a}$, $\vec{b}_{||} = \left(\vec{b}\,.\,\hat{a}\right)\hat{a}$

  - Component of $\vec{b}$ perpendicular to $\vec{a}$, $\vec{b}_{\perp} = \vec{b} - \vec{b}_{||} = \vec{b} - \left(\vec{b}\cdot\hat{a}\right)\hat{a}$

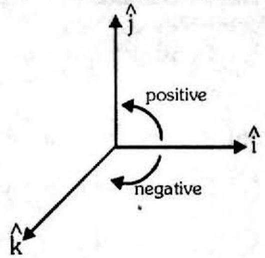
- **Cross Product (Vector product)**

  - $\vec{A}\times\vec{B} = AB\sin\theta\,\hat{n}$ where $\hat{n}$ is a vector perpendicular to $\vec{A}$ & $\vec{B}$ or their plane and its direction given by right hand thumb rule.



  - $\vec{A}\times\vec{B} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ A_x & A_y & A_z \\ B_x & B_y & B_z \end{vmatrix} = \hat{i}\,(A_yB_z - A_zB_y) - \hat{j}\,(A_xB_z - B_xA_z) + \hat{k}\,(A_xB_y - B_xA_y)$

  - $\vec{A}\times\vec{B} = -\vec{B}\times\vec{A}$



- $(\vec{A}\times\vec{B}).\vec{A} = (\vec{A}\times\vec{B}).\vec{B} = 0$
- $\hat{i}\times\hat{i}=\vec{0}$, $\hat{j}\times\hat{j}=\vec{0}$, $\hat{k}\times\hat{k}=\vec{0}$
- $\hat{i}\times\hat{j}=\hat{k}$; $\hat{j}\times\hat{k}=\hat{i}$,

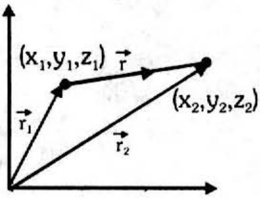
  $\hat{k}\times\hat{i}=\hat{j}$; $\hat{j}\times\hat{i}=-\hat{k}$

  $\hat{k}\times\hat{j}=-\hat{i}$, $\hat{i}\times\hat{k}=-\hat{j}$

- **Differentiation**

- $\dfrac{d}{dt}(\vec{A}.\vec{B}) = \dfrac{d\vec{A}}{dt}.\vec{B} + \vec{A}.\dfrac{d\vec{B}}{dt}$
- $\dfrac{d}{dt}(\vec{A}\times\vec{B}) = \dfrac{d\vec{A}}{dt}\times\vec{B} + \vec{A}\times\dfrac{d\vec{B}}{dt}$

- **When a particle moved from (x_1, y_1, z_1) to (x_2, y_2, z_2) then its displacement vector**



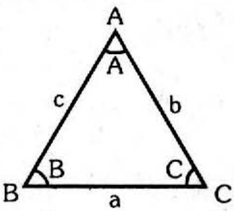
$$\vec{r} = \vec{r}_2 - \vec{r}_1 = (x_2\hat{i} + y_2\hat{j} + z_2\hat{k}) - (x_1\hat{i} + y_1\hat{j} + z_1\hat{k})$$

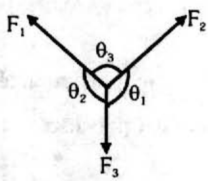
$$= (x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} + (z_2 - z_1)\hat{k}$$

Magnitude

$$r = |\vec{r}| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

- **Lami's theorem**

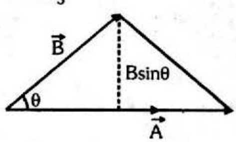




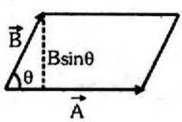
$$\frac{\sin A}{a} = \frac{\sin B}{b} = \frac{\sin C}{c}$$

$$\frac{F_1}{\sin\theta_1} = \frac{F_2}{\sin\theta_2} = \frac{F_3}{\sin\theta_3}$$

- **Area of triangle** Area $= \dfrac{|\vec{A}\times\vec{B}|}{2} = \dfrac{1}{2}AB\sin\theta$



- **Area of parallelogram** Area $= |\vec{A}\times\vec{B}| = AB\sin\theta$



- **For Parallel vectors** $\vec{A}\times\vec{B} = \vec{0}$
- **For perpendicular vectors** $\vec{A}.\vec{B} = 0$
- **For coplanar vectors** $\vec{A}.(\vec{B}\times\vec{C}) = 0$

Examples of dot products :

- Work, $W = \vec{F}.\vec{d} = Fd\cos\theta$ where $F \rightarrow$ force, $d \rightarrow$ displacement
- Power, $P = \vec{F}.\vec{v} = Fv\cos\theta$ where $F \rightarrow$ force, $v \rightarrow$ velocity
- Electric flux, $\phi_E = \vec{E}.\vec{A} = EA\cos\theta$ where $E \rightarrow$ electric field, $A \rightarrow$ Area
- Magnetic flux, $\phi_B = \vec{B}.\vec{A} = BA\cos\theta$ where $B \rightarrow$ magnetic field, $A \rightarrow$ Area
- Potential energy of dipole in where $p \rightarrow$ dipole moment,

  uniform field, $U = -\vec{p}.\vec{E}$ where $E \rightarrow$ Electric field

Examples of cross products :

- Torque $\vec{\tau} = \vec{r} \times \vec{F}$ where $r \rightarrow$ position vector, $F \rightarrow$ force
- Angular momentum $\vec{J} = \vec{r} \times \vec{p}$ where $r \rightarrow$ position vector, $p \rightarrow$ linear momentum
- Linear velocity $\vec{v} = \vec{\omega} \times \vec{r}$ where $r \rightarrow$ position vector, $\omega \rightarrow$ angular velocity
- Torque on dipole placed in electric field $\vec{\tau} = \vec{p} \times \vec{E}$

  where $p \rightarrow$ dipole moment, $E \rightarrow$ electric field

KEY POINTS :

- **Tensor :** A quantity that has different values in different directions is called tensor.

  Ex. Moment of Inertia

  In fact tensors are merely a generalisation of scalars and vectors; a scalar is a zero rank tensor, and a vector is a first rank tensor.
- Electric current is not a vector as it does not obey the law of vector addition.
- A unit vector has no unit.
- To a vector only a vector of same type can be added and the resultant is a vector of the same type.
- A scalar or a vector can never be divided by a vector.

Important Notes

3 Units, Dimension, Measurements and Practical Physics

- **Fundamental or base quantities :**

  The quantities which do not depend upon other quantities for their complete definition are known as *fundamental or base quantities.*

  e.g. : length, mass, time, etc.

- **Derived quantities :**

  The quantities which can be expressed in terms of the fundamental quantities are known as *derived quantities* .e.g.

  Speed (=distance/time), volume, acceleration, force, pressure, etc.

- **Units of physical quantities**

  The chosen reference standard of measurement in multiples of which, a physical quantity is expressed is called the *unit* of that quantity.

  Physical Quantity = Numerical Value × Unit

Systems of Units

	MKS	CGS	FPS	MKSQ	MKSA
(i)	Length (m)	Length (cm)	Length (ft)	Length (m)	Length (m)
(ii)	Mass (kg)	Mass (g)	Mass (pound)	Mass (kg)	Mass (kg)
(iii)	Time (s)	Time (s)	Time (s)	Time (s)	Time (s)
(iv)	–	–	–	Charge (Q)	Current (A)

Fundamental Quantities in S.I. System and their units

S.N.	Physical Qty.	Name of Unit	Symbol
1	Mass	kilogram	kg
2	Length	meter	m
3	Time	second	s
4	Temperature	kelvin	K
5	Luminous intensity	candela	Cd
6	Electric current	ampere	A
7	Amount of substance	mole	mol

SI Base Quantities and Units

Base Quantity	SI Units		
	Name	Symbol	Definition
Length	meter	m	The meter is the length of the path traveled by light in vacuum during a time interval of 1/(299, 792, 458) of a second (1983)
Mass	kilogram	kg	The 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. (1889)
Time	second	s	The 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 (1967)
Electric Current	ampere	A	The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} Newton per metre of length. (1948)
Thermodynamic Temperature	kelvin	K	The kelvin, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. (1967)
Amount of Substance	mole	mol	The 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. (1971)
Luminous Intensity	candela	Cd	The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian (1979).

- **Supplementary Units**
  - Radian (rad) - for measurement of plane angle
  - Steradian (sr) - for measurement of solid angle
- **Dimensional Formula**

  Relation which express physical quantities in terms of appropriate powers of fundamental units.

- **Use of dimensional analysis**
  - To check the dimensional correctness of a given physical relation
  - To derive relationship between different physical quantities
  - To convert units of a physical quantity from one system to another

$$n_1u_1 = n_2u_2 \Rightarrow n_2 = n_1\left(\frac{M_1}{M_2}\right)^a\left(\frac{L_1}{L_2}\right)^b\left(\frac{T_1}{T_2}\right)^c \text{ where } u = M^aL^bT^c$$

- **Limitations of this method :**
  - In Mechanics the formula for a physical quantity depending on more than three other physical quantities cannot be derived. It can only be checked.
  - This method can be used only if the dependency is of multiplication type. The formulae containing exponential, trigonometrical and logarithmic functions can't be derived using this method. Formulae containing more than one term which are added or subtracted like $s = ut + \frac{1}{2}at^2$ also can't be derived.
  - The relation derived from this method gives no information about the dimensionless constants.
  - If dimensions are given, physical quantity may not be unique as many physical quantities have the same dimensions.
  - It gives no information whether a physical quantity is a scalar or a vector.

SI 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 powers of 10.

Prefixes used for different powers of 10

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

Units of important Physical Quantities

Physical quantity	Unit	Physical quantity	Unit
Angular acceleration	rad s^{-2}	Frequency	hertz
Moment of inertia	kg – m^2	Resistance	kg m^2 A^{-2} s^{-3}
Self inductance	Henry	Surface tension	newton/m
Magnetic flux	Weber	Universal gas constant	joule K^{-1} mol^{-1}
Pole strength	A–m	Dipole moment	Coulomb–meter
Viscosity	Poise	Stefan constant	watt m^{-2} K^{-4}
Reactance	Ohm	Permittivity of free space (ε_0)	$Coulomb^2$/N–m^2
Specific heat	J/kg°C	Permeability of free space (μ_0)	Weber/A-m
Strength of magnetic field	newton A^{-1} m^{-1}	Planck's constant	joule–sec
Astronomical distance	Parsec	Entropy	J/K

Dimensions of Important Physical Quantities

Physical quantity	Dimensions	Physical quantity	Dimensions
Momentum	$M^1 L^1 T^{-1}$	Capacitance	$M^{-1} L^{-2} T^4 A^2$
Calorie	$M^1 L^2 T^{-2}$	Modulus of rigidity	$M^1 L^{-1} T^{-2}$
Latent heat capacity	$M^0 L^2 T^{-2}$	Magnetic permeability	$M^1 L^1 T^{-2} A^{-2}$
Self inductance	$M^1 L^2 T^{-2} A^{-2}$	Pressure	$M^1 L^{-1} T^{-2}$
Coefficient of thermal conductivity	$M^1 L^1 T^{-3} K^{-1}$	Planck's constant	$M^1 L^2 T^{-1}$
Power	$M^1 L^2 T^{-3}$	Solar constant	$M^1 L^0 T^{-3}$
Impulse	$M^1 L^1 T^{-1}$	Magnetic flux	$M^1 L^2 T^{-2} A^{-1}$
Hole mobility in a semi conductor	$M^{-1} L^0 T^2 A^1$	Current density	$M^0 L^{-2} T^0 A^1$
Bulk modulus of elasticity	$M^1 L^{-1} T^{-2}$	Young modulus	$M^1 L^{-1} T^{-2}$
Potential energy	$M^1 L^2 T^{-2}$	Magnetic field intensity	$M^0 L^{-1} T^0 A^1$
Gravitational constant	$M^{-1} L^3 T^{-2}$	Magnetic Induction	$M^1 T^{-2} A^{-1}$
Light year	$M^0 L^1 T^0$	Permittivity	$M^{-1} L^{-3} T^4 A^2$
Thermal resistance	$M^{-1} L^{-2} T^3 K$	Electric Field	$M^1 L^1 T^{-3} A^{-1}$
Coefficient of viscosity	$M^1 L^{-1} T^{-1}$	Resistance	$M L^2 T^{-3} A^{-2}$

Sets of Quantities having same dimensions

S.N.	Quantities	Dimensions
1.	Strain, refractive index, relative density, angle, solid angle, phase, distance gradient, relative permeability, relative permittivity, angle of contact, Reynolds number, coefficient of friction, mechanical equivalent of heat, electric susceptibility, etc.	$[M^0 L^0 T^0]$
2.	Mass and inertia	$[M^1 L^0 T^0]$
3.	Momentum and impulse.	$[M^1 L^1 T^{-1}]$
4.	Thrust, force, weight, tension, energy gradient.	$[M^1 L^1 T^{-2}]$
5.	Pressure, stress, Young's modulus, bulk modulus, shear modulus, modulus of rigidity, energy density.	$[M^1 L^{-1} T^{-2}]$
6.	Angular momentum and Planck's constant (h).	$[M^1 L^2 T^{-1}]$
7.	Acceleration, g and gravitational field intensity.	$[M^0 L^1 T^{-2}]$
8.	Surface tension, free surface energy (energy per unit area), force gradient, spring constant.	$[M^1 L^0 T^{-2}]$
9.	Latent heat capacity and gravitational potential.	$[M^0 L^2 T^{-2}]$
10.	Thermal capacity, Boltzmann constant, entropy.	$[ML^2T^{-2}K^{-1}]$
11.	Work, torque, internal energy, potential energy, kinetic energy, moment of force, (q^2/C), (LI^2), (qV), (V^2C), (I^2Rt), $\frac{V^2}{R}t$, (VIt), (PV), (RT), (mL), $(mc\,\Delta T)$	$[M^1 L^2 T^{-2}]$
12.	Frequency, angular frequency, angular velocity, velocity gradient, radioactivity $\frac{R}{L},\frac{1}{RC},\frac{1}{\sqrt{LC}}$	$[M^0 L^0 T^{-1}]$
13.	$\left(\frac{\ell}{g}\right)^{1/2},\left(\frac{m}{k}\right)^{1/2},\left(\frac{L}{R}\right),(RC),(\sqrt{LC})$, time	$[M^0 L^0 T^1]$
14.	(VI), (I^2R), (V^2/R), Power	$[M L^2 T^{-3}]$

Some Fundamental Constants

Gravitational constant (G)	6.67×10^{-11} N m^2 kg^{-2}
Speed of light in vacuum (c)	3×10^8 ms^{-1}
Permeability of vacuum (μ_0)	$4\pi \times 10^{-7}$ H m^{-1}
Permittivity of vacuum (ε_0)	8.85×10^{-12} F m^{-1}
Planck constant (h)	6.63×10^{-34} Js
Atomic mass unit (amu)	1.66×10^{-27} kg
Energy equivalent of 1 amu	931.5 MeV
Electron rest mass (m_e)	9.1×10^{-31} kg $\equiv$ 0.511 MeV
Avogadro constant (N_A)	6.02×10^{23} mol^{-1}
Faraday constant (F)	9.648×10^4 C mol^{-1}
Stefan–Boltzmann constant (σ)	5.67×10^{-8} W m^{-2} K^{-4}
Wien constant (b)	2.89×10^{-3} mK
Rydberg constant (R_∞)	1.097×10^7 m^{-1}
Triple point for water	273.16 K (0.01°C)
Molar volume of ideal gas (NTP)	22.4 L = 22.4×10^{-3} m^3 mol^{-1}

KEY POINTS

- Trigonometric functions $\sin\theta$, $\cos\theta$, $\tan\theta$ etc and their arrangements θ are dimensionless.
- Dimensions of differential coefficients $\left[\frac{d^n y}{dx^n}\right] = \left[\frac{y}{x^n}\right]$
- Dimensions of integrals $\left[\int y\,dx\right] = [yx]$
- We can't add or subtract two physical quantities of different dimensions.
- Independent quantities may be taken as fundamental quantities in a new system of units.

PRACTICAL PHYSICS

- **Rules for Counting Significant Figures**

  For a number greater than 1
  - All non-zero digits are significant.
  - All zeros between two non-zero digits are significant. Location of decimal does not matter.
  - If the numbe is without decimal part, then the terminal or trailing zeros are not significant.
  - Trailing zeros in the decimal part are significant.

- **For a Number Less Than 1**

  Any zero to the right of a non-zero digit is significant. All zeros between decimal point and first non-zero digit are not significant.

- **Significant Figures**

  All accurately known digits in measurement plus the first uncertain digit together form significant figure.

  Ex. $0.108 \rightarrow$ 3SF, $40.000 \rightarrow$ 5SF,
  $1.23 \times 10^{-19} \rightarrow$ 3SF, $0.0018 \rightarrow$ 2SF

- **Rounding off**

  $6.87 \rightarrow 6.9$, $6.84 \rightarrow 6.8$, $6.85 \rightarrow 6.8$,
  $6.75 \rightarrow 6.8$, $6.65 \rightarrow 6.6$, $6.95 \rightarrow 7.0$

- **Order of magnitude** :

  Power of 10 required to represent a quantity

  $49 = 4.9 \times 10^{1} \approx 10^{1} \Rightarrow$ order of magnitude $=1$

  $51 = 5.1 \times 10^{1} \approx 10^{2} \Rightarrow$ order of magnitude $= 2$

  $0.051 = 5.1 \times 10^{-2} \approx 10^{-1} \Rightarrow$ order of magnitude $= -1$

- **Propagation of combination of errors**

  Error in Summation and Difference : $x = a + b$ then $\Delta x = \pm (\Delta a + \Delta b)$

- **Error in Product and Division** A physical quantity X depend upon Y & Z as $X = Y^{a} Z^{b}$ then maximum possible fractional error in X.

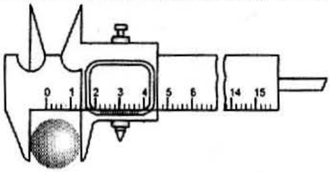
$$\frac{\Delta X}{X} = |a| \frac{\Delta Y}{Y} + |b| \frac{\Delta Z}{Z}$$

- **Error in Power of a Quantity** : $x = \frac{a^{m}}{b^{n}}$ then $\frac{\Delta x}{x} = \pm \left[m\left(\frac{\Delta a}{a}\right) + n\left(\frac{\Delta b}{b}\right) \right]$

- **Least count** : The smallest value of a physical quantity which can be measured accurately with an instrument is called the least count of the measuring instrument.

- **Vernier Callipers** Least count = 1MSD – 1 VSD

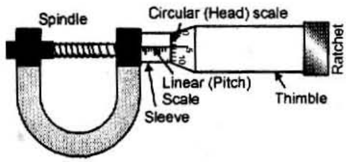
  (MSD $\rightarrow$ main scale division, VSD $\rightarrow$ Vernier scale division)



Ex. A vernier scale has 10 parts, which are equal to 9 parts of main scale having each path equal to 1 mm then least count = $1\text{ mm} - \frac{9}{10}\text{ mm} = 0.1\text{ mm}$ [$\because$ 9 MSD = 10 VSD]

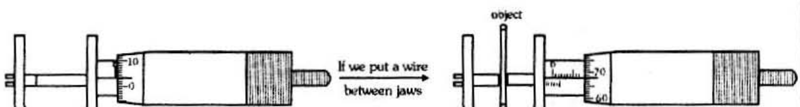
- **Screw Gauge** :

$$\text{Least count} = \frac{\text{pitch}}{\text{total no. of divisions on circular scale}}$$



Zero Error :

If there is no object between the jaws (i.e. jaws are in contact), the screwgauge should give zero reading. But due to extra material on jaws, even if there is no object, it gives some excess reading. This excess reading is called Zero error.



Excess reading = 0.07 mm (zero error)

It gives 3.07 mm

In which there is 0.07 mm excess reading which has to be subtracted.
so actual thickness = 3.07 – 0.07 = 3.00 mm

Observed (reading) excess reading (zero error)

Actual reading = observed reading – excess reading (zero error)

Excess reading = 0.07 mm (zero error)

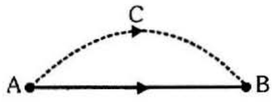
Ex. The distance moved by spindle of a screw gauge for each turn of head is 1mm. The edge of the humble is provided with a angular scale carrying 100 equal divisions. The least count = $\frac{1\text{mm}}{100} = 0.01\text{ mm}$

Important Notes

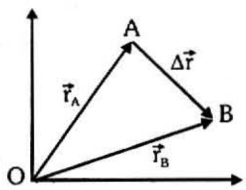
4 Kinematics

- **Distance and Displacement**

  Total length of path (ACB) covered by the particle, in definite time interval is called distance. Displacement vector or displacement is the minimum distance (AB) and directed from initial position to final position.



- **Displacement in terms of position vector**



  From ΔOAB $\quad \Delta\vec{r} = \vec{r}_B - \vec{r}_A$

  $\vec{r}_B = x_2\hat{i} + y_2\hat{j} + z_2\hat{k}$ and $\vec{r}_A = x_1\hat{i} + y_1\hat{j} + z_1\hat{k}$

  $\Delta\vec{r} = (x_2 - x_1)\hat{i} + (y_2 - y_1)\hat{j} + (z_2 - z_1)\hat{k}$

- **Average velocity** $= \dfrac{\text{Displacement}}{\text{Time interval}} = \vec{v}_{av} = \dfrac{\Delta\vec{r}}{\Delta t}$

- **Average speed** $= \dfrac{\text{Distance travelled}}{\text{Time interval}}$

- **For uniform motion**

  Average speed $= |\text{average velocity}| = |\text{instataneous velocity}|$

- **Velocity** $\vec{v} = \dfrac{d\vec{r}}{dt} = \dfrac{d}{dt}\left(x\hat{i} + y\hat{j} + z\hat{k}\right) = \dfrac{dx}{dt}\hat{i} + \dfrac{dy}{dt}\hat{j} + \dfrac{dz}{dt}\hat{k} = v_x\hat{i} + v_y\hat{j} + v_z\hat{k}$

- **Average Acceleration** $= \dfrac{\text{total change in velocity}}{\text{total time taken}} = \vec{a}_{av} = \dfrac{\Delta\vec{v}}{\Delta t}$

- **Acceleration**

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}\left(v_x\hat{i} + v_y\hat{j} + v_z\hat{k}\right) = \frac{dv_x}{dt}\hat{i} + \frac{dv_y}{dt}\hat{j} + \frac{dv_z}{dt}\hat{k} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k}$$

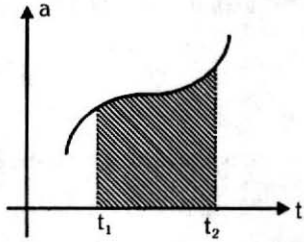
Important points about 1D motion

- Distance $\geq |\text{displacement}|$ and Average speed $\geq |\text{average velocity}|$
- If distance $> |\text{displacement}|$ this implies

  (a) atleast at one point in path, velocity is zero.

(b) The body must have retarded during the motion

- Acceleration positive indicates velocity increases and speed may increase or decrease
- Speed increase if acceleration and velocity both are positive or negative (i.e. both have same sign)
- **In 1-D motion** $a = \frac{dv}{dt} = v\frac{dv}{dx}$
- **Graphical integration in Motion analysis**

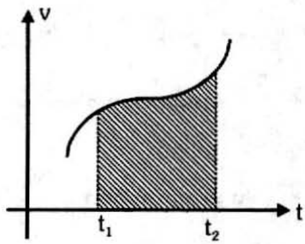


shaded area = change in velocity

• $a = \frac{dv}{dt} \Rightarrow \int_{v_1}^{v_2} dv = \int_{t_1}^{t_2} a\,dt \Rightarrow v_2 - v_1 = \int_{t_1}^{t_2} a\,dt$

$\Rightarrow$ Change in velocity

= Area between acceleration curve and time axis, from t_1 to t_2.



shaded area = displacement

• $v = \frac{dx}{dt} \Rightarrow \int_{x_1}^{x_2} dx = \int_{t_1}^{t_2} v\,dt \Rightarrow x_2 - x_1 = \int_{t_1}^{t_2} v\,dt$

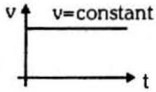
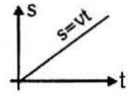
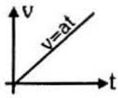
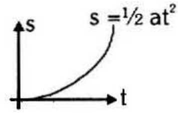
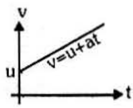
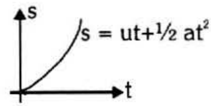
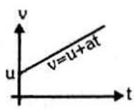
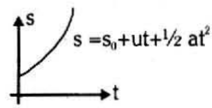
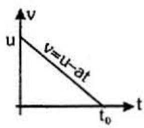
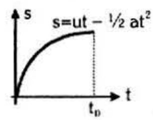
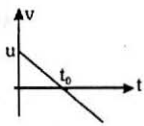
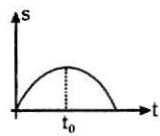
$\Rightarrow$ Change in position = displacement

= area between velocity curve and time axis, from t_1 to t_2.

Important point about graphical analysis of motion

- Instantaneous velocity is the slope of position time curve. $\left(v = \frac{dx}{dt}\right)$
- Slope of velocity-time curve = instantaneous acceleration $\left(a = \frac{dv}{dt}\right)$
- v-t curve area gives displacement. $\left[\Delta x = \int v\,dt\right]$
- a-t curve area gives change in velocity. $\left[\Delta v = \int a\,dt\right]$

$$\begin{tikzcd}
\boxed{\textbf{Displacement}} \arrow[r, shift left, "\text{Differentiation}"] & \boxed{\textbf{Velocity}} \arrow[l, shift left, "\text{Integration}"] \arrow[r, shift left, "\text{Differentiation}"] & \boxed{\textbf{Acceleration}} \arrow[l, shift left, "\text{Integration}"]
\end{tikzcd}$$

	Different Cases	v–t graph	s–t graph
1.	Uniform motion		
2.	Uniformly accelerated motion with $u = 0$ at $t = 0$		
3.	Uniformly accelerated with $u \neq 0$ at $t = 0$		
4.	Uniformly accelerated motion with $u \neq 0$ and $s = s_0$ at $t = 0$		
5.	Uniformly retarded motion till velocity becomes zero		
6.	Uniformly retarded then accelerated in opposite direction		

Motion with constant acceleration : Equations of motion

- *In vector form :*

$$\vec{v} = \vec{u} + \vec{a}t \qquad \Delta\vec{r} = \vec{r}_2 - \vec{r}_1 = \vec{s} = \left(\frac{\vec{u}+\vec{v}}{2}\right)t = \vec{u}t + \frac{1}{2}\vec{a}t^2 = \vec{v}t - \frac{1}{2}\vec{a}t^2$$

$$v^2 = u^2 + 2\vec{a}.\vec{s} \qquad \vec{s}_{n^{th}} = \vec{u} + \frac{\vec{a}}{2}(2n-1)$$

[$S_{n^{th}} \rightarrow$ displacement in n^{th} second]

- *In scalar form (for one dimensional motion) :*

$$v = u + at \qquad s = \left(\frac{u+v}{2}\right)t = ut + \frac{1}{2}at^2 = vt - \frac{1}{2}at^2$$

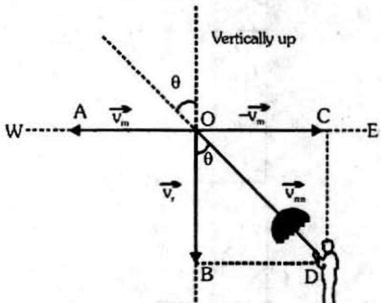
$$v^2 = u^2 + 2as \qquad s_n = u + \frac{a}{2}(2n-1)$$

- **RELATIVE MOTION**

There is no meaning of motion without reference or observer. If reference is not mentioned then we take the ground as a reference of motion. Generally velocity or displacement of the particle w.r.t. ground is called actual velocity or actual displacement of the body. If we describe the motion of a particle w.r.t. and object which is also moving w.r.t. ground then velocity of particle w.r.t. ground is its actual velocity $\left(\vec{v}_{act}\right)$ and velocity of particle w.r.t. moving object is its relative velocity $\left(\vec{v}_{rel.}\right)$ and the velocity of moving object (w.r.t. ground) is the reference velocity $\left(\vec{v}_{ref.}\right)$ then $\vec{v}_{rel} = \vec{v}_{act} - \vec{v}_{ref}$

$$\boxed{\vec{v}_{actual} = \vec{v}_{relative} + \vec{v}_{reference}}$$

- **Relative velocity of Rain w.r.t. the Moving Man :** A man walking west with velocity $\vec{v}_m$, represented by $\overrightarrow{OA}$. Let the rain be falling vertically downwards with velocity $\vec{v}_r$, represented by $\overrightarrow{OB}$ as shown in figure.



The relative velocity of rain w.r.t. man $\vec{v}_{rm} = \vec{v}_r - \vec{v}_m$ will be represented by diagonal $\overrightarrow{OD}$ of rectangle OBDC.

$$\therefore v_{rm} = \sqrt{v_r^2 + v_m^2 + 2v_r v_m \cos 90^\circ} = \sqrt{v_r^2 + v_m^2}$$

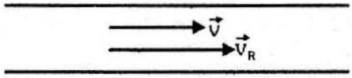
If θ is the angle which $\vec{v}_{rm}$ makes with the vertical direction then

$$\tan\theta = \frac{BD}{OB} = \frac{v_m}{v_r} \Rightarrow \theta = \tan^{-1}\left(\frac{v_m}{v_r}\right)$$

- **Swimming into the River**

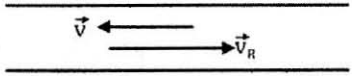
A man can swim with velocity $\vec{v}$, i.e. it is the velocity of man w.r.t. still water. If water is also flowing with velocity $\vec{v}_R$ then velocity of man relative to ground $\vec{v}_m = \vec{v} + \vec{v}_R$

- If the swimming is in the direction of flow of water or along the downstream then



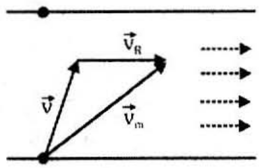
$v_m = v + v_R$

- If the swimming is in the direction opposite to the flow of water or along the upstream then

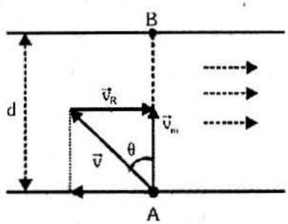


$v_m = v - v_R$

- If man is crossing the river as shown in the figure i.e. $\vec{v}$ and $\vec{v}_R$ not collinear then use the vector algebra $\vec{v}_m = \vec{v} + \vec{v}_R$ **(assuming $v > v_R$)**



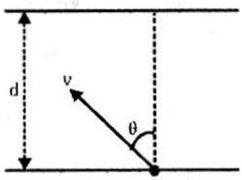
- **For shortest path :**



For minimum displacement

To reach at B, $v\sin\theta = v_R \Rightarrow \sin\theta = \dfrac{v_R}{v}$

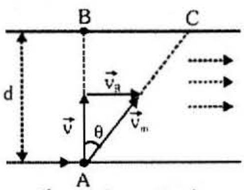
- **Time of crossing**



$t = \dfrac{d}{v\cos\theta}$

Note : If $v_R > v$ then for minimum drifting $\sin\theta = \dfrac{v}{v_R}$

- **For minimum time**

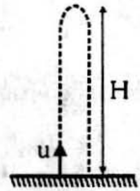


(for minimum time)

then $\boxed{t_{min} = \dfrac{d}{v}}$

MOTION UNDER GRAVITY

If a body is thrown vertically up with a velocity u in the uniform gravitational field (neglecting air resistance) then



(i) Maximum height attained $H = \frac{u^2}{2g}$

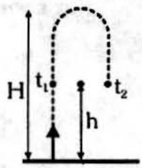
(ii) Time of ascent = time of descent $= \frac{u}{g}$

(iii) Total time of flight $= \frac{2u}{g}$

(iv) Velocity of fall at the point of projection = u (downwards)

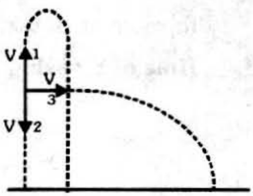
(v) **Gallileo's law of odd numbers** : For a freely falling body ratio of successive distance covered in equal time internval 't'

$$S_1 : S_2 : S_3 : ....S_n = 1 : 3 : 5 : .... : 2n-1$$



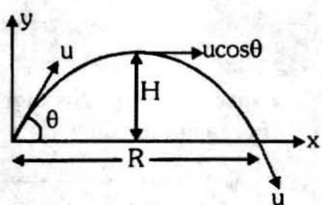
- At any point on its path the body will have same speed for upward journey and downward journey.
- If a body thrown upwards crosses a point in time t_1 & t_2 respectively then height of point $h = ½\, gt_1t_2$

Maximum height $H = \frac{1}{8} g(t_1 + t_2)^2$



- A body is thrown upward, downward & horizontally with same speed takes time t_1, t_2 & t_3 respectively to reach the ground then $t_3 = \sqrt{t_1t_2}$ & height from where the particle was throw is $H = \frac{1}{2}gt_1t_2$

- **PROJECTILE MOTION**



□ **Horizontal Motion**

$u\cos\theta = u_x$

$a_x = 0$

$x = u_xt = (u\cos\theta)t$

□ **Vertical Motion :**

$v_y = u_y - gt$ where $u_y = u\sin\theta$; $y = u_yt - \frac{1}{2}gt^2 = u\sin\theta t - \frac{1}{2}gt^2$

Net acceleration = $\vec{a} = a_x\hat{i} + a_y\hat{j} = -g\hat{j}$

□ **At any instant** : $v_x = u\cos\theta$, $v_y = u\sin\theta - gt$

- **For projectile motion** :

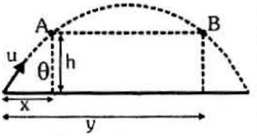
- A body crosses two points at same height in time t_1 and t_2 the points are at distance x and y from starting point then

  (a) $x + y = R$

  (b) $t_1 + t_2 = T$

  (c) $h = \frac{1}{2}\ g t_1 t_2$

  (d) Average velocity from A to B is $u\cos\theta$



- If a person can throw a ball to a maximum distance 'x' then the maximum height to which he can throw the ball will be (x/2)

- **Velocity of particle at time t** :

$$\vec{v} = v_x\hat{i} + v_y\hat{j} = u_x\hat{i} + (u_y - gt)\hat{j} = u\cos\theta\hat{i} + (u\sin\theta - gt)\hat{j}$$

If angle of velocity $\vec{v}$ from horizontal is α, then

$$\tan\alpha = \frac{v_y}{v_x} = \frac{u_y - gt}{u_x} = \frac{u\sin\theta - gt}{u\cos\theta} = \tan\theta - \frac{gt}{u\cos\theta}$$

- At highest point : $v_y = 0,\ v_x = u\cos\theta$

- Time of flight : $T = \dfrac{2u_y}{g} = \dfrac{2u\sin\theta}{g}$

- Horizontal range : $R = (u\cos\theta)T = \dfrac{2u^2\sin\theta\cos\theta}{g} = \dfrac{u^2\sin 2\theta}{g} = \dfrac{2u_x u_y}{g}$

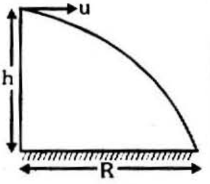
  It is same for θ and $(90° - \theta)$ and maximum for $\theta = 45°$

- Maximum height $H = \dfrac{u_y^2}{2g} = \dfrac{u^2\sin^2\theta}{2g} = \dfrac{1}{8}gT^2$

- $\dfrac{H}{R} = \dfrac{1}{4}\tan\theta$

- Equation of trajectory $y = x\tan\theta - \dfrac{gx^2}{2u^2\cos^2\theta} = x\ \tan\theta\left(1 - \dfrac{x}{R}\right)$

- **Horizontal projection from some height**

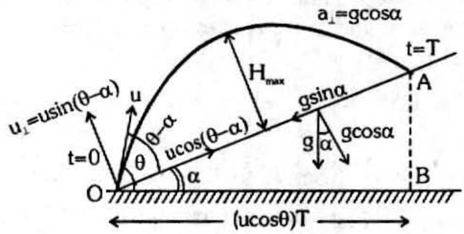


- Time of flight $T = \sqrt{\dfrac{2h}{g}}$

- Horizontal range $R = uT = u\sqrt{\dfrac{2h}{g}}$

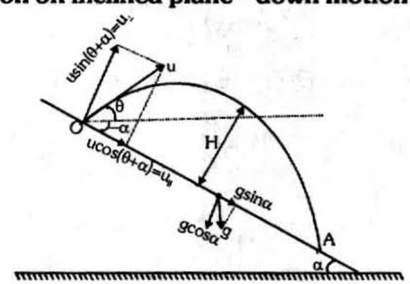
- Angle of velocity at any instant with horizontal $\theta = \tan^{-1}\left(\dfrac{gt}{u}\right)$

- **Projectile motion on inclined plane- up motion**



- Time of flight $T=\frac{2u_\perp}{g_\perp}=\frac{2u\sin(\theta-\alpha)}{g\cos\alpha}$
- Maximum height $H_{max}=\frac{u_\perp^2}{2g_\perp}=\frac{u^2\sin^2(\theta-\alpha)}{2g\cos\alpha}$
- Range on inclined plane $R=OA=\frac{2u^2\sin(\theta-\alpha)\cos\theta}{g\cos^2\alpha}$
- Maximum range $R_{max}=\frac{u^2}{g(1+\sin\alpha)}$ at angle $\theta=\frac{\pi}{4}+\frac{\alpha}{2}$

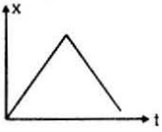
- **Projectile motion on inclined plane – down motion (put α=–α in above)**



- Time of flight $T=2t_H=\frac{2u_\perp}{a_\perp}=\frac{2u\sin(\theta+\alpha)}{g\cos\alpha}$
- Maximum height $H=\frac{u_\perp^2}{2a_\perp}=\frac{u^2\sin^2(\theta+\alpha)}{2g\cos\alpha}$
- Range on inclined plane $R=OA=\frac{2u^2\cos\theta\sin(\theta+\alpha)}{g\cos^2\alpha}$
- Maximum range $R_{max}=\frac{u^2}{g(1-\sin\alpha)}$ at angle $\theta=\frac{\pi}{4}-\frac{\alpha}{2}$

KEY POINTS :

- A positive acceleration can be associated with a "slowing down" of the body because the origin and the positive direction of motion are a matter of choice.
- The x-t graph for a particle undergoing rectilinear motion, cannot be as shown in figure because infinitesimal changes in velocity are physically possible only in infinitesimal time.



- In oblique projection of a projectile the speed gradually decreases up to the highest point and then increases because the tangential acceleration opposes the motion till the particle reaches the highest point, and then it favours the motion of the particle.
- In free fall, the initial velocity of a body may not be zero.
- A body can have acceleration even if its velocity is zero at an instant.
- Average velocity of a body may be equal to its instantaneous velocity.
- The trajectory of an object moving under constant acceleration can be straight line or parabola.
- The path of one projectile as seen from another projectile is a straight line as relative acceleration of one projectile w.r.t. another projectile is zero.

Important Notes

5 Laws of Motion and Friction

- **Force**
  A push or pull that one object exerts on another.

- **Forces in nature**
  There are four fundamental forces in nature :
  1. Gravitational force
  2. Electromagnetic force
  3. Strong nuclear force
  4. Weak force

- **Types of forces on macroscopic objects**
  (a) Field Forces or Range Forces :
  These are the forces in which contact between two objects is not necessary.
  Ex. (i) Gravitational force between two bodies.
  (ii) Electrostatic force between two charges.

  (b) Contact Forces :
  Contact forces exist only as long as the objects are touching each other.
  Ex. (i) Normal force. (ii) Frictional force

  (c) Attachment to Another Body :
  Tension (T) in a string and spring force (F = kx) comes in this group.

- **Newton's first law of motion (or Galileo's law of Inertia)**
  Every body continues in its state of rest or uniform motion in a straight line unless compelled by an external unbalanced force to change that state.
  Inertia : Inertia is the property of the body due to which body opposes the change of it's state. Inertia of a body is measured by mass of the body.

$$\boxed{\text{inertia} \propto \text{mass}}$$

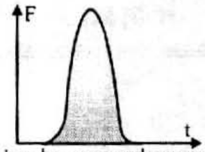
- **Newton's second law**

$$\vec{F} = \frac{d\vec{p}}{dt} = \frac{d}{dt}(m\vec{v}) = m\frac{d\vec{v}}{dt} + \vec{v}\frac{dm}{dt} \quad (\text{Linear momentum } \vec{p} = m\vec{v})$$

  - For constant mass system $\vec{F} = m\vec{a}$

- **Momentum** : It is the product of the mass and velocity of a body i.e. momentum $\vec{p} = m\vec{v}$
  SI Unit : kg m s^{-1} **Dimensions** : $[M L T^{-1}]$

- **Impulse** : Impulse = product of force with time.



impulse = area under curve

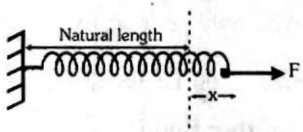
For a finite interval of time from t_1 to t_2 then the impulse = $\int_{t_1}^{t_2} \vec{F}dt$

If constant force acts for an interval Δt then : Impulse = $\vec{F}\Delta t$

Impulse – Momentum theorem

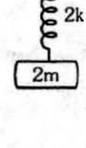
Impulse of a force is equal to the change of momentum $\boxed{\vec{F}\Delta t = \Delta \vec{p}}$

- **Newton's third law of motion** : Whenever a particle A exerts a force on another particle B, B simultaneously exerts a force on A with the same magnitude in the opposite direction.
- **Spring Force (According to Hooke's law) :**
  In equilibrium F=kx (k is spring constant)



Note : Spring force is non impulsive in nature.

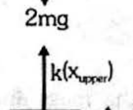
Ex. If the lower spring is cut, find acceleration of the blocks, immediately after cutting the spring.



Sol. Initial stretches $x_{upper} = \dfrac{3mg}{k}$ and $x_{lower} = \dfrac{mg}{k}$

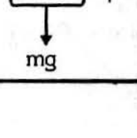
On cutting the lower spring, by virtue of non–impulsive nature of spring the stretch in upper spring remains same immediately after cutting the spring. Thus,

Lower block :



$2mg = 2ma \Rightarrow a = g$

Upper block :



$k\left(\dfrac{3mg}{k}\right) - mg = ma \Rightarrow a = 2g$

- **Motion of bodies in contact**

When two bodies of masses m_1 and m_2 are kept on the frictionless surface and a force F is applied on one body, then the force with which one body presses the other at the point of contact is called force of contact. These two bodies will move with same acceleration a.

(i) When the force F acts on the body with mass m_1 as shown in fig.(i)

$$F = (m_1 + m_2)a$$

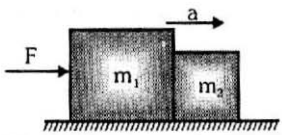


Fig.(1) : When the force F acts on mass m_1

If the force exerted by m_2 on m_1 is f_1 (force of contact) then for body m_1: $(F - f_1) = m_1a$

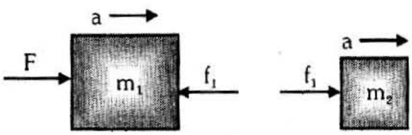


Fig. 1(a) : F.B.D. representation of action and reaction forces.

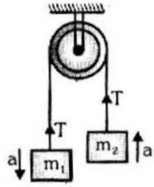
For body m_2 : $f_1 = m_2a \Rightarrow$ action of m_1 on m_2: $f_1 = \dfrac{m_2F}{m_1 + m_2}$

- **Pulley system**

A single fixed pulley changes the direction of force only and in general, assumed to be massless and frictionless.

SOME CASES OF PULLEY

Case – I



Let $m_1 > m_2$

now for mass m_1, $m_1 g - T = m_1a$

for mass m_2, $T - m_2 g = m_2 a$

$$\text{Acceleration} = a = \frac{(m_1 - m_2)}{(m_1 + m_2)}g = \frac{\text{net pulling force}}{\text{total mass to be pulled}}$$

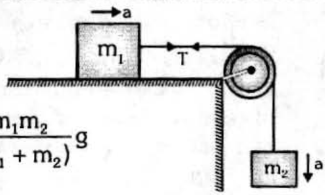
$$\text{Tension} = T = \frac{2m_1m_2}{(m_1 + m_2)}g = \frac{2 \times \text{Product of masses}}{\text{Sum of two masses}}g$$

Reaction at the suspension of pulley $R = 2T = \dfrac{4m_1m_2\,g}{(m_1 + m_2)}$

Case – II

For mass m_1 : $T = m_1 a$

For mass m_2 : $m_2 g - T = m_2 a$



Acceleration $a = \frac{m_2 g}{(m_1 + m_2)}$ and $T = \frac{m_1 m_2}{(m_1 + m_2)} g$

FRAME OF REFERENCE

- **Inertial frames of reference :** A reference frame which is either at rest or in uniform motion along the straight line. A non–accelerating frame of reference is called an inertial frame of reference.

  All the fundamental laws of physics have been formulated in respect of inertial frame of reference.

- **Non–inertial frame of reference :** An accelerating frame of reference is called a non–inertial frame of reference. Newton's laws of motion are not directly applicable in such frames, before application we must add pseudo force.

- **Pseudo force**: The force on a body due to acceleration of non–inertial frame is called fictitious or apparent or pseudo force and is given by $\vec{F} = -m\vec{a}_0$, where $\vec{a}_0$ is acceleration of non–inertial frame with respect to an inertial frame and m is mass of the particle or body. The direction of pseudo force must be opposite to the direction of acceleration of the non–inertial frame.

- When we draw the free body diagram of a mass, with respect to an **inertial frame of reference** we apply only the real forces (forces which are actually acting on the mass). But when the free body diagram is drawn from a non–inertial frame of reference a pseudo force (in addition to all real forces) has to be applied to make the equation $\vec{F} = m\vec{a}$ to be valid in this frame also.

- **Man in a Lift**

  (a) If the lift moving with constant velocity v upwards or downwards. In this case there is no accelerated motion hence no pseudo force experienced by observer inside the lift.

  So apparent weight W′=Mg=Actual weight.

  (b) If the lift is accelerated upward with constant acceleration a. Then forces acting on the man w.r.t. observed inside the lift are

  (i) Weight W=Mg downward

  (ii) Fictitious force F_0=Ma downward.

  So apparent weight $W' = W + F_0 = Mg + Ma = M(g+a)$

(c) If the lift is accelerated downward with acceleration $a<g$.

Then w.r.t. observer inside the lift fictitious force $F_0=Ma$ acts upward while weight of man $W = Mg$ always acts downward.

So apparent weight $W' = W - F_0 = Mg - Ma = M(g-a)$

Special Case :

If $a=g$ then $W'=0$ (condition of weightlessness).

Thus, in a freely falling lift the man will experience weightlessness.

(d) If lift accelerates downward with acceleration $a > g$. Then as in Case (c). Apparent weight $W' = M(g-a)$ is negative, i.e., the man will be accelerated upward and will stay at the ceiling of the lift.

FRICTION

Friction is the force of two surfaces in contact, or the force of a medium acting on a moving object. (i.e. air on aircraft.)

Frictional forces arise due to molecular interactions. In some cases friction acts as a supporting force and in some cases it acts as opposing force.

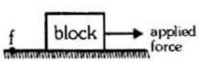
- **Cause of Friction:** Friction is arises on account of strong atomic or molecular forces of attraction between the two surfaces at the point of actual contact.
- **Types of friction**

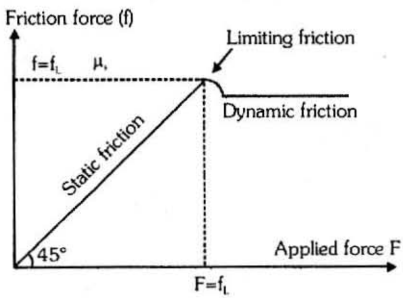
Friction

Static friction (No relative motion between objects)

Dynamic friction (Kinetic friction) (There is relative motion between objects)

- **Graph between applied force and force of friction**



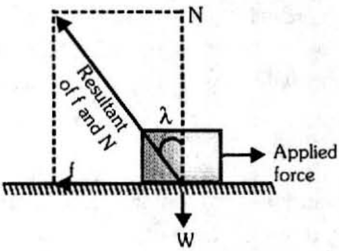


- **Static friction coefficient** $\mu_s = \frac{(f_s)_{max}}{N}$, $0 \le f_s \le \mu_s N$, $\vec{f}_s = -\vec{F}_{applied}$

  $(f_s)_{max} = \mu_s N =$ limiting friction

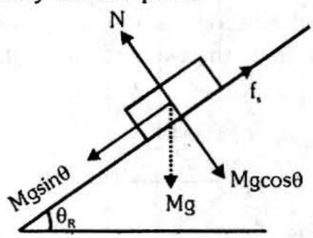
- **Sliding friction coefficient** $\mu_k = \frac{f_k}{N}$, $\vec{f}_k = -(\mu_k N)\hat{v}_{relative}$

- **Angle of Friction (λ)**



$\tan\lambda = \frac{f_S}{N} = \frac{\mu_s N}{N} = \mu_s$

- **Angle of repose** : The maximum angle of an inclined plane for which a block remains stationary on the plane.



$\tan\theta_R = \mu_s$

- For smooth surface $\theta_R = 0$

- **Dependent Motion of Connected Bodies**

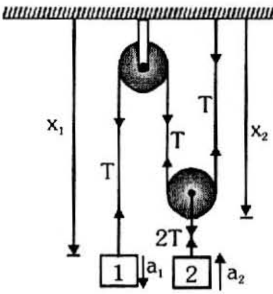
  Method I : Method of constraint equations

$$\boxed{\Sigma x_i = \text{constant} \Rightarrow \Sigma \dot{x}_i = 0 \Rightarrow \Sigma \ddot{x}_i = 0}$$

- For n moving bodies we have $x_1, x_2, \ldots x_n$
- No. of constraint equations = no. of strings

Method II : Method of virtual work : The sum of scalar products of forces applied by connecting links of constant length and displacement of corresponding contact points equal to zero.

$$\boxed{\sum \vec{F}_i \cdot \delta\vec{r}_i = 0 \Rightarrow \sum \vec{F}_i \cdot \vec{v}_i = 0 \Rightarrow \sum \vec{F} \cdot \vec{a}_i = 0}$$



Here $2a_2 = a_1$

KEY POINTS

- Aeroplanes always fly at low altitudes because according to Newton's III law of motion as aeroplane displaces air & at low altitude density of air is high.
- Rockets move by pushing the exhaust gases out so they can fly at low & high altitude.
- Pulling a lawn roller is easier than pushing it because pushing increases the apparent weight and hence friction.
- A moongphaliwala sells his moongphali using a weighing machine in an elevator. He gain more profit if the elevator is accelerating up because the apparent weight of an object increases in an elevator while accelerating upward.
- Pulling (figure I) is easier than pushing (figure II) on a rough horizontal surface because normal reaction is less in pulling than in pushing.

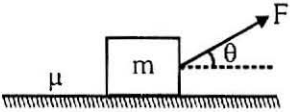


Fig. I ;

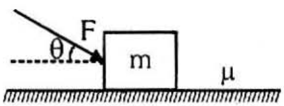


Fig. II

- While walking on ice, one should take small steps to avoid slipping. This is because smaller step increases the normal reaction and that ensure smaller friction.
- A man in a closed cabin (lift) falling freely does not experience gravity as inertial and gravitational mass have equivalence.

Important Notes

6 Work, Energy and Power

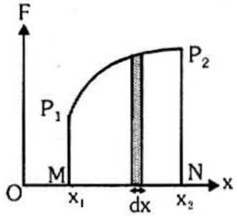
- **Work done** $W = \int dW = \int \vec{F}.d\vec{r} = \int F dr \cos\theta$

  [where θ is the angle between $\vec{F}$ & $\vec{dr}$]

  - For constant force $W = \vec{F}.\vec{d} = Fd\cos\theta$
  - For Unidirectional force

    $W = \int dW = \int F dx =$ Area between F–x curve and x-axis.

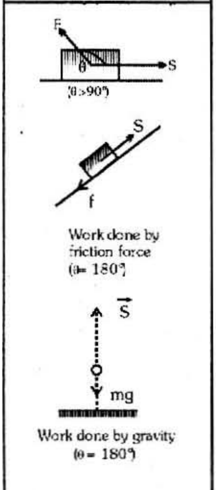
- **Calculation of work done from force–displacement graph :**



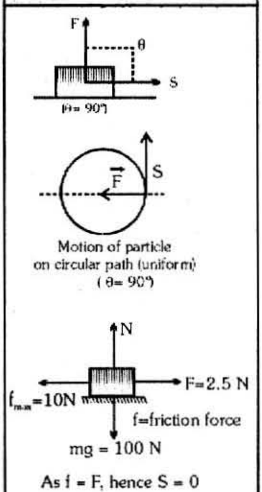
Total work done, $W = \sum_{x_1}^{x_2} dW = \sum_{x_1}^{x_2} F dx =$ Area of $P_1P_2NM = \int_{x_1}^{x_2} F dx$

- **Nature of work done** : Although work done is a scalar quantity, yet its value may be positive, negative or even zero

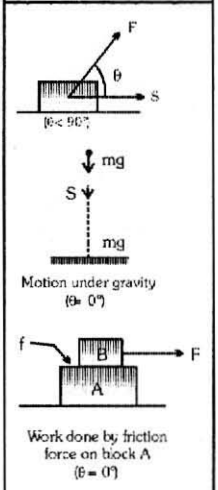
Negative work



Zero work



Positive work



Conservative Forces

- Work done does not depend upon path.
- Work done in a round trip is zero.
- Central forces, spring forces etc. are conservative forces
- When only a conservative force acts within a system, the kinetic energy and potential energy can change into each other. However, their sum, the mechanical energy of the system, doesn't change.
- Work done is completely recoverable.
- If $\vec{F}$ is a conservative force then $\vec{\nabla}\times\vec{F}=\vec{0}$ (i.e. curl of $\vec{F}$ is zero)

Non-conservative Forces

- Work done depends upon path.
- Work done in a round trip is not zero.
- Force are velocity–dependent & retarding in nature e.g. friction, viscous force etc.
- Work done against a non–conservative force may be dissipated as heat energy.
- Work done is not recoverable.

Kinetic energy

- The energy possessed by a body by virtue of its motion is called kinetic energy.

$$K=\frac{1}{2}mv^2=\frac{1}{2}m(\vec{v}.\vec{v})$$

- Kinetic energy is a frame dependent quantity because velocity is a frame depends.

Potential energy

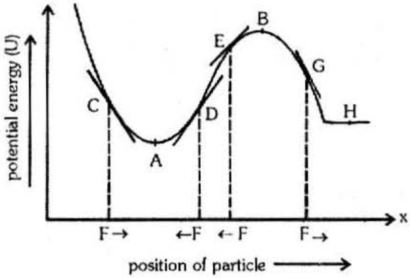
- The energy which a body has by virtue of its position or configuration in a conservative force field.
- Potential energy is a relative quantity.
- Potential energy is defined only for conservative force field.
- Relationship between conservative force field and potential energy :

$$\vec{F}=-\nabla U=-\text{grad}(U)=-\frac{\partial U}{\partial x}\hat{i}-\frac{\partial U}{\partial y}\hat{j}-\frac{\partial U}{\partial z}\hat{k}$$

- If force varies only with one dimension (along x-axis) then

$$F=-\frac{dU}{dx}\Rightarrow U=-\int_{x_1}^{x_2}Fdx$$

- **Potential energy curve and equilibrium**



It is a curve which shows change in potential energy with postion of a particle.

- **Stable Equilibrium :**

When a particle is slightly displaced from equilibrium position and it tends to come back towards equilibrium then it is said to be in stable equilibrium

At point **C** : slope $\frac{dU}{dx}$ is negative so F is positive

At point **D** : slope $\frac{dU}{dx}$ is positive so F is negative

At point **A** : It is the point of stable equilibrium.

$$U = U_{min} \;,\; \frac{dU}{dx} = 0 \quad \text{and} \quad \frac{d^2U}{dx^2} = \text{positive}$$

- **Unstable equilibrium :**

When a particle is slightly displaced from equilibrium and it tends to move away from equilibrium position then it is said to be in unstable equilibrium

At point **E** : slope $\frac{dU}{dx}$ is positive so F is negative

At point **G** : slope $\frac{dU}{dx}$ is negative so F is postive

At point **B** : It is the point of unstable equilibrium.

$$U=U_{max},\; \frac{dU}{dx} = 0 \text{ and } \frac{d^2U}{dx^2} = \text{negative}$$

- **Neutral equilibrium :**

  When a particle is slightly displaced from equilibrium position and no force acts on it then equilbirum is said to be neutral equilibrium. Point H is at neutral equilibrium $\Rightarrow$ U = constant ; $\frac{dU}{dx}=0,\ \frac{d^2U}{dx^2}=0$

- **Work energy theorem** : W = ΔKE

  Change in kinetic energy = work done by all force

- **For conservative force** $F(x)=-\frac{dU}{dx}$

  change in potential energy $\Delta U = -\int F(x)dx$

- **Law of conservation of Mechanical energy**

  Total mechanical (kinetic + potential) energy of a system remains constant if only conservative forces are acting on the system of particles or the work done by all other forces is zero. From work energy theorem W = ΔKE

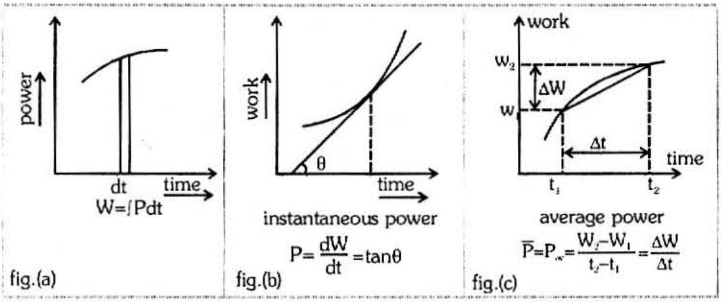
  Proof : For internal conservative forces $W_{int} = -\Delta U$

  So $W = W_{ext} + W_{int} = 0 + W_{int} = -\Delta U \Rightarrow -\Delta U = \Delta KE$

  $\Rightarrow \Delta(KE+U) = 0 \Rightarrow KE + U = \text{constant}$

- Spring force F=–kx, Elastic potential energy stored in spring $U(x)=\frac{1}{2}kx^2$
- Mass and energy are equivalent and are related by $E = mc^2$
- **Power**
  - Power is a scalar quantity with dimension $M^1L^2T^{-3}$
  - SI unit of power is J/s or watt
  - 1 horsepower = 746 watt = 550 ft–lb/sec.
- **Average power** $P_{av} = W/t$

- **Instantaneous power** $P = \frac{dW}{dt} = \frac{\vec{F}.d\vec{r}}{dt} = \vec{F}.\vec{v}$



- For a system of varying mass $\vec{F} = \frac{d}{dt}(m\vec{v}) = m\frac{d\vec{v}}{dt} + \vec{v}\frac{dm}{dt}$
- If $\vec{v}$ = constant then $\vec{F} = \vec{v}\frac{dm}{dt}$ then $P = \vec{F}.\vec{v} = v^2\frac{dm}{dt}$
- In rotatory motion : $P = \tau\frac{d\theta}{dt} = \tau\omega$

KEY POINTS

- A body may gain kinetic energy and potential energy simultaneously because principle of conservation of mechanical energy may not be valid every time.
- Comets move around the sun in elliptical orbits. The gravitational force on the comet due to sun is not normal to the comet's velocity but the work done by the gravitational force is zero in complete round trip because gravitational force is a conservative force.
- Work done by static friction may be positive because static friction may acts along the direction of motion of an object.

Important Notes

7 Circular Motion

- **Definition of Circular Motion**

  When a particle moves in a plane such that its distance from a fixed (or moving) point remains constant then its motion is called as circular motion with respect to that fixed point. That fixed point is called centre and the distance is called radius of circular path.

  Radius Vector :

  The vector joining the centre of the circle and the center of the particle performing circular motion is called radius vector. It has constant magnitude and variable direction. It is directed outward

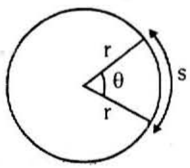
  Frequency (n) :

  No. of revolutions described by particle per sec. is its frequency. Its unit is revolutions per second (r.p.s.) or revolutions per minute (r.p.m.)

  Time Period (T) :

  It is time taken by particle to complete one revolution. $T = \frac{1}{n}$

- Angle $\theta = \frac{\text{arc length}}{\text{radius}} = \frac{s}{r}$



- Average angular velocity $\omega = \frac{\Delta\theta}{\Delta t}$ (a scalar quantity)
- Instantaneous angular velocity $\omega = \frac{d\theta}{dt}$ (a vector quantity)
- For uniform angular velocity $\omega = \frac{2\pi}{T} = 2\pi f$ or $2\pi n$

  Angular displacement $\theta = \omega t$

  $\omega \rightarrow$ Angular frequency n or f = frequency

- Relation between ω and v $\omega = \frac{v}{r}$
  - In vector form velocity $\vec{v} = \vec{\omega} \times \vec{r}$
- Acceleration $\vec{a} = \frac{d\vec{v}}{dt} = \frac{d}{dt}(\vec{\omega} \times \vec{r}) = \frac{d\vec{\omega}}{dt} \times \vec{r} + \vec{\omega} \times \frac{d\vec{r}}{dt} = \vec{\alpha} \times \vec{r} + \vec{\omega} \times \vec{v} = \vec{a}_t + \vec{a}_C$
- Tangential acceleration: $a_t = \frac{dv}{dt} = \alpha r$

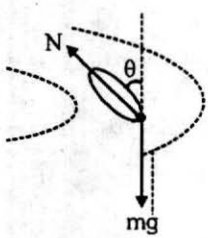
$$\left[\vec{a}_t = \text{component of } \vec{a} \text{ along } \vec{v} = (\vec{a} \cdot \hat{v})\hat{v} = \left(\frac{dv}{dt}\right)\hat{v}\right]$$

- Centripetal acceleration : $a_C = \omega v = \frac{v^2}{r} = \omega^2 r$ or $\vec{a}_C = \omega^2 r(-\hat{r})$
- Magnitude of net acceleration : $a = \sqrt{a_C^2 + a_t^2} = \sqrt{\left(\frac{v^2}{r}\right)^2 + \left(\frac{dv}{dt}\right)^2}$
- Maximum speed of in circular motion.
  - On unbanked road : $v_{max} = \sqrt{\mu_s Rg}$
  - On banked road : $v_{max} = \sqrt{\left(\frac{\mu_s + \tan\theta}{1 - \mu_s \tan\theta}\right)Rg} = \sqrt{\tan(\theta + \phi)Rg}$

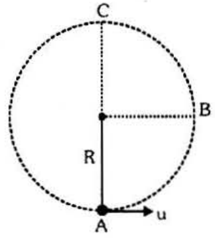
$$v_{min} = \sqrt{Rg\tan(\theta - \phi)}\,;\; v_{min} \le v_{car} \le v_{max}$$

where ϕ = angle of friction = $\tan^{-1}\mu_s$; θ = angle of banking

- Bending of cyclist : $\tan\theta = \frac{v^2}{rg}$



- **Circular motion in vertical plane**



A. Condition to complete vertical circle $u \geq \sqrt{5gR}$

- If $u = \sqrt{5gR}$ then Tension at C is equal to 0

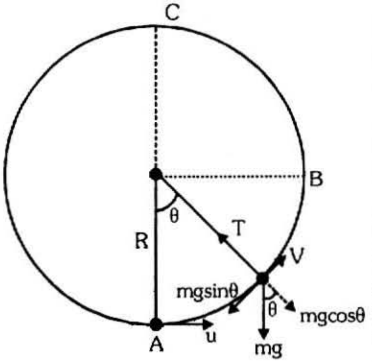
  and tension at A is equal to 6mg

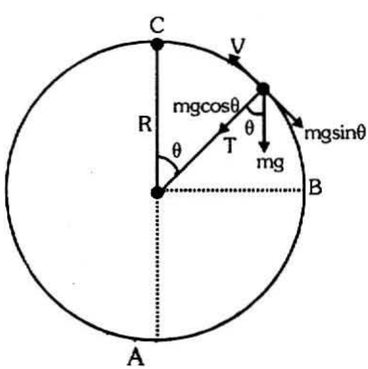
  Velocity at B: $v_B = \sqrt{3gR}$

  Velocity at C: $v_C = \sqrt{gR}$

  From A to B : $T = mg\cos\theta + \frac{mv^2}{R}$

  From B to C : $T = \frac{mv^2}{R} - mg\cos\theta$





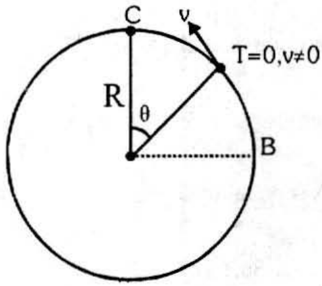
B. Condition for pendulum motion (oscillating condition)

$u \le \sqrt{2gR}$ (in between A to B)

Velocity can be zero but T never be zero between A & B.

Because T is given by $T = mg\cos\theta + \frac{mv^2}{R}$

C. Condition for leaving path : $\sqrt{2gR} < u < \sqrt{5gR}$



Particle crosses the point B but not complete the vertical circle.

Tension will be zero in between B to C & the angle where T = 0

$$\cos\theta = \frac{u^2 - 2gR}{3gR}$$

θ is from vertical line

Note : After leaving the circle, the particle will follow a parabolic path.

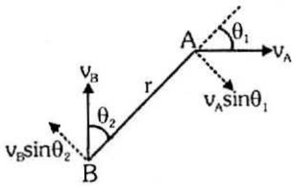
KEY POINTS

- Average angular velocity is a scalar physical quanity whereas instantaneous angular velocity is a vector physical quanity.
- Small Angular displacement $d\vec{\theta}$ is a vector quantity, but large angular displacement θ is scalar quantity.

$$d\vec{\theta}_1 + d\vec{\theta}_2 = d\vec{\theta}_2 + d\vec{\theta}_1 \quad \text{But} \quad \vec{\theta}_1 + \vec{\theta}_2 \ne \vec{\theta}_2 + \vec{\theta}_1$$

- **Relative Angular Velocity**

  Relative angular velocity of a particle 'A' w.r.t. other moving particle B is the angular velocity of the position vector of A w.r.t. B.



That means it is the rate at which position vector of 'A' w.r.t. B rotates at that instant

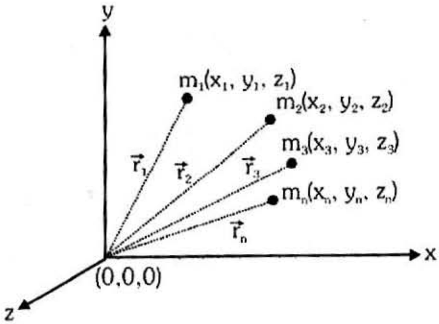
$$\omega_{AB} = \frac{(v_{AB})_{\perp}}{r_{AB}} = \frac{\text{Relative velocity of A w.r.t. B perpendicular to line AB}}{\text{seperation between A and B}}$$

here $(v_{AB})_{\perp} = v_A \sin\theta_1 + v_B \sin\theta_2$ $\qquad \therefore \omega_{AB} = \dfrac{v_A \sin\theta_1 + v_B \sin\theta_2}{r}$

Important Notes

8 Collisions and Centre of Mass

- **Centre of mass :** For a system of particles centre of mass is that point at which its total mass is supposed to be concentrated.
- **Centre of mass of system of discrete particles**



Total mass of the body : $M = m_1 + m_2 + ... + m_n$ then

$$\vec{R}_{CM} = \frac{m_1\vec{r}_1 + m_2\vec{r}_2 + m_3\vec{r}_3 + ...}{m_1 + m_2 + m_3 + ...} = \frac{1}{M}\Sigma m_i\vec{r}_i$$

co-ordinates of centre of mass :

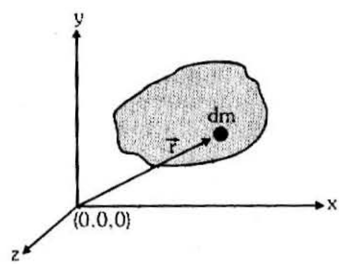
$$x_{cm} = \frac{1}{M}\Sigma m_i x_i\ ,\ y_{cm} = \frac{1}{M}\Sigma m_i y_i \text{ and } z_{cm} = \frac{1}{M}\Sigma m_i z_i$$

- **Centre of mass of continuous distribution of particles**

$$\vec{R}_{CM} = \frac{1}{M}\int \vec{r}dm$$

$$x_{cm} = \frac{1}{M}\int x\, dm\ ,\ y_{cm} = \frac{1}{M}\int y\, dm$$

and $z_{cm} = \frac{1}{M}\int z\, dm$



x, y, z are the co-ordinate of the COM of the dm mass.

The centre of mass after removal of a part of a body

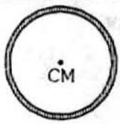
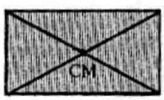
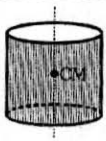
Original mass (M) – mass of the removed part (m)

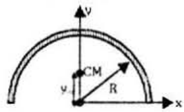
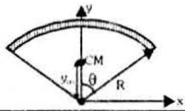
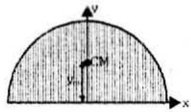
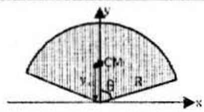
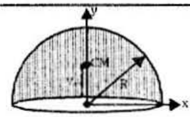
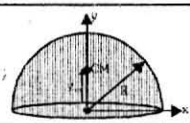
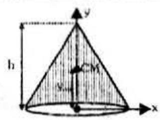
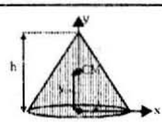
= {original mass (M)} + { – mass of the removed part (m)}

The formula changes to :

$$x_{CM} = \frac{Mx - mx'}{M - m}\ ;\ y_{CM} = \frac{My - my'}{M - m}\ ;\ y_{CM} = \frac{Mz - mz'}{M - m}$$

CENTRE OF MASS OF SOME COMMON OBJECTS

Body	Shape of body	Position of centre of mass
Uniform Ring		Centre of ring
Uniform Disc		Centre of disc
Uniform Rod		Centre of rod
Solid sphere/ hollow sphere		Centre of sphere
Triangular plane lamina		Point of intersection of the medians of the triangle i.e. centroid
Plane lamina in the form of a square or rectangle or parallelogram		Point of intersection of diagonals
Hollow/solid cylinder		Middle point of the axis of cylinder

Body	Shape of body	Position of centre of mass
Half ring		$y_{cm} = \frac{2R}{\pi}$
Segement of a ring		$y_{cm} = \frac{R\sin\theta}{\theta}$
Half disc (plate)		$y_{cm} = \frac{4R}{3\pi}$
Sector of a disc (plate)		$y_{cm} = \frac{2R\sin\theta}{3\theta}$
Hollow hemisphere		$y_{cm} = \frac{R}{2}$
Solid hemisphere		$y_{cm} = \frac{3R}{8}$
Hollow cone		$y_{cm} = \frac{h}{3}$
Solid cone		$y_{cm} = \frac{h}{4}$

MOTION OF CENTRE OF MASS

For a system of particles,
velocity of centre of mass

$$\vec{v}_{CM} = \frac{d\vec{R}_{CM}}{dt} = \frac{m_1\vec{v}_1 + m_2\vec{v}_2 + \ldots}{m_1 + m_2 + \ldots}$$

Similarly acceleration

$$\vec{a}_{CM} = \frac{d}{dt}(\vec{v}_{CM}) = \frac{m_1\vec{a}_1 + m_2\vec{a}_2 + \ldots}{m_1 + m_2 + \ldots}$$

- **Law of conservation of linear momentum**

  Linear momentum of a system of particles is equal to the product of mass of the system with velocity of its centre of mass.

  From Newton's second law $\vec{F}_{ext.} = \frac{d\left(M\vec{v}_{CM}\right)}{dt}$

  If $\vec{F}_{ext.} = \vec{0}$ then $M\vec{v}_{CM}$ = constant

  If no external force acts on a system the velocity of its centre of mass remains constant, i.e., velocity of centre of mass is unaffected by internal forces.

- **Impulse – Momentum theorem**

  $$\boxed{\int_{t_1}^{t_2} \vec{F}dt = \Delta\vec{p}}$$

  Impulse of a force is equal to the change of momentum

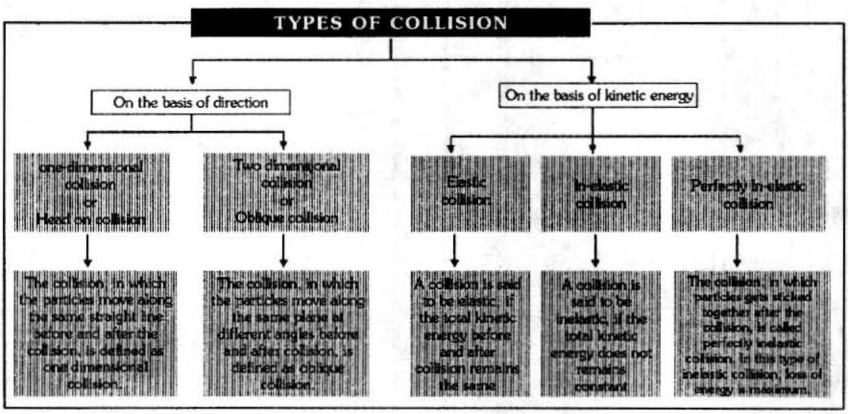
  force time graph area gives change in momentum.

Collision of bodies

The event or the process, in which two bodies either coming in contact with each other or due to mutual interaction at distance apart, affect each others motion (velocity, momentum, energy or direction of motion) is defined as a collision.

In collision

- The particles come closer before collision and after collision they either stick together or move away from each other.
- The particles need not come in contact with each other for a collision.
- The law of conservation of linear momentum is necessarily applicable in a collision, whereas the law of conservation of mechanical energy is not.



- **Coefficient of restitution (Newton's law)**

$$e = -\frac{\text{velocity of separation along line of impact}}{\text{velocity of approach along line of impact}} = \frac{v_2 - v_1}{u_1 - u_2}$$

Value of e is 1 for elastic collision, 0 for perfectly inelastic collision and $0 < e < 1$ for inelastic collision.

- **Head on collision**

Before collision Collision After collision

Head on inelastic collision of two particles

Let the coefficient of restitution for collision is e

(i) Momentum is conserved $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ ...(i)

(ii) Kinetic energy is not conserved.

(iii) According to Newton's law $e = \frac{v_2 - v_1}{u_1 - u_2}$ ...(ii)

By solving eq. (i) and (ii) :

$$v_1 = \left(\frac{m_1 - em_2}{m_1 + m_2}\right)u_1 + \left(\frac{(1+e)m_2}{m_1 + m_2}\right)u_2 = \frac{m_1u_1 + m_2u_2 - m_2e(u_1 - u_2)}{m_1 + m_2}$$

$$v_2 = \left(\frac{m_2 - em_1}{m_1 + m_2}\right)u_2 + \left(\frac{(1+e)m_1}{m_1 + m_2}\right)u_1 = \frac{m_1u_1 + m_2u_2 - m_1e(u_2 - u_1)}{m_1 + m_2}$$

Elastic Collision (e=1)

- **If the two bodies are of equal masses :** $m_1 = m_2 = m$, $v_1 = u_2$ and $v_2 = u_1$

  Thus, if two bodies of equal masses undergo elastic collision in one dimension, then after the collision, the bodies will exchange their velocities.

- **If the mass of a body is negligible as compared to other.**

  If $m_1 >> m_2$ and $u_2 = 0$ then $v_1 = u_1$, $v_2 = 2u_1$ when a heavy body A collides against a light body B at rest, the body A should keep on moving with same velocity and the body B will move with velocity double that of A. If $m_2 >> m_1$ and $u_2 = 0$ then $v_2 = 0$, $v_1 = -u_1$

  When light body A collides against a heavy body B at rest, the body A should start moving with same velocity just in opposite direction while the body B should practically remains at rest.

- **Loss in kinetic energy in inelastic collision**

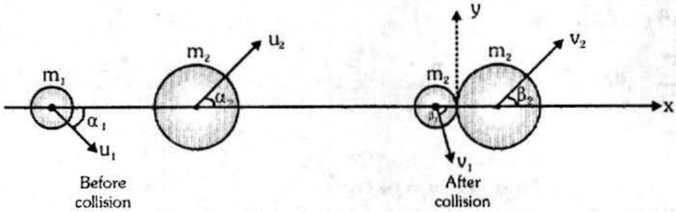
$$\Delta K = \frac{m_1m_2}{2(m_1 + m_2)}(1 - e^2)(u_1 - u_2)^2$$

Oblique Collision

Conserving the momentum of system in directions along normal (x axis in our case) and tangential (y axis in our case)

$m_1u_1\cos\alpha_1 + m_2u_2\cos\alpha_2 = m_1v_1\cos\beta_1 + m_2v_2\cos\beta_2$ and

$m_2u_2\sin\alpha_2 - m_1u_1\sin\alpha_1 = m_2v_2\sin\beta_2 - m_1v_1\sin\beta_1$



Since no force is acting on m_1 and m_2 along the tangent (i.e. y–axis) the individual momentum of m_1 and m_2 remains conserved.

$m_1u_1\sin\alpha_1 = m_1v_1\sin\beta_1$ & $m_2u_2\sin\alpha_2 = m_2v_2\sin\beta_2$

By using Newton's experimental law along the line of impact

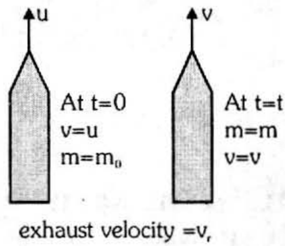
$$e = \frac{v_2\cos\beta_2 - v_1\cos\beta_1}{u_1\cos\alpha_1 - u_2\cos\alpha_2}$$

Rocket propulsion :

Thrust force on the rocket$= v_r\left(-\frac{dm}{dt}\right)$

Velocity of rocket at any instant

$v = u - gt + v_r \ell n\left(\frac{m_0}{m}\right)$



KEY POINTS

- Sum of mass moments about centre of mass is zero. i.e. $\sum m_i \vec{r}_{i/cm} = \vec{0}$
- A quick collision between two bodies is more violent then slow collision, even when initial and final velocities are equal because the rate of change of momentum determines that the impulsive force small or large.
- Heavy water is used as moderator in nuclear reactors as energy transfer is maximum if $m_1 \approx m_2$
- Impulse momentum theorem is equivalent to Newton's second law of motion.
- For a system, conservation of linear momentum is equivalent to Newton's third law of motion.

Important Notes

9 Rotational Motion

- **Angular velocity** $\vec{\omega} = \frac{d\vec{\theta}}{dt}$

- **Angular acceleration** $\vec{\alpha} = \frac{d\vec{\omega}}{dt} = \frac{d^2\vec{\theta}}{dt^2}$

- **Angular momentum** $\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$

- **Torque** $\vec{\tau} = \vec{r} \times \vec{F} = \frac{d\vec{L}}{dt}$

- **Rotational Kinetic energy** $K = \frac{1}{2}I\omega^2 = \frac{L^2}{2I}$

- **Rotational Power** $P = \vec{\tau}.\vec{\omega}$

- **For constant angular acceleration**

$$\omega = \omega_0 + \alpha t,\ \theta = \omega_0 t + \frac{1}{2}\alpha t^2,\ \ \omega^2 = \omega_0^2 + 2\alpha\theta,\ \ \theta_n = \omega_0 + \frac{\alpha}{2}(2n - 1)$$

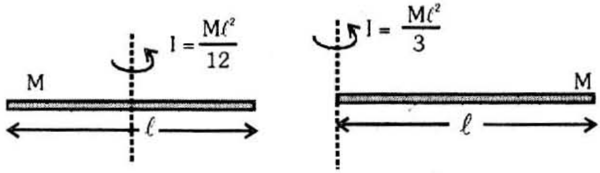
- **Moment of Inertia**
  - A tensor but for fixed axis it is a scalar
  - For discrete distribution of mass $I = m_1 r_1^2 + m_2 r_2^2 + \ldots\ldots = \sum m_i r_i^2$
  - For continuous distribution of mass $I = \int dI = \int dm r^2$

- **Radius of gyration** $k = \sqrt{\frac{I}{M}}$

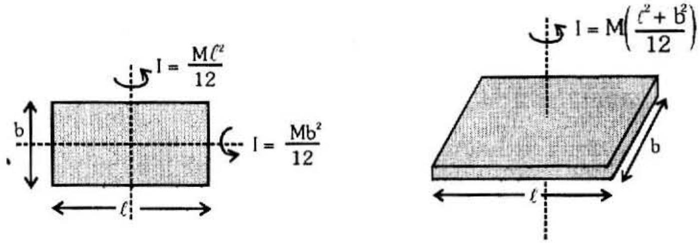
- **Theorems regarding moment of inertia**
  - Theorem of parallel axes $I_{axis} = I_{cm} + md^2$

    where d is the perpendicular distance between parallel axes.
  - Theorem of perpendicular axes $I_z = I_x + I_y$

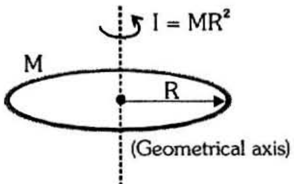
- **Rod**



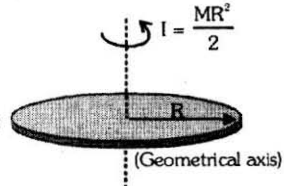
- **Rectangular Lamina**



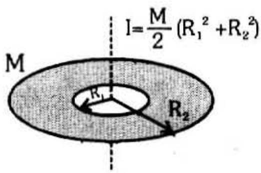
- **Ring :**



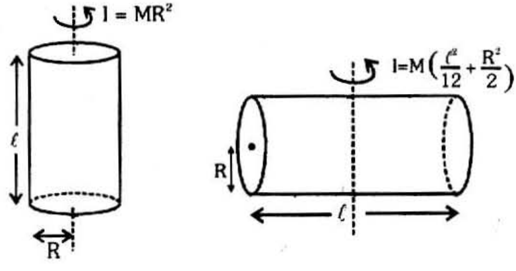
- **Disc :**



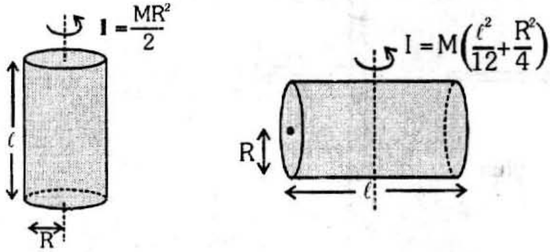
- **Circular Hollow Disk :**



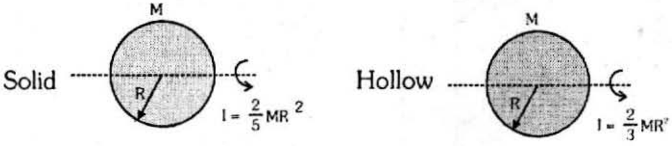
- **Hollow cylinder**



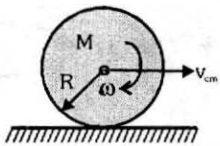
- **Solid cylinder**



- **Solid & Hollow sphere**



- **Rolling motion**



- ▫ Total kinetic energy = $\frac{1}{2}Mv_{CM}^2 + \frac{1}{2}I_{cm}\omega^2$

- ▫ Total angular momentum $= Mv_{CM}R + I_{cm}\omega$

- **Pure rolling (or rolling without slipping) on stationary surface**

- ▫ Condition : $v_{cm} = R\omega$

  In accelerated motion $a_{cm} = R\alpha$

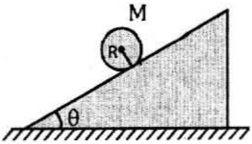
- ▫ If $v_{cm} > R\omega$ then rolling with forward slipping,

- ▫ If $v_{cm} < R\omega$ then rolling with backward slipping

- ▫ Total kinetic energy in pure rolling

$$K_{total} = \frac{1}{2}Mv_{cm}^2 + \frac{1}{2}(Mk^2)\left(\frac{v_{cm}^2}{R^2}\right) = \frac{1}{2}Mv_{cm}^2\left(1+\frac{k^2}{R^2}\right)$$

- **Pure rolling motion on an inclined plane**



- Acceleration $a = \dfrac{g\sin\theta}{1+k^2/R^2}$
- Minimum frictional coefficient $\mu_{min} = \dfrac{\tan\theta}{1+R^2/k^2}$

- **Torque** $\vec{\tau} = I\vec{\alpha} = I\dfrac{d\vec{\omega}}{dt} = \dfrac{d(I\vec{\omega})}{dt} = \dfrac{d\vec{L}}{dt}$ or $\dfrac{d\vec{J}}{dt}$
- **Change in angular momentum** $\Delta\vec{L} = \vec{\tau}\Delta t$
- **Work done by a torque** $W = \int \vec{\tau}\cdot d\vec{\theta}$

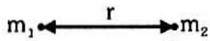
KEY POINTS

- A ladder is more apt to slip, when you are high up on it than when you just begin to climb because at the high up on a ladder the torque is large and on climbing up the torque is small.
- When a sphere is rolls on a horizontal table, it slows down and eventually stops because when the sphere rolls on the table, both the sphere and the surface deform near the contact. As a result the normal force does not pass through the centre and provide an angular deceleration.
- The spokes near the top of a rolling bicycle wheel are more blurred than those near the bottom of the wheel because the spokes near the top of wheel are moving faster than those near the bottom of the wheel.
- Instantaneous angular velocity is a vector quantity because infinitesimal angular displacement is a vector.
- The relative angular velocity between any two points of a rigid body is zero at any instant.
- All particles of a rigid body, which do not lie on an axis of rotation move on circular paths with centres at an axis of rotation.
- Instantaneous axis of rotation is stationary w.r.t. ground.
- Many greater rivers flow toward the equator. The sediment that they carry increases the time of rotation of the earth about its own axis because the angular momentum of the earth about its rotation axis is conserved.
- The hard boiled egg and raw egg can be distinguished on the basis of spinning of both.

Important Notes

10 Gravitation

- **Newton's law of gravitation**

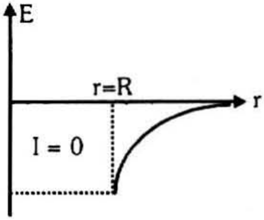


Force of attraction between two point masses $F = \frac{Gm_1m_2}{r^2}$

Directed along the line joining of point masses.

- It is a conservative force field $\Rightarrow$ mechanical energy is conserved.
- It is a central force field $\Rightarrow$ angular momentum is conserved.

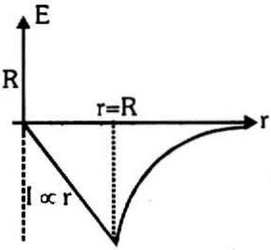
- **Gravitational field due to spherical shell**



- Outside the shell $E_g = \frac{GM}{r^2}$, where $r > R$
- On the surface $E_g = \frac{GM}{R^2}$, where $r=R$
- Inside the shell $E_g = 0$, where $r<R$

[Note : Direction always towards the centre of the sphere]

- **Gravitational field due to solid sphere**



- Outside the sphere $E_g = \frac{GM}{r^2}$, where $r > R$
- On the surface $E_g = \frac{GM}{R^2}$, where $r=R$
- Inside the sphere $E_g = \frac{GMr}{R^3}$, where $r< R$

- **Acceleration due to gravity** $g = \frac{GM}{R^2}$

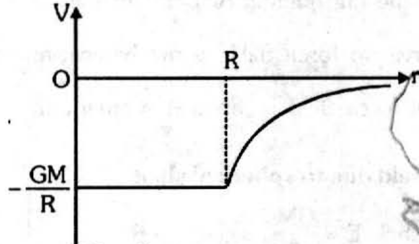
- At height h $g_h = \frac{GM}{(R+h)^2}$ If $h << R$; $g_h \approx g_s\left(1-\frac{2h}{R}\right)$
- At depth d $g_d = \frac{GM(R-d)}{R^3} = g_s\left(1-\frac{d}{R}\right)$
- Effect of rotation on g : $g' = g - \omega^2 R\cos^2\lambda$ where λ is angle of latitude.

- **Gravitational potential**

  Due to a point mass at a distance $V = -\dfrac{GM}{r}$

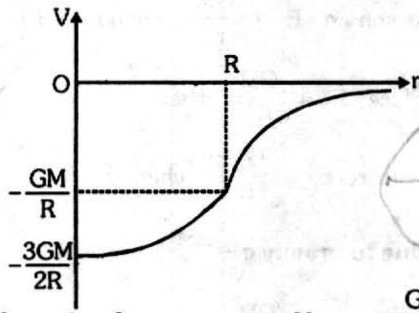
- **Gravitational potential due to spherical shell**

  - Outside the shell $V = -\dfrac{GM}{r}$, $r>R$
  - Inside/on the surface the shell $V = -\dfrac{GM}{R}$, $r \le R$



- **Potential due to solid sphere**

  - Outside the sphere $V = -\dfrac{GM}{r}$, $r > R$
  - On the surface $V = -\dfrac{GM}{R}$, $r = R$
  - Inside the sphere $V = -\dfrac{GM\left(3R^2 - r^2\right)}{2R^3}$, $r < R$



- **Potential on the axis of a thin ring at a distance x** $V = -\dfrac{GM}{\sqrt{R^2 + x^2}}$

- **Escape velocity from a planet of mass M and radius R** $v_e = \sqrt{\dfrac{2GM}{R}}$

- **Orbital velocity of satellite** $v_0 = \sqrt{\dfrac{GM}{r}} = \sqrt{\dfrac{GM}{(R+h)}}$

- For nearby satellite $v_0 = \sqrt{\frac{GM}{R}} = \frac{v_e}{\sqrt{2}}$

  Here V_e = escape velocity on earth surface.

- **Time period of satellite** $T = \frac{2\pi r}{v} = \frac{2\pi r^{3/2}}{\sqrt{GM}}$

- **Energies of a satellite**
  - Potential energy $U = -\frac{GMm}{r}$
  - Kinetic energy $K = \frac{1}{2}mv^2 = \frac{GMm}{2r}$
  - Mechanical energy $E = U + K = -\frac{GMm}{2r}$
  - Binding energy $BE = -E = \frac{GMm}{2r}$

- **Kepler's laws**
  - **I^st^** Law of orbitals

    Path of a planet is elliptical with the sun at a focus.
  - **II^nd^** Law of areas Areal velocity $\frac{dA}{dt}$ = constant $= \frac{L}{2m}$
  - **III^rd^** - Law of periods $T^2 \propto a^3$ or $T^2 \propto \left(\frac{r_{max} + r_{min}}{2}\right)^3 \propto (\text{mean radius})^3$

    For circular orbits $T^2 \propto R^3$

KEY POINTS

- At the centre of earth, a body has centre of mass, but no centre of gravity.
- The centre of mass and centre of gravity of a body coincide if gravitation field is uniform.
- You does not experience gravitational force in daily life due to objects of same size as value of G is very small.
- Moon travellers tie heavy weight at their back before landing on Moon due to smaller value of g at Moon.
- Space rockets are usually launched in equatorial line from West to East because g is minimum at equator and earth rotates from West to East about its axis.
- Angular momentum in gravitational field is conserved because gravitational force is a central force.
- Kepler's second law or constancy of areal velocity is a consequence of conservation of angular momentum.

Important Notes

11 Properties of Matter and Fluid Mechanics

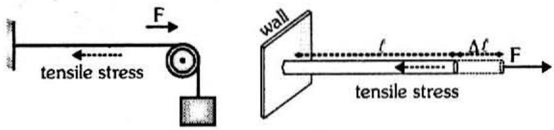
(A) ELASTICITY

STRESS $= \dfrac{\text{Internal restoring force}}{\text{Area of cross-section}} = \dfrac{F_{Res}}{A}$.

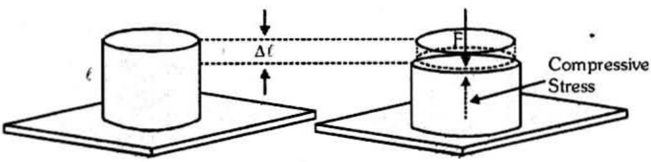
There are three types of stress :-

- **Longitudinal Stress**

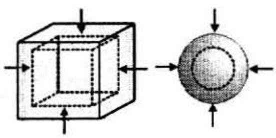
(a) Tensile Stress:



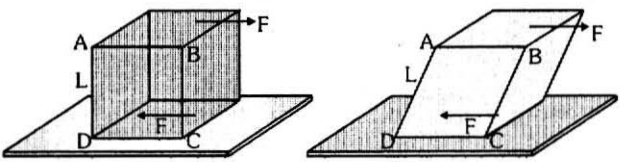
(b) Compressive Stress :



- **Volume Stress**



- **Tangential Stress or Shear Stress**

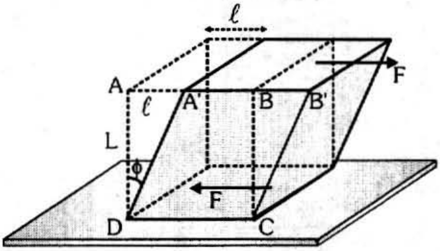


- **Strain** $= \dfrac{\text{Change in size of the body}}{\text{Original size of the body}}$

- **Longitudinal strain** $= \dfrac{\text{change in length of the body}}{\text{initial length of the body}} = \dfrac{\Delta L}{L}$

- **Volume strain** $= \dfrac{\text{change in volume of the body}}{\text{original volume of the body}} = \dfrac{\Delta V}{V}$

- **Shear strain** : $\tan\phi = \frac{\ell}{L}$ or $\phi = \frac{\ell}{L} = \frac{\text{displacement of upper face}}{\text{distance between two faces}}$



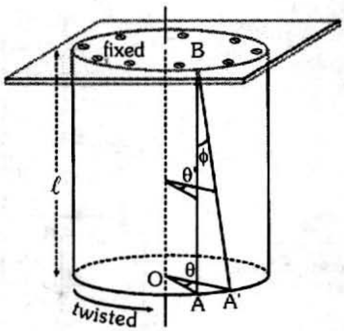
- **Relation between angle of twist (θ) & angle of shear (ϕ)**

$AA' = r\,\theta$ and Arc $AA' = \ell\phi$

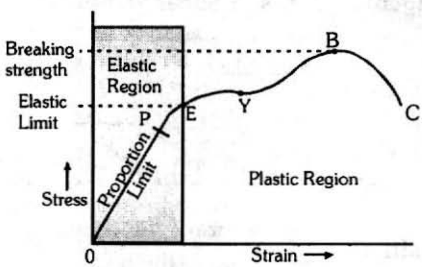
So $r\theta = \ell\phi \Rightarrow \phi = \frac{r\theta}{\ell}$

where θ = angle of twist,

ϕ = angle of shear



- **Stress – Strain Graph**



- **Hooke's Law** within elastic limit $\boxed{\text{Stress} \propto \text{strain}}$

- **Young's modulus of elasticity** $Y = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}} = \frac{F\ell}{A\,\Delta\ell}$

- If L is the length of wire, r is radius and ℓ is the increase in length of the wire by suspending a weight Mg at its one end then Young's modulus of elasticity of the material of wire $Y = \dfrac{(Mg/\pi r^2)}{(\ell/L)} = \dfrac{MgL}{\pi r^2 \ell}$

- **Increment in length due to own weight** $\Delta\ell = \dfrac{MgL}{2AY} = \dfrac{\rho g L^2}{2Y}$

- **Bulk modulus of elasticity** $K = \dfrac{\text{Volume stress}}{\text{Volume strain}} = \dfrac{F/A}{\left(\dfrac{-\Delta V}{V}\right)} = \dfrac{P}{\left(\dfrac{-\Delta V}{V}\right)}$

- **Bulk modulus of an ideal gas is process dependence.**
  - For isothermal process PV = constant

    $\Rightarrow PdV + VdP = 0 \Rightarrow P = \dfrac{-dP}{dV/V}$ So bulk modulus = P

  - For adiabatic process PV^{γ} = constant $\Rightarrow \gamma PV^{\gamma-1}dV + V^{\gamma}dP = 0$

    $\Rightarrow \gamma PdV + VdP = 0 \Rightarrow \gamma P = \dfrac{-dP}{dV/V}$; So bulk modulus = γP

  - For any polytropic process PV^n= constant

    $\Rightarrow nPV^{n-1}dV + V^n dP = 0 \Rightarrow PdV + VdP = 0 \Rightarrow nP = \dfrac{-dP}{dV/V}$

    So bulk modulus = nP

- **Compressibility** $C = \dfrac{1}{\text{Bulk modulus}} = \dfrac{1}{K}$

- **Modulus of rigidity** $\eta = \dfrac{\text{shearing stress}}{\text{shearing strain}} = \dfrac{(F_{\text{tangential}})/A}{\phi}$

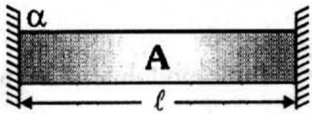
- **Poisson's ratio** $(\sigma) = \dfrac{\text{lateral strain}}{\text{Longitudinal strain}}$

- **Work done in stretching wire**

$$W = \frac{1}{2} \times \text{stress} \times \text{strain} \times \text{volume} :$$

$$W = \frac{1}{2} \times \frac{F}{A} \times \frac{\Delta\ell}{\ell} \times A \times \ell = \frac{1}{2} F \times \Delta\ell$$

- **Rod is rigidly fixed between walls**



  - Thermal Strain = $\alpha\Delta\theta$
  - Thermal stress = $Y\alpha\Delta\theta$
  - Thermal tension = $Y\alpha A\Delta\theta$

- **Effect of Temperature on elasticity**

When temperature is increased then due to weakness of inter molecular force the elastic properties in general decreases i.e. elastic constant decreases. Plasticity increases with temperature. For example, at ordinary room temperature, carbon is elastic but at high temperature, carbon becomes plastic. Lead is not much elastic at room temperature but when cooled in liquid nitrogen exhibit highly elastic behaviour.

For a special kind of steel, elastic constants do not vary appreciably temperature. This steel is called 'INVAR steel'.

- **Effect of Impurity on elasticity**

Y is slightly increase by impurity. The inter molecular attraction force inside wire effectively increase by impurity due to this external force can be easily opposed.

(B) HYDROSTATICS

- **Density** $= \dfrac{\text{mass}}{\text{volume}}$

- **Specific weight** $= \dfrac{\text{weight}}{\text{volume}} = \rho g$

- **Relative density** $= \dfrac{\text{density of given liquid}}{\text{density of pure water at } 4°C}$

- **Density of a Mixture of substance in the proportion of mass**

  the density of the mixture is $\rho = \dfrac{M_1 + M_2 + M_3....}{\dfrac{M_1}{\rho_1} + \dfrac{M_2}{\rho_2} + \dfrac{M_3}{\rho_3} + ...}$

- **Density of a mixture of substance in the proportion of volume**

  the density of the mixture is $\rho = \dfrac{\rho_1 V_1 + \rho_2 V_2 + \rho_3 V_3}{V_1 + V_2 + V_3 + ...}$

- **Pressure** $= \dfrac{\text{normal force}}{\text{area}}$

- **Variation of pressure with depth**

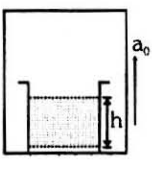
  Pressure is same at two points in the same horizontal level $P_1 = P_2$

  The difference of pressure between two points separated by a depth h

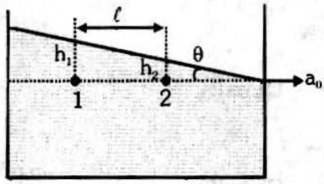
$$(P_2 - P_1) = h\rho g$$

- **Pressure in case of accelerating fluid**

(i) **Liquid placed in elevator:** When elevator accelerates upward with acceleration a_0 then pressure in the fluid, at depth h may be given by, $P = h\rho[g + a_0]$



(ii) Free surface of liquid in case of horizontal acceleration :

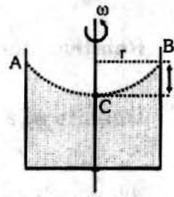


$$\tan\theta = \frac{ma_0}{mg} = \frac{a_0}{g}$$

If P_1 and P_2 are pressures at point 1 & 2 then

$$P_1 - P_2 = \rho g\ (h_1 - h_2) = \rho g \ell \tan\theta = \rho \ell a_0$$

(iii) Free surface of liquid in case of rotating cylinder



$$h = \frac{v^2}{2g} = \frac{\omega^2 r^2}{2g}$$

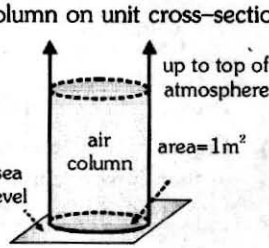
- **Pascal's Law**
  - The pressure in a fluid at rest is same at all the points if gravity is ignored.
  - A liquid exerts equal pressures in all directions.
  - If the pressure in an enclosed fluid is changed at a particular point, the change is transmitted to every point of the fluid and to the walls of the container without being diminished in magnitude. *[for ideal fluids]*

- **Types of Pressure** : Pressure is of three types

  (i) Atmospheric pressure (P_0) (ii) Gauge pressure (P_{gauge})

  (iii) Absolute pressure ($P_{abs.}$)

- **Atmospheric pressure** : Force exerted by air column on unit cross–section area of sea level called atmospheric pressure (P_o)



$$P_o = \frac{F}{A} = 101.3\ \text{kN/m}^2$$

$$\therefore\ P_o = 1.013 \times 10^5\ \text{N/m}^2$$

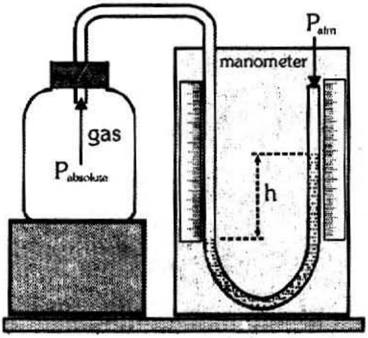
Barometer is used to measure atmospheric pressure.

Which was discovered by **Torricelli**.

Atmospheric pressure varies from place to place and at a particular place from time to time.

- **Gauge Pressure :**

Excess Pressure ($P - P_{atm}$) measured with the help of pressure measuring instrument called Gauge pressure. $P_{gauge} = h\rho g$ or $P_{gauge} \propto h$



Gauge pressure is always measured with help of "**manometer**"

- **Absolute Pressure :**

Sum of atmospheric and Gauge pressure is called absolute pressure.

$$P_{abs} = P_{atm} + P_{gauge} \Rightarrow P_{abs} = P_o + h\rho g$$

The pressure which we measure in our automobile tyres is gauge pressure.

- **Buoyant force** = Weight of displaced fluid = $V\rho g$

- **Apparent weight** = Weight – Upthrust

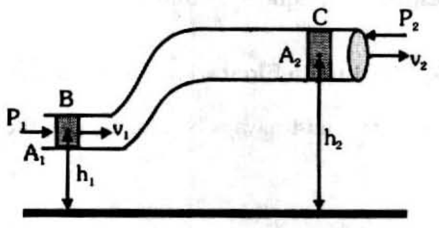
- **Rotatory – Equilibrium in Floatation :** for rotational equilibrium of floating body the meta–centre must always be higher than the centre of gravity of the body.

- **Relative density of body** = $\dfrac{\text{Density of body}}{\text{Density of water}}$

(C) HYDRODYNAMICS

- **Steady and Unsteady Flow :** *Steady flow* is defined as that type of flow in which the fluid characteristics like velocity, pressure and density at a point do not change with time.
- **Streamline Flow :** In steady flow all the particles passing through a given point follow the same path and hence a unique line of flow. This line or path is called a *streamline.*
- **Laminar and Turbulent Flow :** *Laminar flow* is the flow in which the fluid particles move along well–defined streamlines which are straight and parallel.
- **Compressible and Incompressible Flow :** In *compressible flow* the density of fluid varies from point to point i.e. the density is not constant for the fluid whereas in *incompressible flow* the density of the fluid remains constant throughout.
- **Rotational and Irrotational Flow :** *Rotational flow* is the flow in which the fluid particles while flowing along path–lines also rotate about their own axis. In *irrotational flow* particles do not rotate about their axis.
- **Equation of continuity** $A_1v_1 = A_2v_2$ **Based** on conservation of mass
- **Bernoulli's theorem** : $\boxed{P + \frac{1}{2}\rho v^2 + \rho gh = \text{constant}}$

Based on energy conservation



- **Kinetic Energy**

kinetic energy per unit volume $= \dfrac{\text{Kinetic Energy}}{\text{volume}} = \dfrac{1}{2}\dfrac{m}{V}v^2 = \dfrac{1}{2}\rho v^2$

- **Potential Energy**

Potential energy per unit volume $= \dfrac{\text{Potential Energy}}{\text{volume}} = \dfrac{m}{V}gh = \rho gh$

- **Pressure Energy**

Pressure energy per unit volume $= \dfrac{\text{Pressure energy}}{\text{volume}} = P$

- **For horizontal flow in venturimeter**

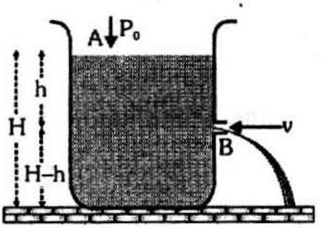
$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v^2 \Rightarrow v_1 = A_2\sqrt{\frac{2gh}{A_1^2 - A_2^2}}$$

- **Rate of flow :**

Volume of water flowing per second $\quad Q = A_1 v_1 = A_1 A_2\sqrt{\dfrac{2gh}{A_1^2 - A_2^2}}$

- **Velocity of efflux** $v = \sqrt{2gh}$

- **Horizontal range** $R = 2\sqrt{h(H-h)}$



(D) SURFACE TENSION

Surface tension is basically a property of liquid. The liquid surface behaves like a stretched elastic membrane which has a natural tendency to contract and tends to have a minimum surface area. This property of liquid is called *surface tension.*

Intermolecular forces

(a) Cohesive force

The force acting between the molecules of one type of molecules of same substance is called cohesive force.

(b) Adhesive force

The force acting between different types of molecules or molecules of different substance is called adhesive force.

- Intermolecular forces are different from the gravitational forces and do not obey the inverse–square law
- The distance upto which these forces effective, is called.molecular range. This distance is nearly 10^{-9} m. Within this limit this increases very rapidly as the distance decreases.
- Molecular range depends on the nature of the substance

Properties of surface tension

- Surface tension is a scalar quantity.
- It acts tangential to liquid surface.
- Surface tension is always produced due to cohesive force.
- More is the cohesive force, more is the surface tension.
- When surface area of liquid is increased, molecules from the interior of the liquid rise to the surface. For this, work is done against the downward cohesive force.

Dependency of Surface Tension

- **On Cohesive Force :** Those factors which increase the cohesive force between molecules increase the surface tension and those which decrease the cohesive force between molecules decrease the surface tension.

- **On Impurities :** If the impurity is completely soluble then on mixing it in the liquid, its surface tension increases. e.g., on dissolving ionic salts in small quantities in a liquid, its surface tension increases. If the impurity is partially soluble in a liquid then its surface tension decreases because adhesive force between insoluble impurity molecules and liquid molecules decreases cohesive force effectively, e.g.

  (a) On mixing detergent in water its surface tension decreases.

  (b) Surface tension of water is more than (alcohol + water) mixture.

- **On Temperature**

  On increasing temperature surface tension decreases. At critical temperature and boiling point it becomes zero.

  Note : Surface tension of water is maximum at 4°C

- **On Contamination**

  The dust particles or lubricating materials on the liquid surface decreases its surface tension.

- **On Electrification**

  The surface tension of a liquid decreases due to electrification because a force starts acting due to it in the outward direction normal to the free surface of liquid.

Definition of surface tension

The force acting per unit length of an imaginary line drawn on the free liquid surface at right angles to the line and in the plane of liquid surface, is defined as surface tension.

- For floating needle $2T\ell \sin\theta = mg$

- **Required excess force for lift**

- Wire $F_{ex} = 2T\ell$
- Hollow disc $F_{ex} = 2\pi T(r_1 + r_2)$
- For ring $F_{ex} = 4\pi rT$
- Circular disc $F_{ex} = 2\pi rT$
- Square frame $F_{ex} = 8aT$
- Square plate $F_{ex} = 4aT$

- **Work** = surface energy = $T\Delta A$
  - Liquid drop $W = 4\pi r^2 T$
  - Soap bubble $W = 8\pi r^2 T$
- **Splitting of bigger drop into smaller droples** $R = n^{1/3}\, r$

  Work done= Change in surface energy = $4\pi R^3 T\left(\frac{1}{r}-\frac{1}{R}\right) = 4\pi R^2 T\,(n^{1/3}-1)$
- **Excess pressure** $P_{ex} = P_{in} - P_{out}$
  - In liquid drop $P_{ex} = \frac{2T}{R}$
  - In soap bubble $P_{ex} = \frac{4T}{R}$

ANGLE OF CONTACT (θ_C)

The angle enclosed between the tangent plane at the liquid surface and the tangent plane at the solid surface at the point of contact inside the liquid is defined as the *angle of contact.*

The angle of contact depends the nature of the solid and liquid in contact.

- **Angle of contact** $\theta < 90° \Rightarrow$ concave shape, Liquid rise up

  Angle of contact $\theta > 90° \Rightarrow$ convex shape, Liquid falls

  Angle of contact $\theta = 90° \Rightarrow$ plane shape, Liquid neither rise nor falls
- **Effect of Temperature on angle of contact**

  On increasing temperature surface tension decreases, thus $\cos\theta_c$ increases $\left[\because \cos\theta_c \propto \frac{1}{T}\right]$ and θ_c decrease. So on increasing temperature, θ_c decreases.
- **Effect of Impurities on angle of contact**

  (a) Solute impurities increase surface tension, so $\cos\theta_c$ decreases and angle of contact θ_c increases.

  (b) Partially solute impurities decrease surface tension, so angle of contact θ_c decreases.

- **Effect of Water Proofing Agent**

  Angle of contact increases due to water proofing agent. It gets converted acute to obtuse angle.

- **Capillary rise** $h = \frac{2T\cos\theta}{r\rho g}$

  - Zurin's law $h \propto \frac{1}{r}$

  - Jeager's method $T = \frac{rg}{2}(H\rho - hd)$

  - The height 'h' is measured from the bottom of the meniscus. However, there exist some liquid above this line also. If correction of this is applied

    then the formula will be $T = \frac{r\rho g\left[h + \frac{1}{3}r\right]}{2\cos\theta}$

- When two soap bubbles are in contact then radius of curvature of the common surface $r = \frac{r_1 r_2}{r_1 - r_2} (r_1 > r_2)$

- When two soap bubbles are combining to form a new bubble then radius of new bubble $r = \sqrt{r_1^2 + r_2^2}$

- Force required to separate two plates $F = \frac{2AT}{d}$

(E) VISCOSITY

- **Newton's law of viscosity** $F = \eta A \frac{\Delta v_x}{\Delta y}$

  - **SI UNITS :** $\frac{N \times s}{m^2}$ or deca poise

  - **CGS UNITS :** dyne–s/cm^2 or poise (1 decapoise = 10 poise)

- **Dependency of viscosity of fluids**

  On Temperature of Fluid

  (a) Since cohesive forces decrease with increase in temperature as increase in K.E.. Therefore with the rise in temperature, the viscosity of liquids decreases.

  (b) The viscosity of gases is the result of diffusion of gas molecules from one moving layer to other moving layer. Now with increase in temperature, the rate of diffusion increases. So, the viscosity also increases. Thus, the viscosity of gases increases with the rise of temperature.

  On Pressure of Fluid

  (a) The viscosity of liquids increases with the increase of pressure.

  (b) The viscosity of gases is practically independent of pressure.

  On Nature of Fluid

- **Poiseuillel's formula** $Q = \frac{dV}{dt} = \frac{\pi p r^4}{8\eta L}$

- **Viscous force** $F_v = 6\pi\eta r v$

- **Terminal velocity** $v_T = \frac{2}{9}\frac{r^2(\rho - \sigma)g}{\eta} \Rightarrow v_T \propto r^2$

- **Reynolds number** $R_e = \frac{\rho v d}{\eta}$

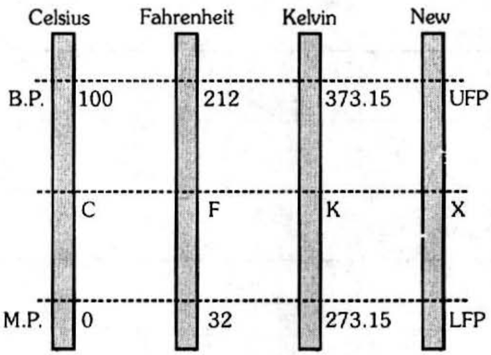
  $R_e < 1000$ laminar flow, $R_e > 2000$ turbulent flow

Important Notes

12 Thermal Physics

TEMPERATURE SCALES AND THERMAL EXPANSION

Name of the scale	Symbol for each degree	Lower fixed point (LFP)	Upper fixed point (UFP)	Number of divisions on the scale
Celsius	°C	0°C	100°C	100
Fahrenheit	°F	32°F	212°F	180
Kelvin	K	273.15 K	373.15 K	100



$$\frac{C-0}{100-0}=\frac{F-32}{212-32}=\frac{K-273.15}{373.15-273.15}=\frac{X-LFP}{UFP-LFP}$$

$$\Rightarrow \frac{\Delta C}{100}=\frac{\Delta F}{180}=\frac{\Delta K}{100}=\frac{\Delta X}{UFP-LFP}$$

- **Old thermometry**

$$\frac{\theta-0}{100-0}=\frac{X-X_0}{X_{100}-X_0}$$ [two fixed points – ice & steam points]

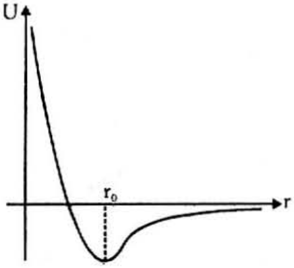
where X is thermometric property i.e. length, resistance etc.

- **Modern thermometry** $\frac{T-0}{273.16-0}=\frac{X}{X_{tr}}$

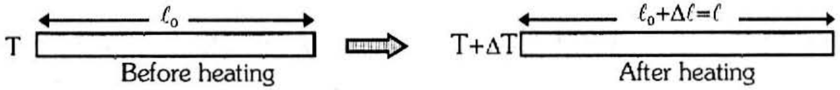
[Only one reference point – triple point of water is chosen]

THERMAL EXPANSION

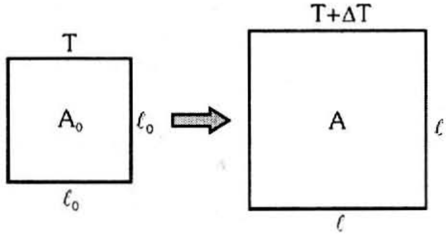
It is due to asymmetry in potential energy curve.



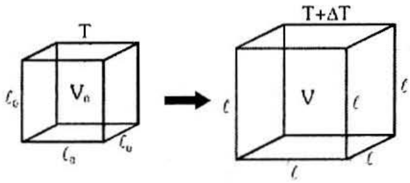
In solids → Linear expansion $\ell = \ell_0\,(1+\alpha\Delta T)$



In solids → Areal expansion $A = A_0\,(1+\beta\Delta T)$



In solids, liquids and gases → volume expansion $V=V_0(1+\gamma\Delta T)$



[For isotropic solids : $\alpha : \beta : \gamma = 1 : 2 : 3$]

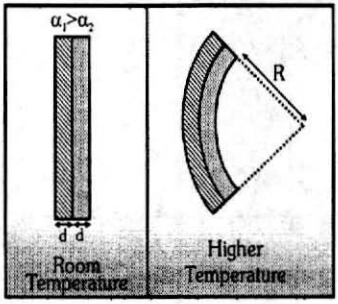
Thermal expansion of an isotropic object may be imagined as a photographic enlargement.

For anisotropic materials $\beta_{xy} = \alpha_x + \alpha_y$ and $\gamma = \alpha_x + \alpha_y + \alpha_z$

If α is variable : $\Delta\ell = \int_{T_1}^{T_2} \ell_0 \alpha \, dT$

Application of Thermal expansion in solids

I. Bi-metallic strip *(used as thermostat or auto-cut in electric heating circuits)*



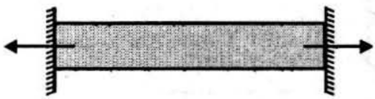
II. Simple pendulum : $T = 2\pi\sqrt{\frac{\ell}{g}} \Rightarrow T \propto \ell^{1/2} \Rightarrow \frac{\Delta T}{T} = \frac{1}{2}\frac{\Delta \ell}{\ell}$

Fractional change in time period $= \frac{\Delta T}{T} = \frac{1}{2}\alpha\Delta\theta$

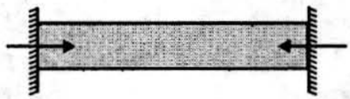
III. Scale reading : Due to linear expansion / contraction, scale reading will be lesser / more than actual value.

If temperature ↑ then actual value = scale reading $(1+\alpha\Delta\theta)$

IV. Thermal Stress



Cooling [Tensile Stress]

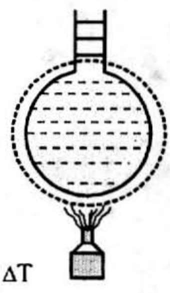


Heating [Compressive Stress]

Thermal strain $= \frac{\Delta \ell}{\ell} = \alpha\Delta\theta$

As Young's modulus $Y = \frac{F/A}{\Delta\ell/\ell}$; So thermal stress = $YA\alpha\Delta\theta$

Thermal expansion in liquids (Only volume expansion)



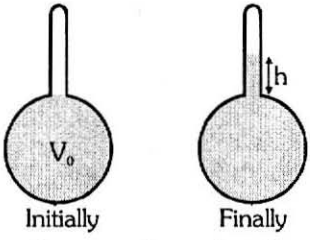
$$\gamma_a = \frac{\text{Apparent increase in volume}}{\text{Initial volume} \times \text{Temperature rise}}$$

$$\gamma_r = \frac{\text{real increse in volume}}{\text{initial volume} \times \text{temperature rise}}$$

$$\gamma_r = \gamma_a + \gamma_{vessel}$$

Change in volume of liquid w.r.t. vessel $\Delta V = V_0(\gamma_r - 3\alpha)\Delta T$

Expansion in enclosed volume



[$\alpha \to$ vessel; $\gamma_L \to$ liquid]

Increase in height of liquid level in tube when bulb was initially completely filled.

$$h = \frac{\text{apparent change in volume of liquid}}{\text{area of tube}} = \frac{V_0(\gamma_L - 3\alpha)\Delta T}{A_0(1+2\alpha)\Delta T}$$

Anomalous expansion of water :

In the range 0°C to 4 °C water contract on heating and expands on cooling.

At 4°C $\rightarrow$ density is maximum.

Aquatic life is able to survive in very cold countries as the lake bottom remains unfrozen at the temperature around 4°C.

Thermal expansion of gases :

- Coefficient of volume expansion $\gamma_V = \frac{\Delta V}{V_0 \Delta T} = \frac{1}{T}$

  [PV = nRT at constant pressure $V \propto T \Rightarrow \frac{\Delta V}{V} = \frac{\Delta T}{T}$]

- Coefficient of pressure expansion $\gamma_P = \frac{\Delta P}{P_0 \Delta T} = \frac{1}{T}$

KEY POINTS :

- Liquids usually expand more than solids because the intermolecular forces in liquids are weaker than in solids.
- Rubber contract on heating because in rubber as temperature increases, the amplitude of transverse vibrations increases more than the amplitude of longitudinal vibrations.
- Water expands both when heated or cooled from 4°C because volume of water at 4°C is minimum.
- In cold countries, water pipes sometimes burst, because water expands on freezing.

CALORIMETRY

$$\boxed{1 \text{ cal} = 4.186 \text{ J} ; 4.2 \text{ J}}$$

- **Thermal capacity of a body** = $\frac{Q}{\Delta T}$

  Amount of heat required to raise the temp. of a given body by 1°C (or 1K).

- **Specific heat capacity** = $\frac{Q}{m\Delta T}$ (m = mass)

  Amount of heat required to raise the temperature of unit mass of a body through 1°C (or 1K)

- **Molar heat capacity**= $\frac{Q}{n\Delta T}$ (n=number of moles)

- **Water equivalent :** If thermal capacity of a body is expressed in terms of mass of water, it is called water equivalent. Water equivalent of a body is the mass of water which when given same amount of heat as to the body, changes the temperature of water through same range as that of the body.

  Therefore water equivalent of a body is the quantity of water, whose heat capacity is the same as the heat capacity of the body.

  Water equivalent of the body,

  $$W = \text{mass of body} \times \left(\frac{\text{specific heat of body}}{\text{specific heat of water}}\right)$$

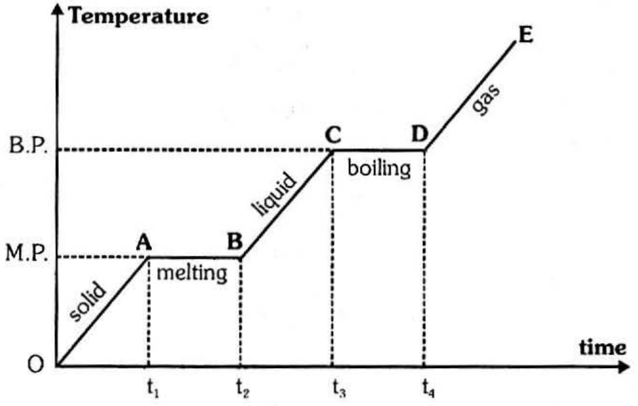
  Unit of water equivalent is g or kg.

- **Latent Heat (Hidden heat) :** The amount of heat that has to supplied to (or removed from) a body for its complete change of state (from solid to liquid, liquid to gas etc) is called latent heat of the body. Remember that phase transformation is an isothermal (i.e. temperature = constant) change.

- **Principle of calorimetry** : Heat lost = heat gained

  For temperature change $Q = ms\Delta T$, For phase change $Q = mL$

- **Heating curve :** If to a given mass (m) of a solid, heat is supplied at constant rate (Q) and a graph is plotted between temperature and time, the graph is called heating curve.

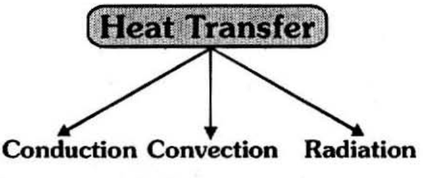


Specific heat (or thermal capacity) $\propto \dfrac{1}{\text{slope of curve}}$

Latent heat $\propto$ length of horizontal line.

KEY POINTS

- Specific heat of a body may be greater than its thermal capacity as mass of the body may be less than unity.
- The steam at 100°C causes more severe burn to human body than the water at 100°C because steam has greater internal energy than water due to latent heat of vaporization.
- Heat is energy in transit which is transferred from hot body to cold body.
- One calorie is the amount of heat required to raise the temperature of one gram of water through 1°C (more precisely from 14.5 °C to 15.5°C).
- Clausins & clapeyron equation (effect of pressure on boiling point of liquids & melting point of solids related with latent heat) $\dfrac{dP}{dT} = \dfrac{L}{T(V_2 - V_1)}$



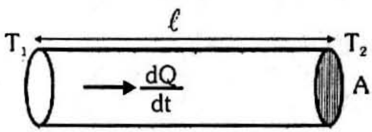
In conduction, heat is transferred from one point to another without the actual motion of heated particles.

In the process of convection, the heated particles of matter actually move.

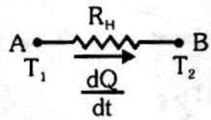
In radiation, intervening medium is not affected and heat is transferred without any material medium.

Conduction	Convection	Radiation
Heat Transfer due to Temperature difference	Heat transfer due to density difference	Heat transfer with out any medium
Due to free electron or vibration motion of molecules	Actual motion of particles	Electromagnetic radiation
Heat transfer in solid body (in mercury also)	Heat transfer in fluids (Liquid + gas)	All
Slow process	Slow process	Fast process (3×10^8 m/sec)
Irregular path	Irregular path	Straight line (like light)

THERMAL CONDUCTION



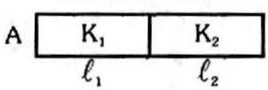
Electrical equivalent



Rate of heat flow $\frac{dQ}{dt} = -KA\frac{dT}{dx}$ or $\frac{Q}{t} = \frac{KA(T_1 - T_2)}{\ell}$

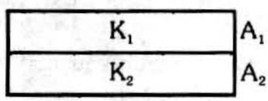
Thermal resistance $R_H = \frac{\ell}{KA}$

Rods in series



$K_{eq} = \frac{\Sigma \ell}{\Sigma \ell / K}$

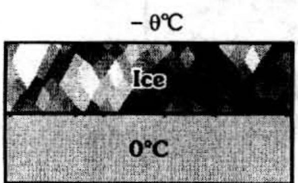
Rods in parallel



$K_{eq} = \frac{\Sigma KA}{\Sigma A}$

Growth of Ice on Ponds

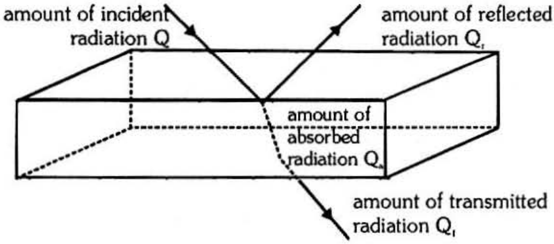
Time taken by ice to grow a thickness from x_1 to x_2 : $t = \frac{\rho L}{2K\theta}(x_2^2 - x_1^2)$



[K = thermal conductivity of ice, ρ = density of ice]

RADIATION

- **Spectral, emissive, absorptive and transmittive power of a given body surface** : Due to incident radiations on the surface of a body following phenomena occur by which the radiation is divided into three parts.
  (a) Reflection (b) Absorption (c) Transmission



From energy conservation

$$Q = Q_r + Q_a + Q_t \Rightarrow \frac{Q_r}{Q} + \frac{Q_a}{Q} + \frac{Q_t}{Q} = 1 \Rightarrow r + a + t = 1$$

- Reflective Coefficient : $r = \frac{Q_r}{Q}$
- Absorptive Coefficient : $a = \frac{Q_a}{Q}$
- Transmittive Coefficient : $t = \frac{Q_t}{Q}$

$r = 1$ and $a = 0$, $t = 0$ $\Rightarrow$ Perfect reflector
$a = 1$ and $r = 0$, $t = 0$ $\Rightarrow$ Ideal absorber (ideal black body)
$t = 1$ and $a = 0$, $r = 0$ $\Rightarrow$ Perfect transmitter (daithermanons)

$$\text{Reflection power (r)} = \left[\frac{Q_r}{Q} \times 100\right]\%$$

$$\text{Absorption power (a)} = \left[\frac{Q_a}{Q} \times 100\right]\%$$

$$\text{Transmission power (t)} = \left[\frac{Q_t}{Q} \times 100\right]\%$$

- **Stefan's Boltzmann law :**
  Radiated energy emitted by a perfect black body per unit area/sec $E = \sigma T^4$
  For a general body $E = \sigma e_r T^4$ [where $0 \le e_r \le 1$]

- **Prevost's theory of heat exchange :** A body is simultaneously emitting radiations to its surrounding and absorbing radiations from the surroundings.
  If surrounding has temperature T_0 then $E_{net} = e_r \sigma (T^4 - T_0^4)$
- **Kirchhoff's law :** The ratio of emissive power to absorptive power is same for all surfaces at the same temperature and is equal to the emissive power

of a perfectly black body at that temperature.

$$\frac{e}{a}=\frac{E}{A}=\frac{E}{1}\Rightarrow\frac{e}{a}=E\Rightarrow e\propto a$$

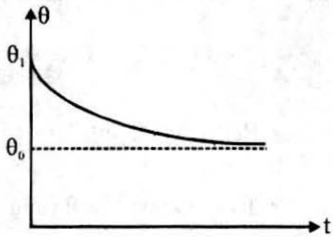
Therefore a good absorber is a good emitter.

- **Perfectly Black Body :** A body which absorbs all the radiations incident on it is called a perfectly black body.

- **Absorptive Power (a) :** Absorptive power of a surface is defined as the ratio of the radiant energy absorbed by it in a given time to the total radiant energy incident on it in the same time.
  For ideal black body, absorptive power =1

- **Emissive power(e) :** For a given surface it is defined as the radiant energy emitted per second per unit area of the surface.

- **Newton's law of cooling:**
  If temperature difference is small



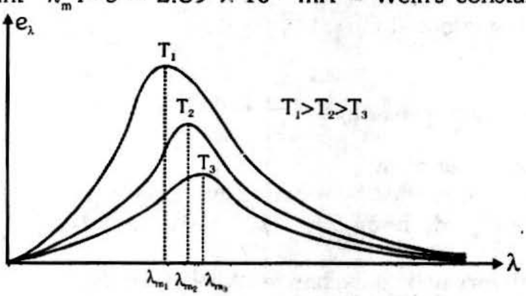
  Rate of cooling $\frac{d\theta}{dt}\propto(\theta-\theta_0)$

  $\Rightarrow\theta=\theta_0+(\theta_1-\theta_0)e^{-kt}$

  [where k = constant]

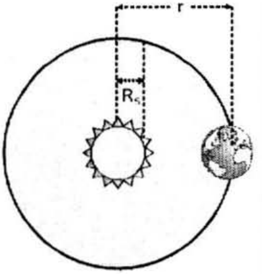
  when a body cools from θ_1 to θ_2 in time 't' in a surrounding of temperature θ_0 then $\frac{\theta_1-\theta_2}{t}=k\left[\frac{\theta_1+\theta_2}{2}-\theta_0\right]$ [where k= constant]

- **Wien's Displacement Law :** Product of the wavelength λ_m of most intense radiation emitted by a black body and absolute temperature of the black body is a constant $\lambda_m T=b=2.89\times10^{-3}$ mK = Wein's constant



Area under $e_\lambda-\lambda$ graph$=\int_0^\infty e_\lambda d\lambda=e=\sigma T^4$

Solar constant



The Sun emits radiant energy continuously in space of which an insignificant part reaches the Earth. The solar radiant energy received per unit area per unit time by a black surface held at right angles to the Sun's rays and placed at the mean distance of the Earth (in the absence of atmosphere) is called solar constant.

$$S=\frac{P}{4\pi r^2}=\frac{4\pi R_S^2\sigma T^4}{4\pi r^2}=\left(\frac{R_S}{r}\right)^2 T^4$$

where R_S = radius of sun

r = average distance between sun and earth.

Note :- $S = 2 \text{ cal cm}^{-2}\text{min} = 1.4 \text{ kWm}^{-2}$

T = temperature of sun ≈ 5800 K

KEY POINTS :

- Stainless steel cooking pans are preferred with extra copper bottom because thermal conductivity of copper is more than steel.
- Two layers of cloth of same thickness provide warmer covering than a single layer of cloth of double the thickness because air (which is better insulator of heat) is trapped between them.
- Animals curl into a ball when they feel very cold to reduce the surface area of the body.
- Water cannot be boiled inside a satellite by convection because in weightlessness conditions, natural movement of heated fluid is not possible.
- Metals have high thermal conductivity because metals have free electrons.

KINETIC THEORY OF GASES

It related the macroscopic properties of gases to the microscopic properties of gas molecules.

Basic postulates of Kinetic theory of gases

- Every gas consists of extremely small particles known as molecules. The molecules of a given gas are all identical but are different than those another gas.
- The molecules of a gas are identical, spherical, rigid and perfectly elastic point masses.
- The size is negligible in comparision to inter molecular distance (10^{-9} m)

Assumptions regarding motion :

- Molecules of a gas keep on moving randomly in all possible direction with all possible velocities.
- The speed of gas molecules lie between zero and infinity (very high speed).
- The number of molecules moving with most probable speed is maximum.

Assumptions regarding collision:

- The gas molecules keep colliding among themselves as well as with the walls of containing vessel. These collision are perfectly elastic. (ie., the total energy before collision = total energy after the collisions.)

Assumptions regarding force:

- No attractive or repulsive force acts between gas molecules.
- Gravitational attraction among the molecules is ineffective due to extremely small masses and very high speed of molecules.

Assumptions regarding pressure:

- Molecules constantly collide with the walls of container due to which their momentum changes. This change in momentum is transferred to the walls of the container. Consequently pressure is exerted by gas molecules on the walls of container.

Assumptions regarding density:

- The density of gas is constant at all points of the container.

Kinetic interpretation of pressure : $PV = \frac{1}{3}mNv_{rms}^2$

[m = mass of a molecule, N = no. of molecules]

Ideal gas equation $PV = \mu RT \Rightarrow P = \frac{\mu RT}{V} = \frac{\mu N_A kT}{V} = \left(\frac{N}{V}\right)kT = nkT$

Gas laws

- **Boyle's law** :For a given mass at constant temperature. $V \propto \frac{1}{P}$
- **Charles' law** : For a given mass at constant pressure $V \propto T$
- **Gay-Lussac's law** For a given mass at constant volume $P \propto T$
- **Avogadro's law**:If P,V & T are same then no. of molecules $N_1 = N_2$
- **Graham's law** : At constant P and T, Rate of diffusion $\propto \frac{1}{\sqrt{\rho}}$
- **Dalton's law** : $P = P_1 + P_2 + ...$
  Total pressure =Sum of partial pressures

Real gas equation [Vander Waal's equation] $\left(P + \frac{\mu^2 a}{V^2}\right)(V - \mu b) = \mu RT$

where a & b are vander waal's constant and depend on the nature of gas.

Critical temperature $T_C = \dfrac{8a}{27Rb}$

The maximum temperature below which a gas can be liquefied by pressure alone.

Critical volume $V_c = 3b$ **Critical pressure** $P_c = \dfrac{a}{27b^2}$

Note :- For a real gas $\dfrac{P_C V_C}{RT_C} = \dfrac{3}{8}$

Different speeds of molecules

$$v_{rms} = \sqrt{\frac{3RT}{M_w}} = \sqrt{\frac{3kT}{m}} \qquad v_{mp} = \sqrt{\frac{2RT}{M_w}} = \sqrt{\frac{2kT}{m}} \qquad v_{av} = \sqrt{\frac{8RT}{\pi M_w}} = \sqrt{\frac{8kT}{\pi m}}$$

Kinetic Interpretation of Temperature :

Temperature of an ideal gas is proportional to the average KE of molecules,

$$PV = \frac{1}{3}mNV_{rms}^2 \ \& \ PV = \mu RT \Rightarrow \frac{1}{2}mv_{rms}^2 = \frac{3}{2}kT$$

Degree of Freedom (F) :

Number of minimum coordinates required to specify the dynamical state of a system.

For monoatomic gas (He, Ar etc) f=3 (only translational)

For diatomic gas (H_2, O_2 etc) f=5 (3 translational + 2 rotational)

At higher temperature, diatomic molecules have two degree of freedom due to vibrational motion (one for KE + one for PE)

At higher temperature diatomic gas has f=7

Maxwell's Law of equipartition of energy:

Kinetic energy associated with each degree of freedom of particles of an ideal gas is equal to $\dfrac{1}{2}kT$

- Average KE of a particle having f degree of freedom= $\dfrac{f}{2}kT$
- Translational KE of a molecule = $\dfrac{3}{2}kT$
- Translational KE of a mole = $\dfrac{3}{2}RT$
- Internal energy of an ideal gas: $U = \dfrac{f}{2}\mu RT$

Specific heats (C_P and C_V) :

- Molar specific heat of a gas $C = \frac{dQ}{\mu dT}$
- $C_V = \left(\frac{dQ}{\mu dT}\right)_{V=\text{constant}} = \frac{dU}{\mu dT}$
- $C_P = \left(\frac{dQ}{\mu dT}\right)_{dP=0} = C_V + R \leftarrow$ Mayer's equation

Atomicity	Translational	Rotational	Total (f)	$\gamma = \frac{C_P}{C_V}$	$C_V = \frac{f}{2}R$	$C_P=C_V+R$
Monoatomic [He, Ar, Ne..].	3	0	3	$\frac{5}{3}=1.67$	$\frac{3}{2}R$	$\frac{5}{2}R$
Diatomic [H_2, N_2..]	3	2	5	$\frac{7}{5}=1.4$	$\frac{5}{2}R$	$\frac{7}{2}R$
Triatomic (Linear CO_2)	3	2	5	$\frac{7}{5}=1.4$	$\frac{5}{2}R$	$\frac{7}{2}R$
Triatomic Non-linear-NH_3) & Polyatomic	3	3	6	$\frac{4}{3}=1.33$	3R	4R

Mean free path :

Average distance between two consecutive collisions $\lambda_m = \frac{1}{\sqrt{2}\pi d^2 n}$

where d = diameter of molecule, n = molecular density = $\frac{N}{V}$

For mixture of non-reacting gases

Molecular weight $M_{W_{mix}} = \frac{\mu_1 M_{W_1} + \mu_2 M_{W_2} + ...}{\mu_1 + \mu_2 + ...}$

Specific heat at constant V $C_{V_{mix}} = \frac{\mu_1 C_{V_1} + \mu_2 C_{V_2} + ...}{\mu_1 + \mu_2 + ...}$

Specific heat at constant P $C_{P_{mix}} = \frac{\mu_1 C_{P_1} + \mu_2 C_{P_2} + ...}{\mu_1 + \mu_2 + ...}$

$$\gamma_{mix} = \frac{C_{P_{mix}}}{C_{V_{mix}}} = \frac{\mu_1 C_{P_1} + \mu_2 C_{P_2} + ...}{\mu_1 C_{V_1} + \mu_2 C_{V_2} + ...}$$

KEY POINTS :

- Kinetic energy per unit volume $E_V = \frac{1}{2}\left(\frac{mN}{V}\right)v_{rms}^2 = \frac{3}{2}P$
- At absolute zero, the motion of all molecules of the gas stops.
- At higher temperature and low pressure or at higher temperature and low density, a real gas behaves as an ideal gas.
- **For any general process**

  (a) Internal energy change $\Delta U = nC_V dT$

  (b) Heat supplied to a gas $\Delta Q = nCdT$

  where C for any polytropic process PV^x = constant is $C = C_V + \frac{R}{1-x}$

  (c) Work done for any process $\Delta W = P\Delta V$

  It can be calculated as area under P-V curve

  (d) Work done $= \Delta Q - \Delta U = \frac{nR}{1-x}dT$

  For any polytropic process PV^x = constant

THERMODYNAMICS

- **Zeroth law of thermodynamics :** If two systems are each in thermal equilibrium with a third, they are also in thermal equilibrium with each other.

- **First law of thermodynamics :** Heat supplied (Q) to a system is equal to algebraic sum of change in internal energy (ΔU) of the system and mechanical work (W) done by the system

  $Q = W + \Delta U$ [Here $W = \int PdV$; $\Delta U = nC_V\Delta T$]

For differential change $\boxed{\underbrace{\delta Q = \delta W}_{\text{path dependent}} + \underbrace{dU}_{\text{path independent}}}$

- **Sign Convention**

  Heat absorbed by the system →positive

  Heat rejected by the system → negative

  Increase in internal energy (i.e. rise in temperature)→positive

  Decrease in internal energy (i.e. fall in temperature)→ negative

  Work done by the system →positive

  Work done on the system →negative

- **For cyclic process** $\Delta U = 0 \Rightarrow Q=W$

- **For isochoric process** V = constant $\Rightarrow P \propto T$ & $W = 0$

  $Q = \Delta U = \mu C_V \Delta T$

- **For isobaric process** P = constant $\Rightarrow V \propto T$

  $Q = \mu C_P \Delta T$, $\Delta U = \mu C_V \Delta T$

  $W = P(V_2 - V_1) = \mu R \Delta T$

- **For adiabatic process** PV^γ = constant

  or $T^\gamma P^{1-\gamma}$ = constant

  or $TV^{\gamma-1}$ = constant

  In this process $Q = 0$ and

  $$W = -\Delta U = \mu C_V (T_1 - T_2) = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$$

- **For Isothermal Process** T = constant

  or $\Delta T = 0 \Rightarrow PV$ = constant

  In this process $\Delta U = \mu C_V \Delta T = 0$

  $$\text{So, } Q = W = \mu RT\, \ell n\left(\frac{V_2}{V_1}\right) = \mu RT \ell n\left(\frac{P_1}{P_2}\right)$$

- **For any general polytropic process** PV^x = constant

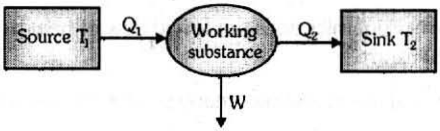
  - Molar heat capacity $C = C_V + \dfrac{R}{1-x}$

  - Work done by gas $W = \dfrac{nR(T_1 - T_2)}{x-1} = \dfrac{(P_1V_1 - P_2V_2)}{x-1}$

  - Slope of P-V diagram

    (also known as indicator diagram at any point $\dfrac{dP}{dV} = -x\dfrac{P}{V}$)

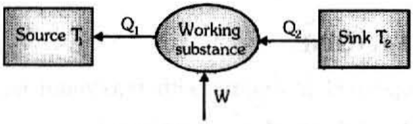
Efficiency of a cycle



$$\eta = \frac{\text{Work done by working substance}}{\text{Heat supplied}} = \frac{W}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1}$$

For carnot cycle $\quad \dfrac{Q_2}{Q_1} = \dfrac{T_2}{T_1}$ so $\eta = 1 - \dfrac{Q_2}{Q_1} = 1 - \dfrac{T_2}{T_1}$

For refrigerator



$$\text{Coefficient of performance } \beta = \frac{Q_2}{W} = \frac{Q_2}{Q_1 - Q_2} = \frac{T_2}{T_1 - T_2}$$

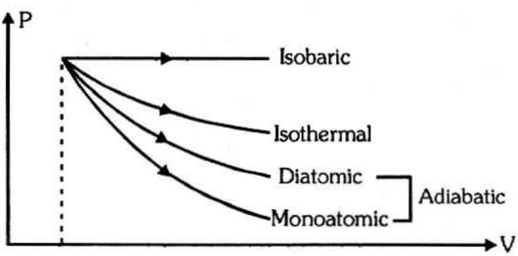
Bulk modulus of gases : $B = \dfrac{\Delta P}{-\dfrac{\Delta V}{V}}$

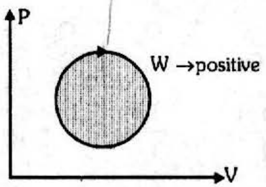
Isothermal bulk modulus of elasticity, $B_{IT} = -V\left(\dfrac{\partial P}{\partial V}\right)_{T=\text{constant}}$

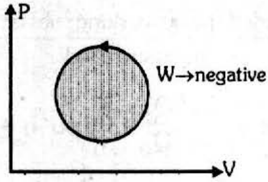
Adiabatic bulk modulus of elasticity, $B_{AD} = -\gamma V\left(\dfrac{\partial P}{\partial V}\right) \Rightarrow B_{AD} = \gamma B_{IT}$

KEY POINTS

- Work done is least for monoatomic gas (adiabatic process) in shown expansion.



- Air quickly leaking out of a balloon becomes cooler as the leaking air undergoes adiabatic expansion.
- First law of thermodynamics does not forbid flow of heat from lower temperature to higher temperature.
- First law of thermodynamics allows many processes which actually don't happen.
- 

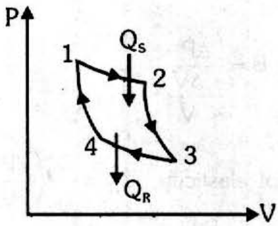


- **CARNOT ENGINE**

  It is a hypothetical engine with maximum possible efficiency

  Process 1→2 & 3→4 are isothermal

  Process 2→3 & 4→1 are adiabatic.



$$\eta = 1 - \frac{T_{3-4}}{T_{1-2}}$$

Important Notes

13 Oscillations

SIMPLE HARMONIC MOTIONS

- **Periodic Motion**

  Any motion which repeats itself after regular interval of time (i.e. time period) is called periodic motion or harmonic motion.

  Ex. (i) Motion of planets around the sun.

  (ii) Motion of the pendulum of wall clock.

- **Oscillatory Motion**

  The motion of body is said to be oscillatory or vibratory motion if it moves back and forth (to and fro) about a fixed point after regular interval of time.

  The fixed point about which the body oscillates is called mean position or equilibrium position.

  Ex.: (i) Vibration of the wire of 'Sitar'.

  (ii) Oscillation of the mass suspended from spring.

  Note : Every oscillatory motion is periodic but every periodic motion is not oscillatory.

- **Simple Harmonic Motion (S.H.M.)**

  Simple harmonic motion is the simplest form of vibratory or oscillatory motion.

- **Some Basic Terms in SHM**

  - **Mean Position**

    The point at which the restoring force on the particle is zero and potential energy is minimum, is known as its mean position.

  - **Restoring Force**

    The force acting on the particle which tends to bring the particle towards its mean position, is known as restoring force.

    Restoring force always acts in a direction opposite to that of displacement. Displacement is measured from the mean position.

  - **Amplitude**

    The maximum (positive or negative) value of displacement of particle from mean position is defined as amplitude.

  - **Time period (T)**

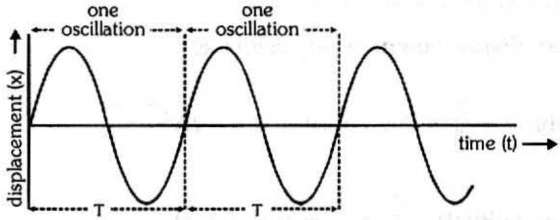
The minimum time after which the particle keeps on repeating its motion is known as time period.

The smallest time taken to complete one oscillation or vibration is also defined as time period.

It is given by $T = \frac{2\pi}{\omega} = \frac{1}{n}$ where ω is angular frequency and n is frequency.

- **One oscillation or One vibration**

When a particle goes on one side from mean position and returns back and then it goes to other side and again returns back to mean position, then this process is known as one oscillation.



- **Frequency (n or f)**

The number of oscillations per second is defined as frequency.

It is given by $n = \frac{1}{T} = \frac{\omega}{2\pi}$

- **Phase**

Phase of a vibrating particle at any instant is the state of the vibrating particle regarding its displacement and direction of vibration at that particular instant.

In the equation $x = A \sin(\omega t + \phi)$, $(\omega t+\phi)$ is the phase of the particle.

The phase angle at time t = 0 is known as initial phase or epoch.

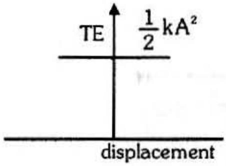
The difference of total phase angles of two particles executing SHM with respect to the mean position is known as phase difference.

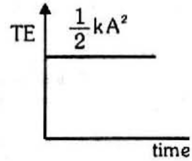
Two vibrating particles are said to be in same phase if the phase difference between them is an even multiple of π, i.e. $\Delta\phi = 2n\pi$ where n = 0, 1, 2, 3,....

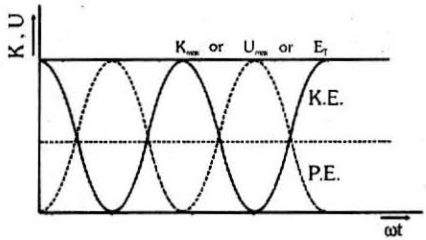
Two vibrating particle are said to be in opposite phase if the phase difference between them is an odd multiple of π i.e., $\Delta\phi = (2n + 1)\pi$ where n = 0, 1, 2, 3,....

- **Angular frequency (ω)** :The rate of change of phase angle of a particle with respect to time is defined as its angular frequency. $\omega = \sqrt{\dfrac{k}{m}}$

- **For linear SHM** ($F \propto -x$) : $F = m\dfrac{d^2x}{dt^2} = -kx = -m\omega^2 x$ where $\omega = \sqrt{\dfrac{k}{m}}$
- **For angular SHM** ($\tau \propto -\theta$) : $\tau = I\dfrac{d^2\theta}{dt^2} = I\alpha = -k\theta = -m\omega^2\theta$ where $\omega = \sqrt{\dfrac{k}{m}}$
- **Displacement** $x = A\sin(\omega t + \phi)$,
- **Angular displacement** $\theta = \theta_0 \sin(\omega t + \phi)$
- **Velocity** $v = \dfrac{dx}{dt} = A\omega\cos(\omega t + \phi) = \omega\sqrt{A^2 - x^2}$
- **Angular velocity** $\dfrac{d\theta}{dt} = \theta_0\,\omega\cos(\omega t + \phi)$
- **Acceleration** $a = \dfrac{d^2x}{dt^2} = -A\omega^2\sin(\omega t + \phi) = -\omega^2 x$
- **Angular acceleration** $\dfrac{d^2\theta}{dt^2} = -\theta_0\omega^2\sin(\omega t + \phi) = -\omega^2\theta$
- **Kinetic energy** $K = \dfrac{1}{2}mv^2 = \dfrac{1}{2}m\omega^2 A^2\cos^2(\omega t + \phi)$
- **Potential energy** $U = \dfrac{1}{2}kx^2 = \dfrac{1}{2}m\omega^2 A^2\sin^2(\omega t + \phi)$
- **Total energy** $E = K + U = \dfrac{1}{2}m\omega^2 A^2 = \text{constant}$







Note :

(i) Total energy of a particle in S.H.M. is same at all instant and at all displacement.

(ii) Total energy depends upon mass, amplitude and frequency of vibration of the particle executing S.H.M.

- **Average energy in SHM**

(i) The time average of P.E. and K.E. over one cycle is

(a) $<K>_t = \frac{1}{4}kA^2$ (b) $<PE>_t = \frac{1}{4}kA^2$ (c) $<TE>_t = \frac{1}{2}kA^2 + U_0$

(ii) The position average of P.E. and K.E. between x = – A to x=A

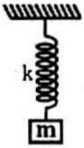
(a) $<K>_x = \frac{1}{3}kA^2$ (b) $<PE>_x = U_0 + \frac{1}{6}kA^2$ (c) $<TE>_x = \frac{1}{2}kA^2 + U_0$

- **Differential equation of SHM**

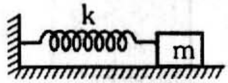
- Linear SHM: $\frac{d^2x}{dt^2} + \omega^2 x = 0$

- Angular SHM: $\frac{d^2\theta}{dt^2} + \omega^2\theta = 0$

- **Spring block system**



$T = 2\pi\sqrt{\frac{m}{k}}$



$T = 2\pi\sqrt{\frac{m}{k}}$

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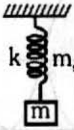
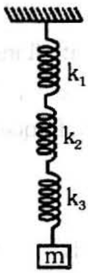
$T = 2\pi\sqrt{\frac{\mu}{k}}$ where μ=reduced mass $= \frac{m_1 m_2}{m_1 + m_2}$

- When spring mass is not negligible :



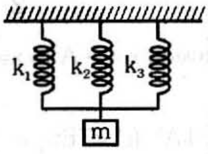
$T = 2\pi\sqrt{\frac{m + \frac{m_s}{3}}{k}}$

- **Series combination of springs**



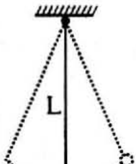
$T = 2\pi\sqrt{\frac{m}{k_{eff}}}$ where $\frac{1}{k_{eff}} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3}$

- **Parallel combination of springs**

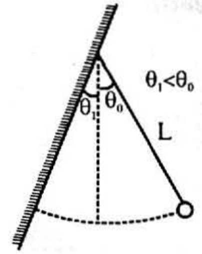


$T = 2\pi\sqrt{\frac{m}{k_{eff}}}$ where $k_{eff} = k_1 + k_2 + k_3$

- **Time period of simple pendulum**



Time period $T = 2\pi\sqrt{\frac{L}{g}}$



Time period $T=\left\{\pi+2\sin^{-1}\left(\frac{\theta_1}{\theta_0}\right)\right\}\sqrt{\frac{L}{g}}$

If length of simple pendulum is comparable to the radius of the earth R, then

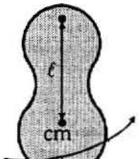
$T=2\pi\sqrt{\frac{1}{g\left(\frac{1}{\ell}+\frac{1}{R}\right)}}$. If $\ell << R$ then $T=2\pi\sqrt{\frac{\ell}{g}}$

If $\ell >> R$ then $T=2\pi\sqrt{\frac{R}{g}} \approx 84$ minutes

- **Second pendulum**

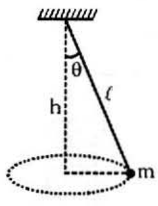
  Time period = 2 seconds, Length ≈ 1 meter (on earth's surface)

- **Time period of Physical pendulum**



$$T=2\pi\sqrt{\frac{I}{mg\ell}}=2\pi\sqrt{\frac{\frac{k^2}{\ell}+\ell}{g}}$$ where $I_{cm}=mk^2$

- **Time period of Conical pendulum**



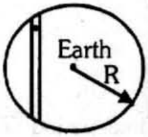
$$T=2\pi\sqrt{\frac{\ell\cos\theta}{g}}=2\pi\sqrt{\frac{h}{g}}$$

- **Time period of Torsional pendulum** $T=2\pi\sqrt{\frac{I}{k}}$

  where k = torsional constant of the wire

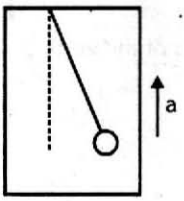
  I=moment of inertia of the body about the vertical axis

- **SHM of a particle in a tunnel inside the earth.**



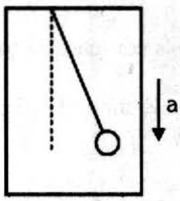
$$T = 2\pi\sqrt{\frac{R}{g}}$$

In accelerating cage



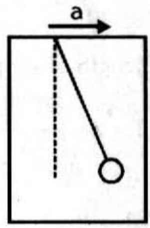
$g_{eff} = g + a$

$$T = 2\pi\sqrt{\frac{\ell}{g+a}}$$



$g_{eff} = g - a$

$$T = 2\pi\sqrt{\frac{\ell}{g-a}}$$



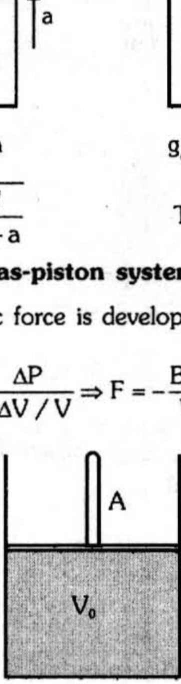
$g_{eff} = \sqrt{g^2 + a^2}$

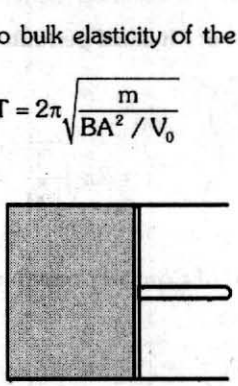
$$T = 2\pi\sqrt{\frac{\ell}{(g^2+a^2)^{1/2}}}$$

- **SHM of gas-piston system**

Here elastic force is developed due to bulk elasticity of the gas

$$B = \frac{\Delta P}{-\Delta V / V} \Rightarrow F = -\frac{BA^2}{V_0}x \Rightarrow T = 2\pi\sqrt{\frac{m}{BA^2/V_0}}$$





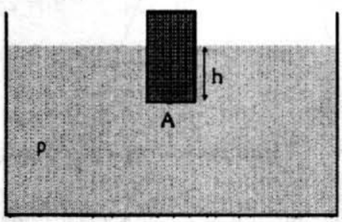
- **SHM of Floating Body**

Restoring force $\rightarrow$ Thurst

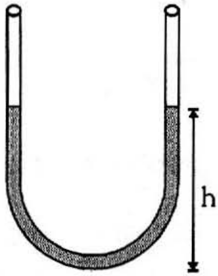
mg $=\rho$Ahg $\rightarrow$ Equilibrium

Restoring force F= $-$ (ρAg)x

$$T = 2\pi\sqrt{\frac{h}{g}}$$



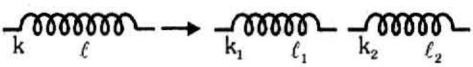
- **SHM in U-tube**



$$T = 2\pi\sqrt{\frac{h}{g}}$$

KEY POINTS

- SHM is the projection of uniform circular motion along one of the diameters of the circle.
- The periodic time of a hard spring is less as compared to that of a soft spring because the spring constant is large for hard spring.
- For a system executing SHM, the mechanical energy remains constant.
- Maximum kinetic energy of a particle in SHM may be greater than mechanical energy as potential energy of a system may be negative.
- The frequency of oscillation of potential energy and kinetic energy is twice as that of displacement or velocity or acceleration of a particle executing S.H.M.
- **Spring cut into two parts :**



Here $\frac{\ell_1}{\ell_2} = \frac{m}{n}$

$$\ell_1 = \left(\frac{m}{m+n}\right)\ell, \quad \ell_2 = \left(\frac{n}{m+n}\right)\ell \qquad \text{But } k\ell = k_1\ell_1 = k_2\ell_2$$

$$\Rightarrow k_1 = \frac{(m+n)}{m}k; \quad k_2 = \frac{(m+n)}{n}k$$

FREE, DAMPED, FORCED OSCILLATIONS AND RESONANCE

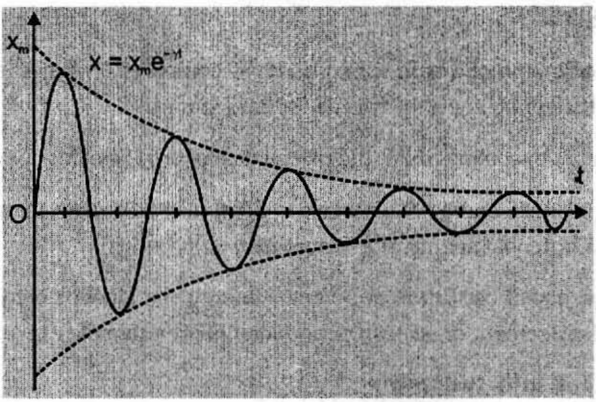
Free oscillation

- The oscillations of a particle with fundamental frequency under the influence of restoring force are defined as free oscillations.

Damped oscillations

- The oscillations of a body whose amplitude goes on decreasing with time are defined as damped oscillations.
- In these oscillations the amplitude of oscillations decreases exponentially due to damping forces like frictional force, viscous force etc.
- If initial amplitude is X_m then amplitude after time t will be $x = x_m e^{-\gamma t}$ where

  γ = Damping coefficient



FORCED OSCILLATIONS

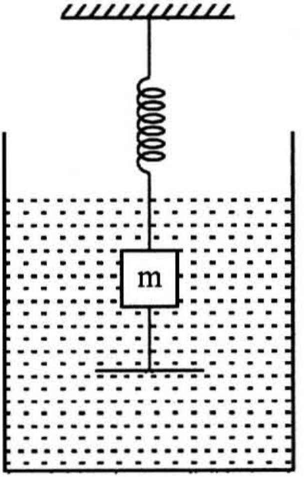
- The oscillations in which a body oscillates under the influence of an external periodic force (driver) are known as forced oscillations.
- The driven body does not oscillate with its natural frequency rather it oscillates with the frequency of the driver.
- The amplitude of oscillator decreases due to damping forces but on account of the energy gained from the external source (driver) it remains constant.

RESONANCE

- When the frequency of external force (driver) is equal to the natural frequency of the oscillator (driven), then this state of the driver and the driven is known as the state of resonance.

- In the state of resonance, there occurs maximum transfer of energy from the driver to the driven. Hence the amplitude of motion becomes maximum.
- In the state of resonance the frequency of the driver (ω) is known as the resonant frequency.

Damped Oscillations :



Damping force $F_d = -bv$

where v = velocity,

b = damping constant

Restoring force on block $F = -kx$

So net force on block

$$F_{net} = -kx - bv$$

$$\Rightarrow \quad ma = -kx - bv$$

$$\Rightarrow \quad \boxed{m\frac{d^2x}{dt^2} + kx + bv = 0}$$

It is the differential equation of damped oscillation.

Solution of this equation is given by

$$\boxed{x = A_0 e^{\left(-\frac{bt}{2m}\right)} \sin(\omega' t + \phi)}$$

where $A(t) = A_0 e^{\left(-\frac{bt}{2m}\right)}$

$$\Rightarrow \quad A(t) = A_0 e^{-\gamma t}$$

so $\boxed{\gamma = \frac{b}{2m}}$ and $\omega' = \sqrt{\frac{k}{m} - \frac{b^2}{4m^2}}$

Energy in damped oscillation

$$E(t) = \frac{1}{2}kA^2(t) = \frac{1}{2}k\left[A_0 e^{-\frac{bt}{2m}}\right]^2$$

$$\Rightarrow \quad E(t) = \frac{1}{2}kA_0^2 e^{(-bt/m)} \Rightarrow \boxed{E(t) = E_0 e^{(-bt/m)}}$$

Important Notes

14 Wave Motion and Doppler's Effect

A wave is a disturbance that propagates in space, transports energy and momentum from one point to another without the transport of matter.

CLASSIFICATION OF WAVES

Medium Necessity
- → Mechanical (Elastic) waves
- → Non-mechanical waves (EM waves)

Propagation of energy
- → Progressive waves
- → Stationary (standing) waves

Vibration of medium particle
- → Transverse waves
- → Longitudinal waves

Dimension
- → 1-D (Waves on strings)
- → 2-D (Surface waves or ripples on water)
- → 3-D (Sound or light waves)

- A mechanical wave will be transverse or longitudinal depending on the nature of medium and mode of excitation.
- In strings, mechanical waves are always transverse.
- In gases and liquids, mechanical waves are always longitudinal because fluids cannot sustain shear.
- Partially transverse waves are possible on a liquid surface because surface tension provide some rigidity on a liquid surface. These waves are called as ripples as they are combination of transverse & longitudinal.
- In solids mechanical waves (may be sound) can be either transverse or longitudinal depending on the mode of excitation.
- In longitudinal wave motion, oscillatory motion of the medium particles produce regions of compression (high pressure) and rarefaction (low pressure).

Plane Progressive Waves

- Wave equation : $y = A\sin(\omega t - kx)$ where $k = \frac{2\pi}{\lambda}$ = wave propagation constant
- Differential equation : $\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$

Wave velocity (phase velocity) $\boxed{v = \frac{dx}{dt} = \frac{\omega}{k}}$ $\because \omega t - kx = \text{constant} \Rightarrow \frac{dx}{dt} = \frac{\omega}{k}$

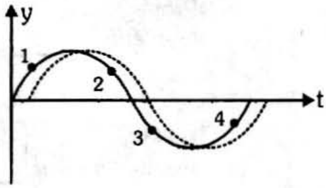
- Particle velocity $v_p = \frac{dy}{dt} = A\omega\cos(\omega t - kx)$ $\boxed{v_p = -v \times \text{slope} = -v\left(\frac{dy}{dx}\right)}$
- Particle acceleration : $a_p = \frac{\partial^2 y}{\partial t^2} = -\omega^2 A\sin(\omega t - kx) = -\omega^2 y$

For particle 1 : $v_p \downarrow$ and $a_p \downarrow$

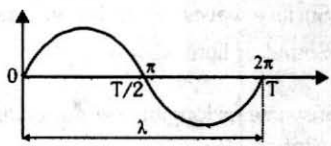
For particle 2 : $v_p \uparrow$ and $a_p \downarrow$

For particle 3 : $v_p \uparrow$ and $a_p \uparrow$

For particle 4 : $v_p \downarrow$ and $a_p \uparrow$



- Relation between phase difference, path difference & time difference



$$\boxed{\frac{\Delta\phi}{2\pi} = \frac{\Delta\lambda}{\lambda} = \frac{\Delta T}{T}}$$

Energy in Wave Motion

- $\frac{KE}{\text{volume}} = \frac{1}{2}\left(\frac{\Delta m}{\text{volume}}\right)v_p^2 = \frac{1}{2}\rho v_p^2 = \frac{1}{2}\rho\omega^2 A^2\cos^2(\omega t - kx)$
- $\frac{PE}{\text{volume}} = \frac{1}{2}\rho v^2\left(\frac{dy}{dx}\right)^2 = \frac{1}{2}\rho\omega^2 A^2\cos^2(\omega t - kx)$
- $\frac{TE}{\text{volume}} = \rho\omega^2 A^2\cos^2(\omega t - kx)$
- Pressure energy density [i.e. Average total energy / volume] $\boxed{u = \frac{1}{2}\rho\omega^2 A^2}$
- **Power :** P = (energy density) (volume/ time) $P = \left(\frac{1}{2}\rho\omega^2 A^2\right)(Sv)$

[where S = Area of cross-section]

- **Intensity :** $I = \dfrac{\text{Power}}{\text{area of cross-section}} = \dfrac{1}{2}\rho\omega^2A^2v$

- **Speed of transverse wave on string :**

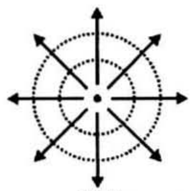
$v = \sqrt{\dfrac{T}{\mu}}$ where μ = mass/length and T = tension in the string.

KEY POINTS

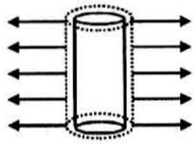
- A wave can be represented by function $y = f(kx \pm \omega t)$ because it satisfy the differential equation $\dfrac{\partial^2 y}{\partial x^2} = \dfrac{1}{v^2}\left(\dfrac{\partial^2 y}{\partial t^2}\right)$ where $v = \dfrac{\omega}{k}$.
- A pulse whose wave function is given by $y=4 / [(2x+5t)^2+2]$ propagates in −x direction as this wave function is of the form $y=f(kx + \omega t)$ which represent a wave travelling in −x direction.
- Longitudinal waves can be produced in solids, liquids and gases because bulk modulus of elasticity is present in all three.

WAVE FRONT

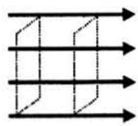
- Spherical wave front (source →point source)



- Cylindrical wave front (source →linear source)



- Plane wave front (source → point / linear source at very large distance)



INTENSITY OF WAVE

- Due to point source $I \propto \dfrac{1}{r^2}$ $\qquad y(r,t) = \dfrac{A}{r}\sin\left(\omega t - \vec{k}\cdot\vec{r}\right)$
- Due to cylindrical source $I \propto \dfrac{1}{r}$ $\qquad y(r,t) = \dfrac{A}{\sqrt{r}}\sin\left(\omega t - \vec{k}\cdot\vec{r}\right)$
- Due to plane source I = constant $\qquad y(r,t) = A\sin\left(\omega t - \vec{k}\cdot\vec{r}\right)$

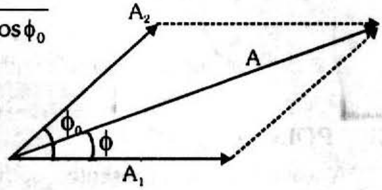
INTERFERENCE OF WAVES

$y_1 = A_1\sin(\omega t - kx)$, $y_2 = A_2\sin(\omega t - kx + \phi_0)$

$y = y_1 + y_2 = A\sin(\omega t - kx + \phi)$

where $A = \sqrt{A_1^2 + A_2^2 + 2A_1A_2\cos\phi_0}$

and $\tan\phi = \dfrac{A_2\sin\phi_0}{A_1 + A_2\cos\phi_0}$



As $I \propto A^2$

So $\boxed{I = I_1 + I_2 + 2\sqrt{I_1I_2}\cos\phi_0}$

- For constructive interference [Maximum intensity]

  $\phi_0 = 2n\pi$ or path difference $= n\lambda$ where $n = 0, 1, 2, 3, ...$

  $$\boxed{I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2}$$

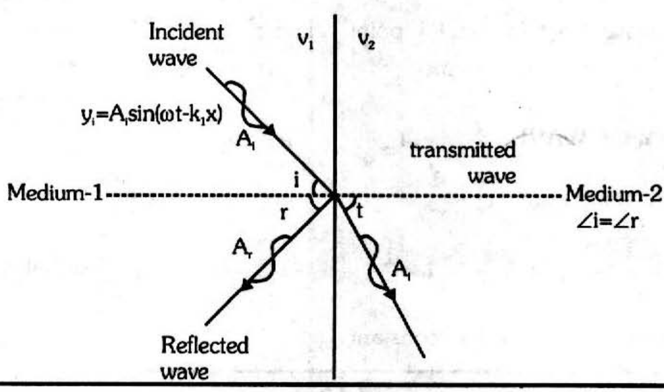
- For destructive interference [Minimum Intensity]

  $\phi_0 = (2n+1)\pi$ or path difference $= (2n+1)\dfrac{\lambda}{2}$

  where $n = 0, 1, 2, 3, ...$ $\boxed{I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2}$

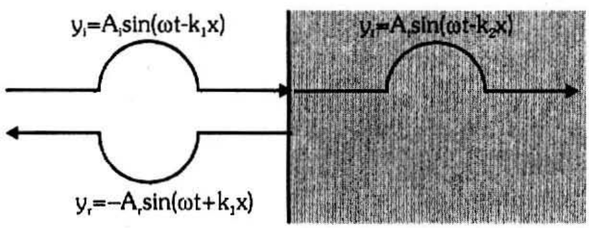
- Degree of hearing $= \dfrac{I_{max} - I_{min}}{I_{max} + I_{min}} \times 100$

Reflection and Refraction (transmission) of waves

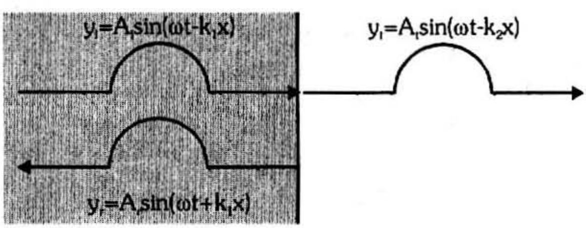


- The frequency of the wave remain unchanged.
- Amplitude of reflected wave→ $A_r = \left(\frac{v_2 - v_1}{v_1 + v_2}\right) A_i$
- Amplitude of transmitted wave → $A_t = \left(\frac{2v_2}{v_1 + v_2}\right) A_i$
- If $v_2 > v_1$ i.e. medium-2 is rarer
  $A_r > 0 \Rightarrow$ no phase change in reflected wave
- If $v_2 < v_1$ i.e. medium-1 is rarer
  $A_r < 0 \Rightarrow$ There is a phase change of π in reflected wave
- As A_t is always positive whatever be v_1 & v_2 the phase of transmitted wave always remains unchanged.
- In case of reflection from a denser medium or rigid support or fixed end, there is inversion of reflected wave i.e. phase difference of π between reflected and incident wave.
- the transmitted wave is never inverted.

Rarer **Denser**

- 

Denser **Rarer**

- 

Beats :

When two sound waves of nearly equal (but not exactly equal) frequencies travel in same direction, at a given point due to their super position, intensity alternatively increases and decreases periodically. This periodic waxing and waning of sound at a given position is called beats.

Beat frequency = difference of frequencies of two interfering waves

Stationary waves or standing waves : When two waves of same frequency and amplitude travel in opposite direction at same speed, their superstition gives rise to a new type of wave, called stationary waves or standing waves. Formation of standing wave is possible only in bounded medium.

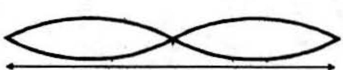
- Let two waves are $y_1 = A\sin(\omega t - kx)$; $y_2 = A\sin(\omega t + kx)$ by principle of superposition $y = y_1 + y_2 = 2A\cos kx \sin\omega t$ ← Equation of stationary wave
- As this equation satisfies the wave equation $\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$, it represent a wave.
- Its amplitude is not constant but varies periodically with position.
- **Nodes** → amplitude is minimum : $\cos kx = 0 \Rightarrow x = \frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, ...$
- **Antinodes** → amplitude is maximum : $\cos kx = 1 \Rightarrow x = 0, \frac{\lambda}{2}, \lambda, \frac{3\lambda}{2}, ...$
- The nodes divide the medium into segments (loops). All the particles in a segment vibrate in same phase but in opposite phase with the particles in the adjacent segment.
- As nodes are permanently at rest, so no energy can be transmitted across them, i.e. energy of one region (segment) is confined in that region.

Transverse stationary waves in stretched string

- [Fixed at both ends] [fixed end →Node & free end→Antinode]

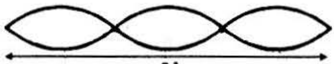
$\ell = \frac{\lambda}{2}$

Fundamental or first harmonic $f = \frac{v}{2\ell}$



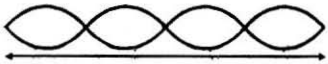
$\ell = \lambda$

second harmonic first overtone $f = \frac{2v}{2\ell}$



$\ell = \frac{3\lambda}{2}$

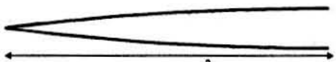
third harmonic
second overtone $f = \frac{3v}{2\ell}$



$\ell = 2\lambda$

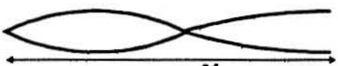
fourth harmonic
third overtone $f = \frac{4v}{2\ell}$

- **Fixed at one end**



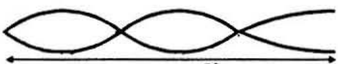
$\ell = \frac{\lambda}{4}$

Fundamental $f = \frac{v}{4\ell}$



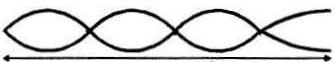
$\ell = \frac{3\lambda}{4}$

third harmonic
first overtone $f = \frac{3v}{4\ell}$



$\ell = \frac{5\lambda}{4}$

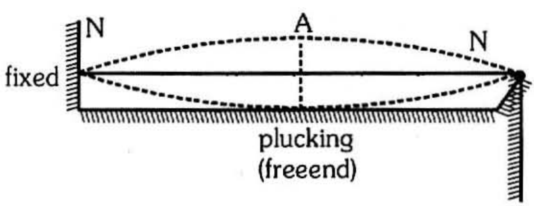
fifth harmonic
second overtone $f = \frac{5v}{4\ell}$



$\ell = \frac{7\lambda}{4}$

seventh harmonic
third overtone $f = \frac{7v}{4\ell}$

Sonometer



$$f_n = \frac{p}{2\ell}\sqrt{\frac{T}{\mu}}$$

[p : number of loops]

Sound Waves

Velocity of sound in a medium of elasticity E and density ρ is

$$v=\sqrt{\frac{E}{\rho}}$$

Solids (Young's Modulus) $\quad v=\sqrt{\frac{Y}{\rho}}$

Fluids (Bulk Modulus) $\quad v=\sqrt{\frac{B}{\rho}}$

- **Newton's formula** : Sound propagation is isothermal $B = P \Rightarrow v = \sqrt{\frac{P}{\rho}}$
- **Laplace correction** : Sound propagation is adiabatic $B = \gamma P \Rightarrow v = \sqrt{\frac{\gamma P}{\rho}}$

KEY POINTS

- With rise in temperature, velocity of sound in a gas increases as $v = \sqrt{\frac{\gamma RT}{M_w}}$
- With rise in humidity velocity of sound increases due to presence of water in air.
- Pressure has no effect on velocity of sound in a gas as long as temperature remains constant.

Displacement and pressure wave

A sound wave can be described either in terms of the longitudinal displacement suffered by the particles of the medium (called displacement wave) or in terms of the excess pressure generated due to compression and rarefaction (called pressure wave).

Displacement wave $\quad y=A\sin(\omega t-kx)$

Pressure wave $\quad p = p_0\cos(\omega t-kx)$

where $\quad p_0 = ABk = \rho A v\omega$

Note : As sound-sensors (e.g., ear or mike) detect pressure changes, description of sound as pressure wave is preferred over displacement wave.

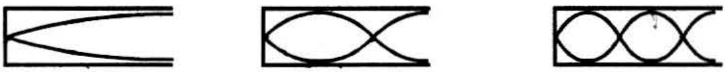
KEYPOINTS

- The pressure wave is 90° out of phase w.r.t. displacement wave, i.e. displacement will be maximum when pressure is minimum and vice-versa.
- Intensity in terms of pressure amplitude $I = \frac{p_0^2}{2\rho v}$

Vibrations of organ pipes

Stationary longitudinal waves closed end → displacement node, open end→ displacement antinode

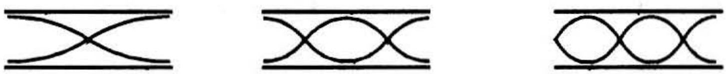
- **Closed end organ pipe**



$\ell = \frac{\lambda}{4} \Rightarrow f = \frac{v}{4\ell}$ $\qquad$ $\ell = \frac{3\lambda}{4} \Rightarrow f = \frac{3v}{4\ell}$ $\qquad$ $\ell = \frac{5\lambda}{4} \Rightarrow f = \frac{5v}{4\ell}$

- Only odd harmonics are present
- Maximum possible wavelength = 4ℓ
- Frequency of m^{th} overtone $= (2m+1)\frac{v}{4\ell}$

- **Open end organ pipe**



$\ell = \frac{\lambda}{2} \Rightarrow f = \frac{v}{2\ell}$ $\qquad$ $\ell = \lambda \Rightarrow f = \frac{2v}{2\ell}$ $\qquad$ $\ell = \frac{3\lambda}{2} \Rightarrow f = \frac{3v}{2\ell}$

- All harmonics are present
- Maximum possible wavelength is 2ℓ.
- Frequency of m^{th} overtone $= (m+1)\frac{v}{2\ell}$

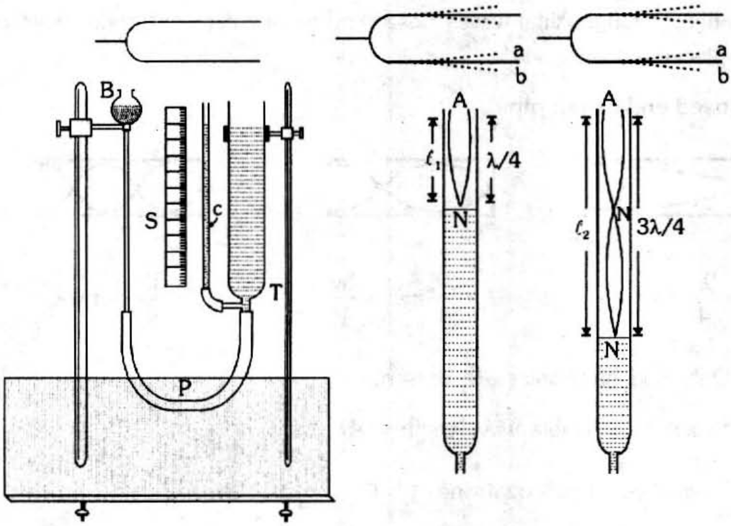
- **End correction** :

Due to finite momentum of air molecules in organ pipes reflection takes place not exactly at open end but some what above it, so antinode is not formed exactly at free end but slightly above it.

In closed organ pipe $f_1 = \frac{v}{4(\ell + e)}$ where e = 0.6 R (R=radius of pipe)

In open organ pipe $f_1 = \frac{v}{2(\ell + 2e)}$

- **Resonance Tube**



Wavelength $\lambda=2(\ell_2-\ell_1)$ End correction $e=\dfrac{\ell_2-3\ell_1}{2}$

Intensity of sound in decibels

Sound level, $SL = 10\log_{10}\left(\dfrac{I}{I_0}\right)$

Where I_0 = threshold of human ear = 10^{-12} W/m^2

Characteristics of sound

- Loudness → Sensation received by the ear due to intensity of sound.
- Pitch → Sensation received by the ear due to frequency of sound.
- Quality (or Timbre)→ Sensation received by the ear due to waveform of sound.

Doppler's effect in sound :

A stationary source emits wave fronts that propagate with constant velocity with constant separation between them and a stationary observer encounters them at regular constant intervals at which they were emitted by the source.

A moving observer will encounter more or lesser number of wavefronts depending on whether he is approaching or receding the source.

A source in motion will emit different wave front at different places and therefore alter wavelength i.e. separation between the wavefronts.

The apparent change in frequency or pitch due to relative motion of source and observer along the line of sight is called Doppler Effect.

Observed frequency $n' = \dfrac{\text{speed of sound wave w.r.t. observer}}{\text{observed wavelength}}$

$$n' = \frac{v + v_0}{\left(\dfrac{v - v_s}{n}\right)} = \left(\frac{v + v_0}{v - v_s}\right)n$$

If v_0, v_s <<<v then $n' \approx \left(1 + \dfrac{v + v_s}{v}\right)n$

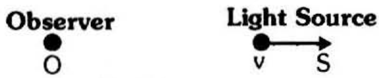
- Mach Number$=\dfrac{\text{speed of source}}{\text{speed of sound}}$

- **Doppler's effect in light :**

Case I :

$$\left.\begin{aligned} &\text{Frequency} \quad \nu' = \left(\sqrt{\frac{1+\frac{v}{c}}{1-\frac{v}{c}}}\right)\nu \approx \left(1+\frac{v}{c}\right)\nu \\ &\text{Wavelength} \quad \lambda' = \left(\sqrt{\frac{1-\frac{v}{c}}{1+\frac{v}{c}}}\right)\lambda \approx \left(1-\frac{v}{c}\right)\lambda \end{aligned}\right\}\text{Violet Shift}$$

Case II :



$$\left.\begin{aligned} &\text{Frequency} \quad \nu' = \left(\sqrt{\frac{1-\frac{v}{c}}{1+\frac{v}{c}}}\right)\nu \approx \left(1-\frac{v}{c}\right)\nu \\ &\text{Wavelength} \quad \lambda' = \left(\sqrt{\frac{1+\frac{v}{c}}{1-\frac{v}{c}}}\right)\lambda \approx \left(1+\frac{v}{c}\right)\lambda \end{aligned}\right\}\text{Red Shift}$$

Important Notes

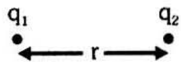
15 Electrostatics

Electric Charge

Charge of a material body is that property due to which it interacts with other charges. There are two kinds of charges- positive and negative. S.I. unit is coulomb. Charge is quantized, conserved, and additive.

Coulomb's law :

Force between two charges $\vec{F} = \dfrac{1}{4\pi \epsilon_0 \epsilon_r} \dfrac{q_1 q_2}{r^2} \hat{r}$ $\quad \epsilon_r$ = dielectric constant



NOTE :The Law is applicable only for static and point charges. Moving charges may result in magnetic interaction. And if charges are extended, induction may change the charge distribution.

Principle Of Superposition

Force on a point charge due to many charges is given by

$$\vec{F} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + ...$$

NOTE : The force due to one charge is not affected by the presence of other charges.

Electric Field or Electric Field Intensity or Electric Field Strength (Vector Quantity)

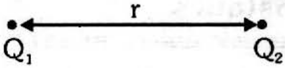
In the surrounding region of a charge there exist a physical property due to which other charge experiences a force. The direction of electric field is direction of force experienced by a positively charged particle and the magnitude of the field (electric field intensity) is the force experienced by a unit charge.

$$\vec{E} = \frac{\vec{F}}{q} \text{ unit is N/C or V/m.}$$

- **Electric field intensity due to charge Q**

$$\vec{E} = \lim_{q_0 \to 0} \frac{\vec{F}}{q_0} = \frac{1}{4\pi \epsilon_0} \frac{Q}{r^2} \hat{r}$$

Null point for two charges :



If $|Q_1| > |Q_2|$

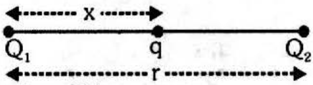
$\Rightarrow$ Null point near Q_2

$$x = \frac{\sqrt{Q_1}\,r}{\sqrt{Q_1} \pm \sqrt{Q_2}}$$ $x \rightarrow$ distance of null point from Q_1 charge

(+) for like charges

(–) for unlike charges

☐ Equilibrium of three point charges

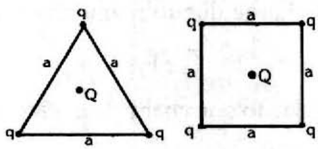


(i) Two charges must be of like nature.

(ii) Third charge should be of unlike nature.

$$x = \frac{\sqrt{Q_1}}{\sqrt{Q_1} + \sqrt{Q_2}}\,r \quad \text{and} \quad q = \frac{-Q_1Q_2}{(\sqrt{Q_1} + \sqrt{Q_2})^2}$$

☐ Equilibrium of symmetric geometrical point charged system

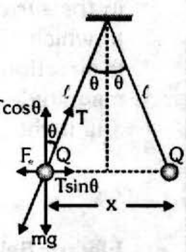


Value of Q at centre for which system to be in state of equilibrium

(i) For equilateral triangle $Q = \frac{-q}{\sqrt{3}}$ (ii) For square $Q = \frac{-q(2\sqrt{2}+1)}{4}$

☐ Equilibrium of suspended point charge system

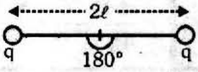
For equilibrium position



$$T\cos\theta = mg \;\&\; T\sin\theta = F_e = \frac{kQ^2}{x^2} \Rightarrow \tan\theta = \frac{F_e}{mg} = \frac{kQ^2}{x^2 mg}$$

$$T = \sqrt{(F_e)^2 + (mg)^2}$$

- If whole set up is taken into an artificial satellite ($g_{eff} \simeq 0$)



$$T = F_e = \frac{kq^2}{4\ell^2}$$

- **Electric potential difference** $\Delta V = \dfrac{\text{work}}{\text{charge}} = W/q$

- **Electric potential** $V_P = -\int_{\infty}^{P} \vec{E}.\vec{dr}$

  It is the work done against the field to take a unit positive charge from infinity (reference point) to the given point

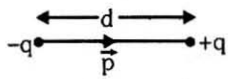
  - For point charge : $V = K\dfrac{q}{r}$
  - For several point charges : $V = K\sum \dfrac{q_i}{r_i}$

- **Relation between $\vec{E}$ & V**

  $\vec{E} = -\text{grad } V = -\nabla V$, $E = -\dfrac{\partial V}{\partial r}$; $\vec{E} = -\dfrac{\partial V}{\partial x}\hat{i} - \dfrac{\partial V}{\partial y}\hat{j} - \dfrac{\partial V}{\partial z}\hat{k}$, $V = \int -\vec{E}.\vec{dr}$

- **Electric potential energy of two charges :** $U = \dfrac{1}{4\pi\epsilon_0}\dfrac{q_1q_2}{r}$

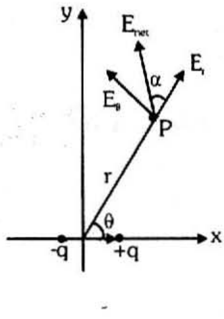
- **Electric dipole**



  - Electric dipole moment $p = qd$
  - Torque on dipole placed in uniform electric field $\vec{\tau} = \vec{p} \times \vec{E}$
  - Work done in rotating dipole placed in uniform electric field

    $$W = \int \tau d\theta = \int_{\theta_0}^{\theta} PE\sin\theta d\theta = pE(\cos\theta_0 - \cos\theta)$$

  - Potential energy of dipole placed in an uniform field $U = -\vec{p}.\vec{E}$
  - At a point which is at a distance r from dipole midpoint and making angle θ with dipole axis.



    - Potential $V = \dfrac{1}{4\pi\epsilon_0}\dfrac{p\cos\theta}{r^2}$
    - Electric field $E = \dfrac{1}{4\pi\epsilon_0}\dfrac{p\sqrt{1+3\cos^2\theta}}{r^3}$
    - Direction $\tan\alpha = \dfrac{E_\theta}{E_r} = \dfrac{1}{2}\tan\theta$

  - Electric field at axial point (or End-on) $\vec{E} = \dfrac{1}{4\pi\epsilon_0}\dfrac{2\vec{p}}{r^3}$ of dipole
  - Electric field at equatorial position (Broad-on) of dipole $\vec{E} = \dfrac{1}{4\pi\epsilon_0}\dfrac{(-\vec{p})}{r^3}$

Equipotential Surface And Equipotential Region

In an electric field the locus of points of equal potential is called an equipotential surface. An equipotential surface and the electric field line meet at right angles. The region where E = 0, Potential of the whole region must remain constant as no work is done in displacement of charge in it. It is called as equipotential region like conducting bodies.

Mutual Potential Energy Or Interaction Energy

"The work to be done to integrate the charge system".

For 2 particle system $U_{mutual} = \dfrac{q_1q_2}{4\pi\varepsilon_0 r}$

For 3 particle system $U_{mutual} = \dfrac{q_1q_2}{4\pi\varepsilon_0 r_{12}} + \dfrac{q_2q_3}{4\pi\varepsilon_0 r_{23}} + \dfrac{q_3q_1}{4\pi\varepsilon_0 r_{31}}$

For n particles there will be $\dfrac{n(n-1)}{2}$ terms .

Total energy of a system = $U_{self} + U_{mutual}$

Electric flux : $\phi = \int \vec{E}.d\vec{s}$

(i) For uniform electric field; $\phi = \vec{E}.\vec{A} = EA\cos\theta$ where θ = angle between $\vec{E}$ & area vector $(\vec{A})$. Flux is contributed only due to the component of electric field which is perpendicular to the plane.

(ii) If $\vec{E}$ is not uniform throughout the area A , then $\phi = \int \vec{E}.d\vec{A}$

Gauss's Law : $\oint \vec{E}.d\vec{s} = \dfrac{\sum q}{\epsilon_0}$ (Applicable only to closed surface)

Net flux emerging out of a closed surface is $\dfrac{q_{en}}{\varepsilon_0}$.

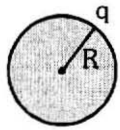
$\phi = \oint \vec{E}\cdot d\vec{A} = \dfrac{q_{en}}{\varepsilon_0}$ where q_{en}= net charge enclosed by the closed surface .

ϕ does not depend on the

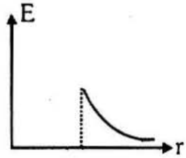
(i) Shape and size of the closed surface

(ii) The charges located outside the closed surface.

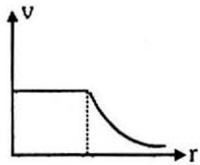
- **For a conducting sphere**



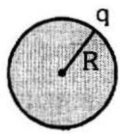
☐ For $r \geq R : E = \frac{1}{4\pi \epsilon_0}\frac{q}{r^2}, V = \frac{1}{4\pi \epsilon_0}\frac{q}{r}$



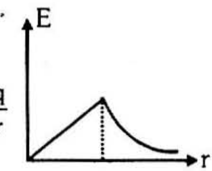
☐ For $r < R: E = 0, V = \frac{1}{4\pi \epsilon_0}\frac{q}{R}$



- **For a non-conducting sphere**

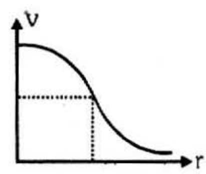


☐ For $r \geq R : E = \frac{1}{4\pi \epsilon_0}\frac{q}{r^2}, V = \frac{1}{4\pi \epsilon_0}\frac{q}{r}$

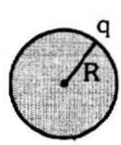


☐ For $r < R : E = \frac{1}{4\pi \epsilon_0}\frac{qr}{R^3}, \; V = \frac{1}{4\pi \epsilon_0}\frac{q(3R^2 - r^2)}{2R^3}$

$$V_C = V_{max} = \frac{3}{2}\frac{Kq}{R} = 1.5V_{Surface}$$



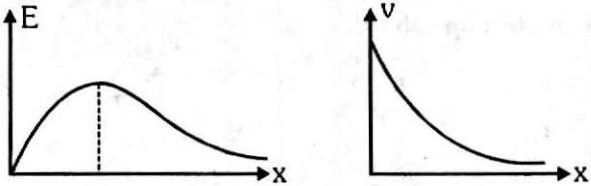
- **For a conducting/non conducting spherical shell**

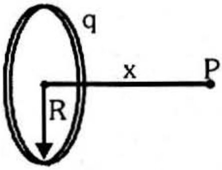


☐ For $r \geq R : E = \frac{1}{4\pi \epsilon_0}\frac{q}{r^2}, V = \frac{1}{4\pi \epsilon_0}\frac{q}{r}$

☐ For $r < R : E = 0, V = \frac{1}{4\pi \epsilon_0}\frac{q}{R}$

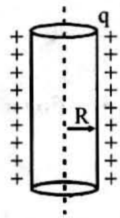
- **For a charged circular ring**





$$E_P = \frac{1}{4\pi \epsilon_0} \frac{qx}{(x^2 + R^2)^{3/2}}, \; V_P = \frac{1}{4\pi \epsilon_0} \frac{q}{(x^2 + R^2)^{1/2}}$$

Electric field will be maximum at $x = \pm \frac{R}{\sqrt{2}}$



- **For a charged long conducting cylinder**

  ❒ For $r \geq R : E = \frac{q}{2\pi \epsilon_0 r}$

  ❒ For $r < R : E = 0$

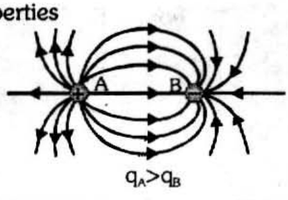
- **Electric field intensity at a point near a charged conductor** $E = \frac{\sigma}{\epsilon_0}$
- **Mechanical pressure on a charged conductor**

  $P = \frac{\sigma^2}{2 \epsilon_0}$

- **For non-conducting long sheet of surface charge density σ** $E = \frac{\sigma}{2 \epsilon_0}$
- **For conducting long sheet of surface charge density** $E = \frac{\sigma}{\epsilon_0}$
- **Energy density in electric field** $u_E = \frac{1}{2} \epsilon_0 E^2$

Electric lines of force

Electric lines of electrostatic field have following properties



(i) Imaginary

(ii) Can never cross each other

(iii) Can never be closed loops

(iv) The number of lines originating or terminating on a charge is proportional to the magnitude of charge. In rationalised MKS system $(1/\varepsilon_0)$ electric lines are associated with unit charge, so if a body encloses a charge q , total lines of force associated with it (called flux) will be q/ε_o.

(v) Lines of force ends or starts normally at the surface of a conductor.

(vi) If there is no electric field there will be no lines of force.

(vii) Lines of force per unit area normal to the area at a point represents magnitude of intensity , crowded lines represent strong field while distant lines weak field.

(viii) Tangent to the line of force at a point in an electric field gives the direction of intensity.

KEY POINTS

- Electric field is always perpendicular to a conducting surface (or any equipotential surface).

  No tangential component of electric field on such surfaces.

- When a conductor is charged, the charge resides only on the surface.
- Charge density at convex sharp points on a conductor is greater. Lesser is radius of curvature at a convex part, greater is the charge density.
- For a conductor of any shape E (just outside)= $\dfrac{\sigma}{\varepsilon_o}$
- Potential difference between two points in an electric field does not depend on the path between them.
- Potential at a point due to positive charge is positive & due to negative charge is negative.
- Positive charge flows from higher to lower (i.e. in the direction of electric field) potential and negative charge from lower to higher (i.e. opposite to the electric field) potential.
- When $\vec{p} \parallel \vec{E}$ the dipole is in stable equilibrium
- When $\vec{p} \parallel (-\vec{E})$ the dipole is in unstable equilibrium

- When a charged isolated conducting sphere is connected to an uncharged small conducting sphere then potential become same on both sphere and redistribution of charge take place.
- Self potential energy of a charged conducting spherical shell $= \frac{KQ^2}{2R}$.
- Self potential energy of an insulating uniformly charged sphere= $\frac{3KQ^2}{5R}$
- A spherically symmetric charge {i.e ρ depends only on r} behaves as if its charge is concentrated at its centre (for outside points).
- **Dielectric strength of material :** The minimum electric field required to ionize the medium or the maximum electric field which the medium can bear without breaking down.
- The particles such as photon or neutrino which have no (rest) mass can never has a charge because charge cannot exist without mass.
- Electric charge is invariant because value of electric charge does not depend on frame of reference.
- A spherical body behaves like a point charge for outside points because a finite charged body may behave like a point charge if it produces an inverse square field.
- Any arbitrary displacement of charges inside a shell does not introduce any change in the electrostatic field of the outer space because a closed conducting shell divides the entire space into the inner and outer parts which are completely independent of one another in respect of electric fields.
- A charged particle is free to move in an electric field. It may or may not move along an electric line of force because initial conditions affect the motion of charged particle.
- Electrostatic experiments do not work well in humid days because water is a good conductor of electricity.
- A metallic shield in form of a hollow conducting shell may be built to block an electric field because in a hollow conducting shell, the electric field is zero at every point.

16 Capacitance and Capacitor

CAPACITOR & CAPACITANCE

A capacitor consists of two conductors carrying charges of equal magnitude and opposite sign. The capacitance C of any capacitor is the ratio of the charge Q on either conductor to the potential difference V between them $C = \frac{Q}{V}$

The capacitance depends only on the geometry of the conductors and not on an external source of charge or potential difference.

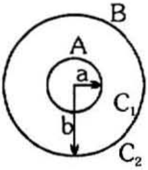
Capacitance Of An Isolated Spherical Conductor

$C = 4\pi \epsilon_0 \epsilon_r R$ in a medium $C = 4\pi \epsilon_0 R$ in air

* This sphere is at infinite distance from all the conductors .

Spherical Capacitor :

It consists of two concentric spherical shells as shown in figure. Here capacitance of region between the two shells is C_1 and that outside the shell is C_2. We have



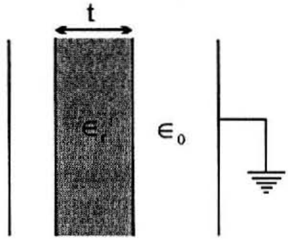
$C_1 = \frac{4\pi \epsilon_0 ab}{b-a}$ and $C_2 = 4\pi \epsilon_0 b$

PARALLEL PLATE CAPACITOR :

(i) Uniform Di-electric Medium :If two parallel plates each of area A & separated by a distance d are charged with equal & opposite charge Q, then the system is called a parallel plate capacitor & its capacitance is given by, $C = \frac{\epsilon_0 \epsilon_r A}{d}$ in a medium; $C = \frac{\epsilon_0 A}{d}$ with air as medium

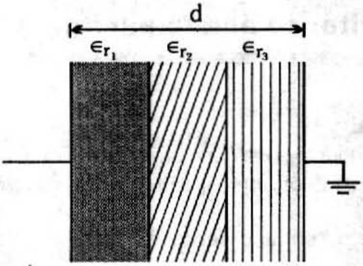
This result is only valid when the electric field between plates of capacitor is constant.

(ii) Medium Partly Air : $C = \dfrac{\epsilon_0 A}{d - \left(t - \frac{t}{\epsilon_r}\right)}$



When a di-electric slab of thickness t & relative permittivity ϵ_r is introduced between the plates of an air capacitor, then the distance between the plates is effectively reduced by $\left(t - \frac{t}{\epsilon_r}\right)$ irrespective of the position of the di-electric slab .

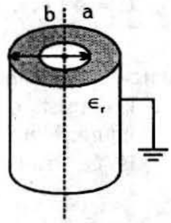
(iii) COMPOSITE MEDIUM :



$$C=\frac{\epsilon_0 A}{\frac{t_1}{\epsilon_{r_1}}+\frac{t_2}{\epsilon_{r_2}}+\frac{t_3}{\epsilon_{r_3}}}$$

CYLINDRICAL CAPACITOR :

It consists of two co-axial cylinders of radii a & b, the outer conductor is earthed. The di-electric constant of the medium filled in the space between the cylinders is ϵ_r.

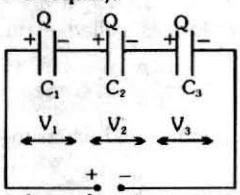


The capacitance per unit length is $C=\frac{2\pi\epsilon_0\epsilon_r}{\ell n\left(\frac{b}{a}\right)}$

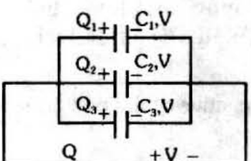
COMBINATION OF CAPACITORS :

(i) CAPACITORS IN SERIES :In this arrangement all the capacitors when uncharged get the same charge Q but the potential difference across each will differ (if the capacitance are unequal).

$$\frac{1}{C_{eq.}}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+.....+\frac{1}{C_n}$$



(ii) CAPACITORS IN PARALLEL : When one plate of each capacitor is connected to the positive terminal of the battery & the other plate of each capacitor is connected to the negative terminals of the battery, then the capacitors are said to be in parallel connection. The capacitors have the same potential difference, V but the charge on each one is different (if the capacitors are unequal). $C_{eq.}=C_1+C_2+C_3+......+C_n$.



ENERGY STORED IN A CHARGED CAPACITOR :

Capacitance C, charge Q & potential difference V; then energy stored is

$$U = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C}$$

This energy is stored in the electrostatic field set up in the di-electric medium between the conducting plates of the capacitor .

HEAT PRODUCED IN SWITCHING IN CAPACITIVE CIRCUIT :

Due to charge flow always some amount of heat is produced when a switch is closed in a circuit which can be obtained by energy conservation as –

Heat = Work done by battery – Energy absorbed by capacitor.

- **Work done by battary to charge a capacitor** $W = CV^2 = QV = \frac{Q^2}{C}$

SHARING OF CHARGES :

When two charged conductors of capacitance C_1 & C_2 at potential V_1 & V_2 respectively are connected by a conducting wire, the charge flows from higher potential conductor to lower potential conductor, until the potential of the two condensers becomes equal. The common potential (V) after sharing of charges;

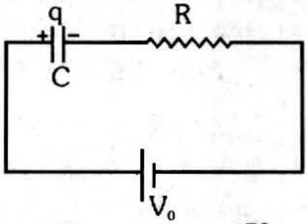
$$V = \frac{\text{net charge}}{\text{net capacitance}} = \frac{q_1 + q_2}{C_1 + C_2} = \frac{C_1V_1 + C_2V_2}{C_1 + C_2}.$$

charges after sharing $q_1 = C_1V$ & $q_2 = C_2V$. In this process energy is lost in the connecting wire as heat.

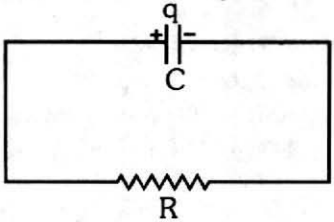
This loss of energy is $U_{initial} - U_{final} = \frac{C_1C_2}{2(C_1 + C_2)}(V_1 - V_2)^2$.

- **Attractive force between capacitor plate** $F = \left(\frac{\sigma}{2\epsilon_0}\right)(\sigma A) = \frac{Q^2}{2\epsilon_0 A}$

- **Charging of a capacitor** : $q = q_0(1 - e^{-t/RC})$ where $q_0 = CV_0$



- **Discharging of a capacitor :** $q = q_0e^{-t/RC}$



KEY POINTS

- The energy of a charged conductor resides outside the conductor in its electric field, where as in a condenser it is stored within the condenser in its electric field.
- The energy of an uncharged condenser = 0.
- The capacitance of a capacitor depends only on its size & geometry & the dielectric between the conducting surface. (i.e. independent of the conductor, whether it is copper, silver, gold etc)
- The two adjacent conductors carrying same charge can be at different potential because the conductors may have different sizes and means difference capacitance.
- When a capacitor is charged by a battery, both the plates received charge equal in magnitude, no matter sizes of plates are identical or not because the charge distribution on the plates of a capacitor is in accordance with charge conservation principle.
- On filling the space between the plates of a parallel plate air capacitor with a dielectric, capacity of the capacitor is increased because the same amount of charge can be stored at a reduced potential.
- The potential of a grounded object is taken to be zero because capacitance of the earth is very large.

Important Notes

17 Current Electricity and Heating Effects of current

ELECTRIC CURRENT :

Electric charges in motion constitute an electric current. Any medium having practically free electric charges (i.e. free to migrate) is a conductor of electricity. The electric charge flows from higher potential energy state to lower potential energy state. Positive charge flows from higher to lower potential and negative charge flows from lower to higher. Metals such as gold, silver, copper, aluminium etc. are good conductors.

ELECTRIC CURRENT IN A CONDUCTOR :

In absence of potential difference across a conductor, no net current flows through a cross section. When a potential difference is applied across a conductor the charge carriers (electrons in case of metallic conductors) flow in a definite direction which constitutes a net current in it . These electrons are not accelerated by electric field in the conductor produced by potential difference across the conductor. They move with a constant drift velocity . The direction of current is along the flow of positive charge (or opposite to flow of negative charge). $i = nv_d eA$, where v_d = drift velocity .

ELECTRIC CURRENT AND CURRENT DENSITY

The strength of the current i is the rate at which the electric charges are flowing. If a charge Q coulomb passes through a given cross section of the conductor in t second the current I through the conductor is given by

$$I = \frac{Q \text{ coulomb}}{t \text{ second}} = \text{ampere}$$

Ampere is the unit of current. If i is not constant then $i = \frac{dq}{dt}$, where dq is net charge transported at a section in time dt. In a current carrying conductor we can define a vector which gives the direction as current per unit normal, cross sectional area & is known as current density.

$$\text{Thus } \vec{J} = \frac{I}{S}\hat{n} \quad \text{or} \quad I = \vec{J}\cdot\vec{S}$$

Where $\hat{n}$ is the unit vector in the direction of the flow of current.

For random J or S, we use $I = \int \vec{J}\cdot\vec{ds}$

RELATION IN J, E AND v_D:

In conductors drift velocity of electrons is proportional to the electric field inside the conductor as; $v_d = \mu E$

where μ is the mobility of electrons

current density is given as $J = \frac{I}{A} = ne\,v_d = ne(\mu E) = \sigma E$

where $\sigma = ne\mu$ is called conductivity of material and we can also write

$\rho = \frac{1}{\sigma} \rightarrow$ resistivity of material.

Thus $E = \rho J$. It is called as differential form of Ohm's Law.

Sources Of Potential Difference & Electromotive Force :

Dry cells , secondary cells , generator and thermo couple are the devices used for producing potential difference in an electric circuit. The potential difference between the two terminals of a source when no energy is drawn from it, is called the " **Electromotive force**" or " **EMF** " of the source. The unit of potential difference is volt.

1 volt = 1 Ampere × 1 Ohm.

Electrical Resistance :

The property of a substance which opposes the flow of electric current through it, is termed as electrical resistance. Electrical resistance depends on the size, geometery, temperature and internal structure of the conductor.

Law Of Resistance :

The resistance R offered by a conductor depends on the following factors :

$R \propto \ell$ (length of the conductor) ; $R \propto \frac{1}{A}$ (cross section area of the conductor)

at a given temperature $R = \rho \frac{\ell}{A}$.Where ρ is the resistivity of the material of the conductor at the given temperature . It is also known as **specific resistance** of the material & it depends upon nature of conductor.

Dependence Of Resistance On Temperature :

The resistance of most conductors and all pure metals increases with temperature , but there are a few in which resistance decreases with temperature. If R_0 & R be the resistance of a conductor at 0°C and θ°C , then it is found that $R = R_0(1 + \alpha\theta)$.

Here we assume that the dimensions of resistance do not change with temperature if expansion coefficient of material is considerable. Then instead of resistance we use same property for resistivity as $\rho = \rho_0(1 + \alpha\theta)$. *The materials for which resistance decreases with temperature, the temperature coefficient of resistance is negative.*

Where α is called the temperature co-efficient of resistance . The unit of α is K^{-1} or $°C^{-1}$. Reciprocal of resistivity is called conductivity and reciprocal of resistance is called conductance (G) . S.I. unit of G is mho.

OHM'S LAW :

Ohm's law is the most fundamental law of all the laws in electricity . It says that the current through the cross section of the conductor is proportional to the applied potential difference under the given physical condition . V = RI . Ohm's law is applicable to only metalic conductors .

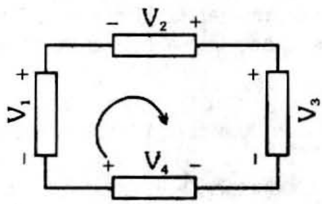
KRICHHOFF'S LAW'S :

I - Law (Junction law or Nodal Analysis) : This law is based on law of conservation of charge. It states that " The algebric sum of the currents meeting at a point is zero " or total currents entering a junction equals total current leaving the junction.

$$\Sigma I_{in} = \Sigma I_{out}$$

It is also known as KCL (Kirchhoff's current law) .

II - Law (Loop analysis) : The algebric sum of all the voltages in closed circuit is zero. $\Sigma IR + \Sigma EMF = 0$ in a closed loop . The closed loop can be traversed in any direction . While traversing a loop if higher potential point is entered, put a + ve sign in expression or if lower potential point is entered put a negative sign .

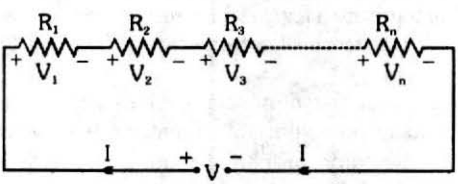


$-V_1 - V_2 + V_3 - V_4 = 0$. Boxes may contain resistor or battery or any other element (linear or non-linear).

It is also known as **KVL (Kirchhoff's voltage law)** .

COMBINATION OF RESISTANCES :

A number of resistances can be connected and all the complited combinations can be reduced to two different types, namely series and parallel .



(i) RESISTANCE IN SERIES :

When the resistances are connected end to end then they are said to be in series . The current through each resistor is same . The effective resistance appearing across the battery;

$R = R_1 + R_2 + R_3 + \ldots\ldots\ldots\ldots\ldots + R_n$ and

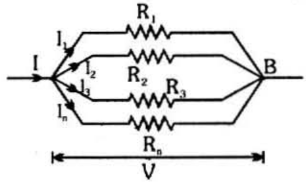
$V = V_1 + V_2 + V_3 + \ldots\ldots\ldots\ldots\ldots + V_n$.

The voltage across a resistor is proportional to the resistance

$$V_1 = \frac{R_1}{R_1+R_2+\ldots\ldots\ldots+R_n} V;\ V_2 = \frac{R_2}{R_1+R_2+\ldots\ldots\ldots+R_n} V;\ \text{etc.}$$

(ii) Resistance In Parallel :

A parallel circuit of resistors is one, in which the same voltage is applied across all the components in a parallel grouping of resistors R_1, R_2, R_3, ..., R_n .



Conclusions :

(a) Potential difference across each resistor is same .

(b) $I = I_1 + I_2 + I_3 + \ldots\ldots\ldots\ I_n$.

(c) Effective resistance (R) then $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots\ldots + \frac{1}{R_n}$.

(d) Current in different resistors is inversally proportional to the resistance .

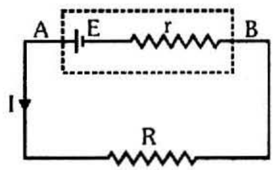
$$I_1 : I_2 : \ldots\ldots\ I_n = \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3} : \ldots\ldots\ldots : \frac{1}{R_n} .$$

$$I_1 = \frac{G_1}{G_1+G_2+\ldots\ldots\ldots+G_n} I,\ I_2 = \frac{G_2}{G_1+G_2+\ldots\ldots\ldots+G_n} I,\ \text{etc}.$$

where $G = \frac{1}{R}$ = Conductance of a resistor .

EMF Of A Cell & Its Internal Resistance :

If a cell of emf E and internal resistance r be connected with a resistance R the total resistance of the circuit is $(R + r)$.



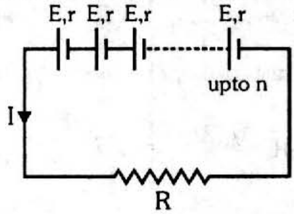
$$I = \frac{E}{R+r}\ ;V_{AB} = \frac{E}{R+r}$$

where V_{AB} = Terminal voltage of the battery .

If $r \to 0$, cell is Ideal & $V \to E$ & $r = R\left(\frac{E}{V} - 1\right)$

GROUPING OF CELLS :

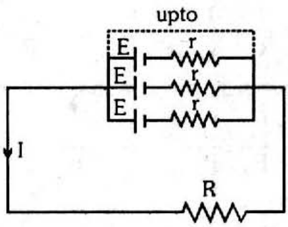
(i) **Cells In Series :** Let there be n cells each of emf E , arranged in series.Let r be the internal resistance of each cell. The total emf = n E . Current in the circuit $I = \frac{nE}{R+nr}$. If $nr << R$ then $I = \frac{nE}{R}$ $\to$Series combination should be used



If nr >> R then $I = \frac{E}{r}$ ⟶ Series combination should not be used .

(ii) CELLS IN PARALLEL : If m cells each of emf E & internal resistance r be connected in parallel and if this combination be connected to an external resistance then the emf of the circuit = E.

Internal resistance of the circuit $= \frac{r}{m}$.



$$I = \frac{E}{R + \frac{r}{m}} = \frac{mE}{mR + r}$$

If mR << r then $I = \frac{mE}{r}$ ⟶ Parallel combination should be used .

If mR >> r then $I = \frac{E}{R}$ ⟶ Parallel combination should not be used .

(iii) CELLS IN MULTIPLE ARC :

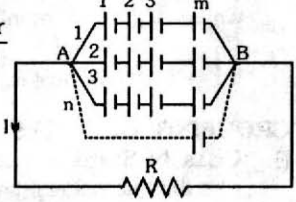
mn = number of identical cells .

n = number of rows

m = number of cells in each rows .

The combination of cells is equivalent to single cell of :

(a) emf = mE & (b) internal resistance $= \frac{mr}{n}$



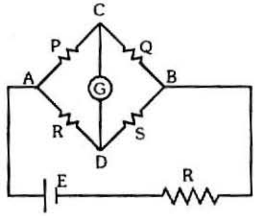
Current $I = \frac{mE}{R + \frac{mr}{n}}$.

For maximum current

$nR = mr$ or $R = \frac{mr}{n}$ so $I_{max} = \frac{nE}{2r} = \frac{mE}{2R}$

For a cell to deliver maximum power across the load internal resistance = load resistance

WHEAT STONE NETWORK :



When current through the galvanometer is zero

(null point or balance point) $\frac{P}{Q}=\frac{R}{S}$.

When

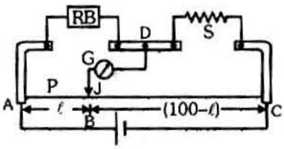
$PS > QR$, $V_C < V_D$ & $PS < QR$, $V_C > V_D$

or $PS = QR \Rightarrow$ products of opposite arms are equal. Potential difference between C & D at null point is zero . The null point is not affected by resistance of G & E. It is not affected even if the positions of G & E are interchanged.

$$I_{CD} \propto (QR - PS)$$

- **Metre Bridge**

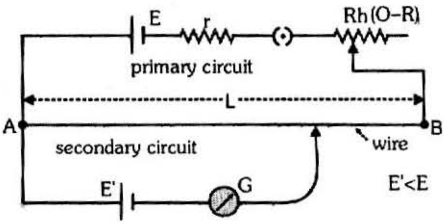
At balance condition : $\frac{P}{Q}=\frac{R}{S} \Rightarrow \frac{r\ell}{r(100-\ell)}=\frac{R}{S} \Rightarrow S=\frac{(100-\ell)}{\ell}R$



POTENTIOMETER :

A potentiometer is a linear conductor of uniform cross-section with a steady current set up in it. This maintains a uniform potential gradient along the length of the wire . Any potential difference which is less than the potential difference maintained across the potentiometer wire can be measured using this . The potentiometer equation is $\frac{E_1}{E_2}=\frac{\ell_1}{\ell_2}$.

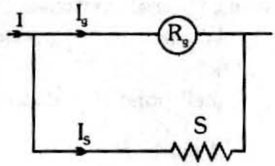
Circuits of potentiometer :



$$x=\frac{V}{L}=\frac{\text{current} \times \text{resitance of potentiometer wire}}{\text{length of potentiometer wire}}=I\left(\frac{R}{L}\right)$$

AMMETER :

It is a modified form of suspended coil galvanometer, it is used to measure current . A shunt (small resistance) is connected in parallel with galvanometer to convert into ammeter .



$$S = \frac{I_g R_g}{I - I_g}$$

where

R_g = galvanometer resistance

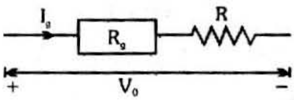
I_g = Maximum current that can flow through the galvanometer .

I = Maximum current that can be measured using the given ammeter .

An ideal ammeter has zero resistance.

VOLTMETER :

A high resistance is put in series with galvanometer. It is used to measure potential difference.



$I_g = \dfrac{V_o}{R_g + R}$; $R \to \infty$, Ideal voltmeter

ELECTRICAL POWER :

The energy liberated per second in a device is called its power. The electrical power P delivered by an electrical device is given by P = VI, where V = potential difference across device & I = current. If the current enters the higher potential point of the device then power is consumed by it (i.e. acts as load) . If the current enters the lower potential point then the device supplies power (i.e. acts as source).

Power consumed by a resistor $P = I^2R = VI = \dfrac{V^2}{R}$

HEATING EFFECT OF ELECTRIC CURRENT :

When a current is passed through a resistor energy is wasted in over coming the resistances of the wire . This energy is converted into heat

$$W = VIt = I^2 Rt = \frac{V^2}{R} t$$

JOULES LAW OF ELECTRICAL HEATING :

The heat generated (in joules) when a current of I ampere flows through a resistance of R ohm for T second is given by :

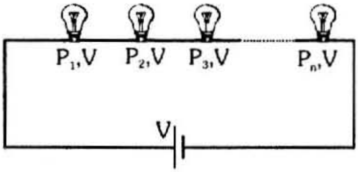
$$H = I^2 RT \text{ joule} = \frac{I^2 RT}{4.2} \text{ calories.}$$

If current is variable passing through the conductor then we use for heat produced in resistance in time 0 to T is: $H = \int_0^T I^2 R dt$

UNIT OF ELECTRICAL ENERGY CONSUMPTION :

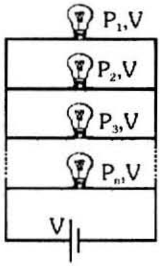
1 unit of electrical energy = kilowatt hour = 1 kWh = 3.6×10^6 joules.

- ***Series combination of Bulbs***



$$\frac{1}{P_{total}} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + ...$$

- **Parallel combination of Bulbs**



$$P_{total} = P_1 + P_2 + P_3 + ...$$

KEY POINTS

- A current flows through a conductor only when there is an electric field within the conductor because the drift velocity of electrons is directly proportional to the applied electric field.
- Electric field outside the conducting wire which carries a constant current is zero because net charge on a current carrying conductor is zero.
- A metal has a resistance and gets often heated by flow of current because when free electrons drift through a metal, they make occasional collisions with the lattice. These collisions are inelastic and transfer energy to the lattice as internal energy.
- Ohm's law holds only for small current in metallic wire, not for high currents because resistance increased with increase in temperature.
- Potentiometer is an ideal instrument to measure the potential difference because potential gradient along the potentiometer wire can be made very small.
- An ammeter is always connected in series whereas a voltmeter is connected in parallel because an ammeter is a low-resistance galvanometer while a voltmeter is a high-resistance galvanometer.
- Current is passed through a metallic wires, heating it red, when cold water is poured over half of the portion, rest of the portion becomes more hot because resistance decreases due to decrease in temperature so current through wire increases.

Important Notes

18 Magnetic Effect of Current and Magnetism

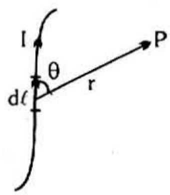
A static charge produces only electric field and only electric field can exert a force on it. A moving charge produces both electric field and magnetic field and both electric field and magnetic field can exert force on it. A current carrying conductor produces only magnetic field and only magnetic field can exert a force on it.

Magnetic charge (i.e. current) , produces a magnetic field . It can not produce electric field as net charge on a current carrying conductor is zero. A magnetic field is detected by its action on current carrying conductors (or moving charges) and magnetic needles (compass). The vector quantity $\vec{B}$ known as MAGNETIC INDUCTION is introduced to characterise a magnetic field . It is a vector quantity which may be defined in terms of the force it produces on electric currents . Lines of magnetic induction may be drawn in the same way as lines of electric field . The number of lines per unit area crossing a small area perpendicular to the direction of the induction bring numerically equal to $\vec{B}$. The number of lines of $\vec{B}$ crossing a given area is referred to as the **magnetic flux** linked with that area. For this reason $\vec{B}$ is also called **magnetic flux density** .

MAGNETIC INDUCTION PRODUCED BY A CURRENT (BIOT-SAVART LAW):

The magnetic induction dB produced by an element dl carrying a current I at a distance r is given by:

$$dB = \frac{\mu_0\mu_r}{4\pi}\frac{I\,d\ell\sin\theta}{r^2} \Rightarrow \overrightarrow{dB} = \frac{\mu_0\,\mu_r}{4\pi}\frac{I\left(d\vec{\ell}\times\vec{r}\right)}{r^3}$$



here the quantity I$d\ell$ is called as current element strength.

μ = permeability of the medium $= \mu_0\,\mu_r$

μ_0 = permeability of free space .

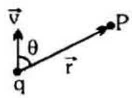
μ_r = relative permeability of the medium (Dimensionless quantity).

Unit of μ_0 & μ is NA^{-2} or Hm^{-1} ;

$\mu_0 = 4\pi\times10^{-7}\ Hm^{-1}$

MAGNETIC INDUCTION DUE TO A MOVING CHARGE

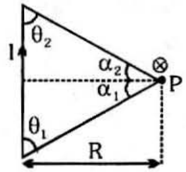
$$dB_P = \frac{\mu_0 qv\sin\theta}{4\pi r^2}$$



In vector form it can be written as $\overrightarrow{dB} = \frac{\mu_0}{4\pi}\frac{q(\vec{v}\times\vec{r})}{r^3}$

Magnetic Induction Due To A Current Carrying Straight Conductor

- **Magnetic induction due to a current carrying straight wire**

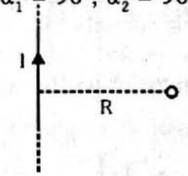


$$B = \frac{\mu_0 I}{4\pi R}(\cos\theta_1 + \cos\theta_2) = \frac{\mu_0 I}{4\pi R}(\sin\alpha_1 + \sin\alpha_2)$$

If the wire is very long $\theta_1 \cong \theta_2 \cong 0°$ then , $B = \frac{\mu_0 I}{2\pi R}$

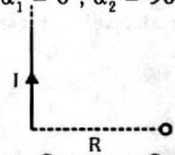
- **Magnetic induction due to a infinitely long wire** $B = \frac{\mu_0 I}{2\pi R} \otimes$

$\alpha_1 = 90°;\ \alpha_2 = 90°$

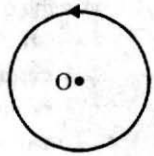


Magnetic Induction due to semi infinite straight conductor $B = \frac{\mu_0 I}{4\pi R} \otimes$

$\alpha_1 = 0°;\ \alpha_2 = 90°$



Magnetic Field Due To A Flat Circular Coil Carrying A Current :



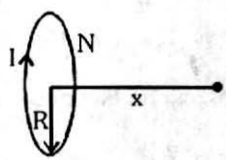
(i) At its centre $B = \frac{\mu_0 NI}{2R} \odot$

where

N = total number of turns in the coil

I = current in the coil

R = Radius of the coil

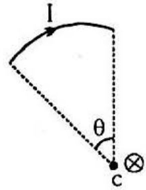


(ii) On the axis $B = \frac{\mu_0 NIR^2}{2\left(x^2 + R^2\right)^{3/2}}$

Where x = distance of the point from the centre .

It is maximum at the centre $B_C = \frac{\mu_0 NI}{2R}$

(iii) MAGNETIC INDUCTION DUE TO FLAT CIRCULAR ARC : $B = \frac{\mu_0 I\theta}{4\pi R}$



- **Magnetic field due to infinite long solid cylindrical conductor of radius R**

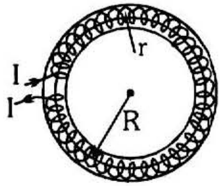
  - For $r \geq R : B = \frac{\mu_0 I}{2\pi r}$
  - For $r < R : B = \frac{\mu_0 Ir}{2\pi R^2}$

MAGNETIC INDUCTION DUE TO SOLENOID

$B = \mu_0 nI$, direction along axis.

where $n \rightarrow$ number of turns per meter; $I \rightarrow$ current

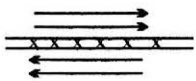
MAGNETIC INDUCTION DUE TO TOROID : $B = \mu_0 nI$



where $n = \frac{N}{2\pi R}$ (no. of turns per m)

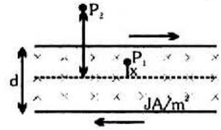
N = total turns $R >> r$

MAGNETIC INDUCTION DUE TO CURRENT CARRYING SHEET



$B = \frac{1}{2}\mu_0 I$ where I = Linear current density (A/m)

MAGNETIC INDUCTION DUE TO THICK SHEET



At point P_2 $\quad B_{out} = \frac{1}{2}\mu_0 Jd$

At point P_1 $\quad B_{in} = \mu_0 Jx$

GILBERT'S MAGNETISM (EARTH'S MAGNETIC FIELD) :

(a) The line of earth's magnetic induction lies in a vertical plane coinciding with the magnetic North - South direction at that place. This plane is called the **MAGNETIC MERIDIAN**. Earth's magnetic axis is slightly inclined to the geometric axis of earth and this angle varies from 10.5^0 to 20^0. The Earth's Magnetic poles are opposite to the geometric poles i.e. at earth's north pole, its magnetic south pole is situated and vice versa.

(b) On the magnetic meridian plane , the magnetic induction vector of the earth at any point, generally inclined to the horizontal at an angle called the **MAGNETIC DIP** at that place , such that $\vec{B}$ = total magnetic induction of the earth at that point.

$\vec{B}_v$ = the vertical component of $\vec{B}$ in the magnetic meridian plane = $B \sin\theta$

$\vec{B}_H$ = the horizontal component of $\vec{B}$ in the magnetic meridian plane=$B \cos\theta$.

$$\frac{B_v}{B_H} = \tan\theta$$

(c) At a given place on the surface of the earth , the magnetic meridian and the geographic meridian may not coincide . The angle between them is called "**DECLINATION AT THAT PLACE**"

AMPERES LAW

$$\oint \vec{B}\,.\,d\vec{\ell} = \mu\Sigma I \quad \text{where } \Sigma I = \text{algebraic sum of all the currents.}$$

MOTION OF A CHARGE IN UNIFORM MAGNETIC FIELD :

(a) When $\vec{v}$ is | | to $\vec{B}$: Motion will be in a straight line and $\vec{F} = 0$

(b) When $\vec{v}$ is $\perp$ to $\vec{B}$: Motion will be in circular path with radius

$R = \dfrac{mv}{qB}$ and angular velocity $\omega = \dfrac{qB}{m}$ and $F = qvB$.

(c) When $\vec{v}$ is at $\angle\theta$ to $\vec{B}$: Motion will be helical with radius

$R_k = \dfrac{mv\sin\theta}{qB}$ and pitch $P_H = \dfrac{2\pi mv\cos\theta}{qB}$ and $F = qvB\sin\theta$.

LORENTZ FORCE :

An electric charge 'q' moving with a velocity $\vec{v}$ through a magnetic field of magnetic induction $\vec{B}$ experiences a force $\vec{F}$, given by $\vec{F} = q\vec{v}\times\vec{B}$. There fore, if the charge moves in a space where both electric and magnetic fields are superposed .

$\vec{F}$ = net electromagnetic force on the charge = $q\vec{E} + q\vec{v}\times\vec{B}$

This force is called the **LORENTZ FORCE**

MOTION OF CHARGE IN COMBINED ELECTRIC FIELD & MAGNETIC FIELD

- When $\vec{v} \parallel \vec{B}$ & $\vec{v} \parallel \vec{E}$, motion will be uniformly accelerated in straight line as $F_{magnetic} = 0$ and $F_{electrostatic} = qE$
  So the particle will be either speeding up or speeding down
- When $\vec{v} \parallel \vec{B}$ & $\vec{v} \perp \vec{E}$, motion will be uniformly accelerated in a parabolic path
- When $\vec{v} \perp \vec{B}$ & $\vec{v} \perp \vec{E}$, the particle may more undeflected & undeivated with same uniform speed if $v = \frac{E}{B}$ (This is called as velocity selector condition)

MAGNETIC FORCE ON A STRAIGHT CURRENT CARRYING WIRE : $\vec{F} = I(\vec{L} \times \vec{B})$

I = current in the straight conductor

$\vec{L}$ = length of the conductor in the direction of the current in it

$\vec{B}$ = magnetic induction. (Uniform throughout the length of conductor)

Note : In general force is $\vec{F} = \int I(d\vec{\ell} \times \vec{B})$

MAGNETIC INTERACTION FORCE BETWEEN TWO PARALLEL LONG STRAIGHT CURRENTS :

When two long straight linear conductors are parallel and carry a current in each , they magnetically interact with each other, one experiences a force. This force is of:

(i) Repulsion if the currents are anti-parallel (i.e. in opposite direction) or

(ii) Attraction if the currents are parallel (i.e. in the same direction)

This force per unit length on either conductor is given by $F = \frac{\mu_0}{2\pi} \frac{I_1 I_2}{r}$.

Where r = perpendicular distance between the parallel conductors

MAGNETIC TORQUE ON A CLOSED CURRENT CIRCUIT :

When a plane closed current circuit of 'N' turns and of area 'A' per turn carrying a current I is placed in uniform magnetic field , it experience a zero net force, but experience a torque given by $\vec{\tau} = NI\vec{A} \times \vec{B} = \vec{M} \times \vec{B} = BINA \sin\theta$

where $\vec{A}$ = area vector outward from the face of the circuit where the current is anticlockwise, $\vec{B}$ = magnetic induction of the uniform magnetic field.

$\vec{M}$ = magnetic moment of the current circuit = $IN\vec{A}$

Note : This expression can be used only if $\vec{B}$ is uniform otherwise calculus will be used.

MOVING COIL GALVANOMETER :

It consists of a plane coil of many turns suspended in a radial magnetic feild. When a current is passed in the coil it experiences a torque which produces a twist in the suspension.

This deflection is directly proportional to the torque $\therefore \text{NIAB} = K\theta$

$I = \left(\frac{K}{NAB}\right)\theta$; K = elastic torsional constant of the suspension

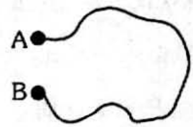
$I = C\theta \qquad C = \frac{K}{NAB}$ = Galvanometer Constant

FORCE EXPERIENCED BY A MAGNETIC DIPOLE IN A NON-UNIFORM MAGNETIC FIELD :

$$|\vec{F}| = \left|M\frac{\partial B}{\partial r}\right|$$

where M = Magnetic dipole moment.

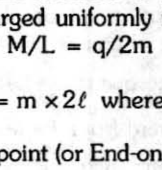
FORCE ON A RANDOM SHAPED CONDUCTOR IN A UNIFORM MAGNETIC FIELD



- Magnetic force on a closed loop in a uniform $\vec{B}$ is zero
- Force experienced by a wire of any shape is equivalent to force on a wire joining points A & B in a uniform magnetic field.

MAGNETIC MOMENT OF A ROTATING CHARGE:

If a charge q is rotating at an angular velocity ω, its equivalent current is given as $I = \frac{q\omega}{2\pi}$ & its magnetic moment is $M = I\pi R^2 = \frac{1}{2}q\omega R^2$.



NOTE: The ratio of magnetic moment to angular momentum of a uniform rotating object which is charged uniformly is always a constant. Irrespective of the shape of conductor M/L = q/2m

- **Magnetic dipole**
  - Magnetic moment $M = m \times 2\ell$ where m = pole strength of the magnet
  - Magnetic field at axial point (or End-on) of dipole $\vec{B} = \frac{\mu_0}{4\pi}\frac{2\vec{M}}{r^3}$
  - Magnetic field at equatorial position (Broad-on) of dipole $\vec{B} = \frac{\mu_0}{4\pi}\frac{\left(-\vec{M}\right)}{r^3}$
  - At a point which is at a distance r from dipole midpoint and making angle θ with dipole axis.

Magnetic Potential $V = \frac{\mu_0}{4\pi}\frac{M\cos\theta}{r^2}$

Magnetic field $B = \frac{\mu_0}{4\pi}\frac{M\sqrt{1+3\cos^2\theta}}{r^3}$

- Torque on dipole placed in uniform magnetic field $\vec{\tau} = \vec{M} \times \vec{B}$
- Potential energy of dipole placed in an uniform field $U = -\vec{M}\cdot\vec{B}$

- **Intensity of magnetisation** $I = M/V$
- **Magnetic induction** $B = \mu H = \mu_0(H + I)$
- **Magnetic permeability** $\mu = \frac{B}{H}$
- **Magnetic susceptibility** $\chi_m = \frac{I}{H} = \mu - 1$
- **Curie law**
  - For paramagnetic materials $\chi_m \propto \frac{1}{T}$
- **Curie Wiess law**
  - For Ferromagnetic materials $\chi_m \propto \frac{1}{T - T_C}$

    Where T_C = curie temperature

KEY POINTS

- A charged particle moves perpendicular to magnetic field. Its kinetic energy will remain constant but momentum changes because magnetic force acts perpendicular to velocity of particle.
- If a unit north pole rotates around a current carrying wire then work has to be done because magnetic field produced by current is always non-conservative in nature.
- In a conductor, free electrons keep on moving but no magnetic force acts on a conductor in a magnetic field because in a conductor, the average thermal velocity of electrons is zero.
- Magnetic force between two charges is generally much smaller than the electric force between them because speeds of charges are much smaller than the free space speed of light.

Note : $\frac{F_{magnetic}}{F_{electric}} = \frac{v^2}{c^2}$

Important Notes

19 Electromagnetic Induction

MAGNETIC FLUX :

$\phi = \vec{B}\cdot\vec{A} = BA\cos\theta$ for uniform $\vec{B}$.

$\phi = \int \vec{B}\cdot d\vec{A}$ for non uniform $\vec{B}$.

FARADAY'S LAWS OF ELECTROMAGNETIC INDUCTION :

(i) An induced emf is setup whenever the magnetic flux linking that circuit changes.

(ii) The magnitude of the induced emf in any circuit is proportional to the rate of change of the magnetic flux linking the circuit, $\varepsilon \propto \frac{d\varphi}{dt}$.

LENZ'S LAWS :

The direction of an induced emf is always such as to oppose the cause producing it .

LAW OF EMI : $e = -\frac{d\varphi}{dt}$.

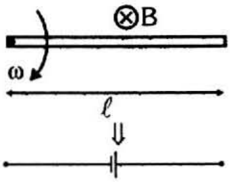
The negative sign indicates that the induced emf opposes the change of the flux.

EMF INDUCED IN A STRAIGHT CONDUCTOR IN UNIFORM MAGNETIC FIELD :

$$E = BLv\sin\theta$$

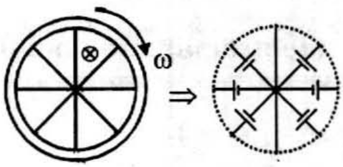
where B = flux density
L = length of the conductor
v = velocity of the conductor
θ = angle between direction of motion of conductor & B .

EMF INDUCED IN A ROD ROTATING PERPENDICULAR TO MAGNETIC FIELD



$$E = \frac{1}{2}B\omega\ell^2$$

For a wheel rotating in a earth magnetic field effective emf induced between the periphery & centre = $\frac{1}{2}B\omega\ell^2$



Coil Rotation In Magnetic Field Such That Axis Of Rotation Is Perpendicular To The Magnetic Field :

Instantaneous induced emf. $\omega \sin E\omega t = E_0 \sin \omega t$

where N = number of turns in the coil

A = area of one turn

B = magnetic induction

ω = uniform angular velocity of the coil

E_0 = maximum induced emf

Self Induction & Self Inductance :

When a current flowing through a coil is changed the flux linking with its own winding changes & due to the change in linking flux with the coil an emf is induced which is known as self induced emf & this phenomenon is known as self induction. This induced emf opposes the causes of Induction. The property of the coil or the circuit due to which it opposes any change of the current coil or the circuit is known as **Self - Inductance**. It's unit is Henry.

Coefficient of Self inductance $L = \frac{\varphi_s}{i}$ or $\phi_s = Li$

i = current in the circuit.

ϕ_s = magnetic flux linked with the circuit due to the current i.

L depends only on ; **(i)** shape of the loop & **(ii)** medium

self induced emf $e_s = \frac{d\varphi_s}{dt} = -\frac{d}{dt}(Li) = -L\frac{di}{dt}$ (if L is constant)

Combination of inductors

- Series combination $L = L_1 + L_2 + \ldots\ldots\ldots$, i same, V in ratio of inductance, U in ratio of inductance, ϕ in ratio of inductance
- Parallel combination $\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \ldots\ldots\ldots$, V same, i in inverse ratio of inductance, U in inverse ratio of inductance, ϕ same

Mutual Induction :

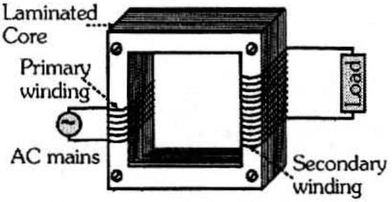
If two electric circuits are such that the magnetic field due to a current in one is partly or wholly linked with the other, the two coils are said to be electromagnetically coupled circuits. Then any change of current in one produces a change of magnetic flux in the other & the later opposes the change by inducing an emf within itself . This phenomenon is called **Mutual Induction** & the induced emf in the later circuit due to a change of current in the former is called **Mutually Induced EMF** . The circuit in which the current is changed, is called the primary & the other circuit in which the emf is induced is called the secondary. The co-efficient of mutual induction (mutual inductance) between two electromagnetically coupled circuit is the magnetic flux linked with the secondary per unit current in the primary.

Mutual inductance = $M = \frac{\varphi_m}{I_p} = \frac{\text{flux linked with secondary}}{\text{current in the primary}}$

mutually induced emf : $E_m = \frac{d\varphi_m}{dt} = -\frac{d}{dt}(MI) = -M\frac{dI}{dt}$ (If M is constant)

M depends on (1) geometry of loops (2) medium (3) orientation & distance of loops .

- **If two coils of self inductance L_1 and L_2 are wound over each other, the mutual inductance** $M = K\sqrt{L_1L_2}$ where K is called coupling constant.
- **For two coils wound in same direction and connected in series**
  $L = L_1 + L_2 + 2M$
- **For two coils wound in opposite direction and connected in series**
  $$L = L_1 + L_2 - 2M$$
- **For two coils in parallel** $L = \frac{L_1L_2 - M^2}{L_1 + L_2 \pm 2M}$
- **Transformer**

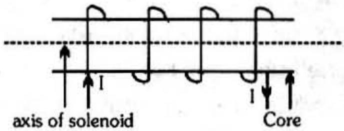


$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

❒ For ideal transformer $\frac{E_2}{E_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$ ❒ Efficiency $\eta = \frac{P_{out}}{P_{in}} \times 100\%$

SOLENOID :

There is a uniform magnetic field along the axis of the solenoid



$B = \mu\, ni$ (ideal : length >> diameter)

where μ = magnetic permeability of the core material

n = number of turns in the solenoid per unit length

i = current in the solenoid

Self inductance of a solenoid $L = \mu_0 n^2 A l$

A = area of cross section of solenoid .

SUPER CONDUCTION LOOP IN MAGNETIC FIELD :

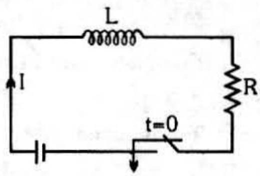
$R = 0$;$\varepsilon = 0$. Therefore ϕ_{total} = constant. Thus in a superconducting loop flux never changes. (or it opposes 100%)

(i) **ENERGY STORED IN AN INDUCTOR** : $W = \frac{1}{2} LI^2$.

(ii) Energy of interaction of two loops $U = I_1\phi_2 = I_2\phi_1 = MI_1I_2$
where M is mutual inductance

GROWTH OF A CURRENT IN AN L – R CIRCUIT :

$I = \frac{E}{R}\,(1 - e^{-Rt/L})$. [If initial current = 0]



$\frac{L}{R}$ = time constant of the circuit.

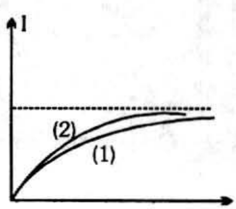
$I_0 = \frac{E}{R}$.

(i) L behaves as open circuit at t = 0 [If i = 0]

(ii) L behaves as short circuit at t = ∞ always.

Curve (1) $\longrightarrow \frac{L}{R}$ Large

Curve (2) $\longrightarrow \frac{L}{R}$ Small



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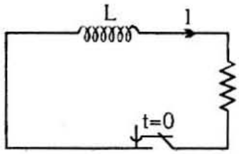
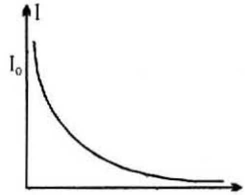
DECAY OF CURRENT :

Initial current through the inductor = I_0 ; Current at any instant $i = I_0e^{-Rt/L}$





KEY POINTS

- An emf is induced in a closed loop where magnetic flux is varied. The induced electric field is not conservative field because for induced electric field, the line integral $\oint \vec{E}.d\vec{\ell}$ around a closed path is non-zero.
- Acceleration of a magnet falling through a long solenoid decrease because the induced current produced in a circuit always flows in such direction that it opposes the change or the cause that produces it.
- The mutual inductance of two coils is doubled if the self inductance of the primary and secondary coil is doubled because mutual inductance $M \propto \sqrt{L_1L_2}$.
- The possibility of an electric bulb fusing is higher at the time of switching ON and OFF because inductive effects produce a surge at the time of switch-off and switch-on.
- Motional emf : If a conductor is moved in a magnetic field then motional emf will be $E = B\ell_{eff}v$

  Here $v \perp \ell_{eff}$ & $v \perp B$ & $B \perp \ell_{eff}$

  $\ell_{eff} \rightarrow$ effective length between the end points of conductor which is perpendicular to the velocity.

Important Notes

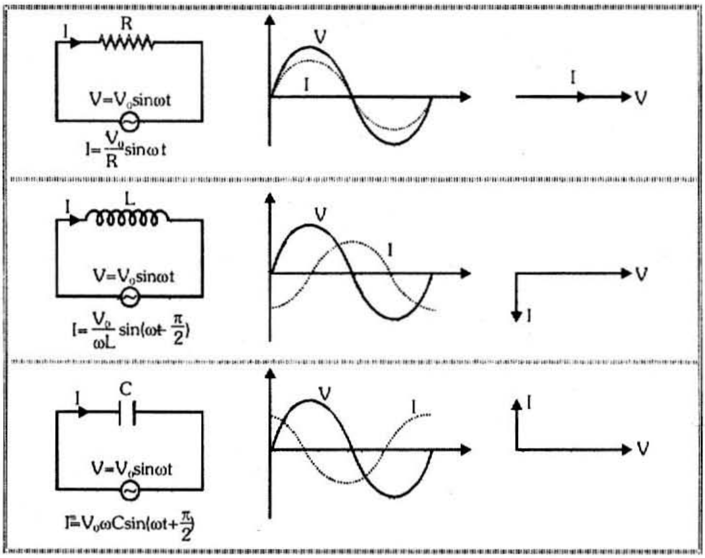
20 Alternating Current and EM Waves

- **Average value** $I_{av} = \dfrac{\int_0^T I\,dt}{\int_0^T dt} = \dfrac{1}{T}\int_0^T I\,dt$ •**RMS value** $I_{rms} = \sqrt{\dfrac{\int_0^T I^2 dt}{\int_0^T dt}}$

- For sinusoidal voltage $V = V_0 \sin\omega t$: $V_{av} = \dfrac{2V_0}{\pi}$ & $V_{rms} = \dfrac{V_0}{\sqrt{2}}$

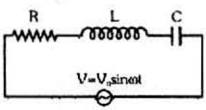
  For sinusoidal current $I = I_0 \sin(\omega t+\phi)$: $I_{av} = \dfrac{2I_0}{\pi}$ & $I_{rms} = \dfrac{I_0}{\sqrt{2}}$

- **AC Circuits**

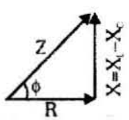


- **Impedance :** $Z = \sqrt{R^2 + X^2}$ where X = reactance

- **Series LCR Circuit**

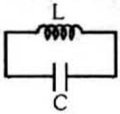


$Z = \sqrt{R^2 + (X_L - X_C)^2}$



$V = \sqrt{V_R^2 + (V_L - V_C)^2}$

- **Power Factor** = $\cos\phi = R/Z$ At resonance : $X_L = X_C \Rightarrow Z = R$, $V = V_R$

- **LC Oscillation** 

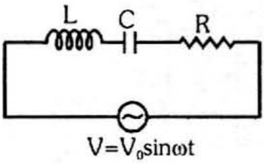
$q = q_0 \sin(\omega t + \theta)$, $I = I_0\cos(\omega t + \theta)$ $\boxed{I_0 = q_0\omega}$

  Energy = $\frac{1}{2}LI^2 + \frac{q^2}{2C} = \frac{q_0^2}{2C} = \frac{1}{2}LI_0^2$ = constant

  Comparison with SHM $q \to x$, $I \to v$, $L \to m$, $C \to \frac{1}{K}$

Comparison of Damped Mechanical & electrical systems

- **(I) Series LCR circuit :**



$$\frac{d^2q}{dt^2} + \frac{R}{L}\frac{dq}{dt} + \frac{1}{LC}q = \frac{V_0}{L}\cos\omega t$$

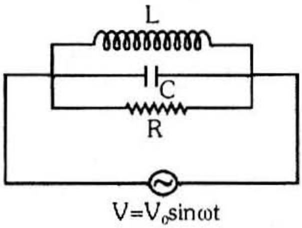
compare with mechanical damped system equation

$$\frac{d^2x}{dt^2} + \frac{b}{m}\frac{dx}{dt} + \frac{k}{m}x = \frac{F_0}{m}\cos\omega t$$

where b = damping coefficient.

Mechanical system	Electrical systems (series RLC)
Displacement (x)	Charge (q)
Driving force (F)	Driving voltage (V)
Kinetic energy $\left(\frac{1}{2}mv^2\right)$	Electromagnetic energy of moving charge $\frac{1}{2}L\left(\frac{dq}{dt}\right)^2 = \frac{1}{2}Li^2$
Potential energy $\frac{1}{2}kx^2$	Energy of static charge $\frac{q^2}{2C}$
mass (m)	L
Power P =Fv	Power P=VI
Damping (b)	Resistance (R)
Spring constant	1/C

- **(II) Parallel LCR circuit :** In this case



$$I = I_L + I_C + I_R = \frac{\phi}{L} + \frac{d}{dt}C\left(\frac{d\phi}{dt}\right) + \frac{1}{R}\frac{d\phi}{dt} \Rightarrow \frac{d^2\phi}{dt^2} + \frac{1}{RC}\frac{d\phi}{dt} + \frac{1}{LC}\phi = \frac{V_0}{ZC}\sin\omega t$$

Displacement **(x)**	$\Longleftrightarrow$	Flux linkage **(ϕ)**
Velocity $\left(\frac{dx}{dt}\right)$	$\Longleftrightarrow$	Voltage $\left(\frac{d\phi}{dt}\right)$
Mass **(m)**	$\Longleftrightarrow$	Capacitance **(C)**
Spring constant **(k)**	$\Longleftrightarrow$	Reciprocal Industance **(1/L)**
Damping coefficient **(b)**	$\Longleftrightarrow$	Reciprocal resistance **(1/R)**
Driving force **(F)**	$\Longleftrightarrow$	Current **(*i*)**

- **Properties of EM Waves**
  - The electric and magnetic fields $\vec{E}$ and $\vec{B}$ are always perpendicular to the direction in which the wave is travelling. Thus the em wave is a transverse wave.
  - EM waves carry momentum and energy.
  - EM wave travel through vacuum with the speed of light c, where

    $$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}} = 3 \times 10^8 \text{ m/s}$$

  - The instantaneous magnitude of $\vec{E}$ and $\vec{B}$ in an EM wave are related by the expression $\frac{E}{B} = c$
  - The cross product $\vec{E} \times \vec{B}$ always gives the direction in which the wave travels.
- **Poynting Vector** : The rate of flow of energy crossing a unit area by electro-magnetic radiation is given by poynting vector $\vec{S}$ where $\vec{S} = \frac{1}{\mu_0}(\vec{E} \times \vec{B})$
- **Displacement current :** In a region of space in which there is a changing electric field, there is a displacement current defined as $I_d = \epsilon_0 \frac{d\phi_E}{dt}$ where ε_0 is the permittivity of free space and $\phi_E = \int \vec{E} \cdot d\vec{S}$ is the electric flux.

- **Maxwell's Equations**

$\oint \vec{E} \cdot d\vec{S} = \frac{q}{\epsilon_0}$ [Gauss law for electricity]

$\oint \vec{B} \cdot d\vec{S} = 0$ [Gauss law for magnetism]

$\oint \vec{E} \cdot d\vec{\ell} = -\frac{d\phi_B}{dt}$ [Faraday's law]

$\oint \vec{B} \cdot d\vec{\ell} = \mu_0 \left[I_C + \epsilon_0 \frac{d\phi_E}{dt} \right]$ [Ampere's law with Maxwell's correction]

KEY POINTS

- An alternating current of frequency 50 Hz becomes zero, 100 times in one second because alternating current changes direction and becomes zero twice in a cycle.
- An alternating current cannot be used to conduct electrolysis because the ions due to their inertia, cannot follow the changing electric field.
- Average value of AC is always defined over half cycle because average value of AC over a complete cycle is always zero.
- AC current flows on the periphery of wire instead of flowing through total volume of wire. This known as skin effect.

Important Notes

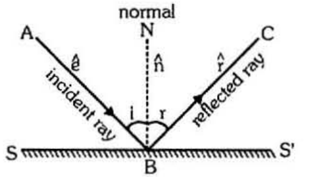
21 Ray Optics and Optical Instruments

REFLECTION

LAWS OF REFLECTION :

The incident ray (AB), the reflected ray (BC) and normal (NB) to the surface (SS') of reflection at the point of incidence (B) lie in the same plane. This plane is called the plane of incidence (also plane of reflection).

The angle of incidence (the angle between normal and the incident ray) and the angle of reflection (the angle between the reflected ray and the normal) are equal $\boxed{\angle i = \angle r}$



In vector form $\boxed{\hat{\mathbf{r}} = \hat{\mathbf{e}} - 2(\hat{\mathbf{e}}.\hat{\mathbf{n}})\hat{\mathbf{n}}}$

OBJECT :

Real : Point from which rays actually diverge.

Virtual: Point towards which rays appear to converge

IMAGE :

Image is decided by reflected or refracted rays only. The point image for a mirror is that point towards which the rays reflected from the mirror, actually converge (real image).

OR

From which the reflected rays appear to diverge (virtual image) .

CHARACTERISTICS OF REFLECTION BY A PLANE MIRROR :

The size of the image is the same as that of the object.

For a real object the image is virtual and for a virtual object the image is real.

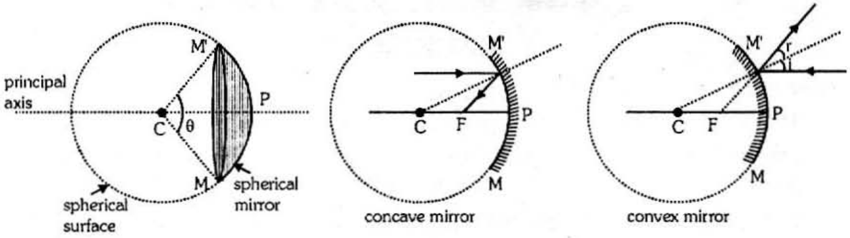
For a fixed incident light ray, if the mirror be rotated through an angle θ the reflected ray turns through an angle 2θ in the same sense.

Number of images (n) in inclined mirror Find $\frac{360}{\theta} = m$

- If m even, then n = m – 1, for all positions of object.
- If m odd , then n = m, If object not on bisector
  and n = m – 1, If object at bisector

- If m fraction then n = nearest even number

SPHERICAL MIRRORS :



PARAXIAL RAYS :

Rays which forms very small angle with axis are called paraxial rays. All formulae are valid for paraxial ray only.

SIGN CONVENTION :

- We follow cartesian co-ordinate system convention according to which the pole of the mirror is the origin.
- The direction of the incident rays is considered as positive x-axis. Vertically up is positive y-axis.
- All distance are measured from pole.

Note : According to above convention radius of curvature and focus of concave mirror is negative and of convex mirror is positive.

MIRROR FORMULA : $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$.

f = x- coordinate of focus u = x-coordinate of object

v = x-coordinate of image **Note :** Valid only for paraxial rays.

TRANSVERSE MAGNIFICATION : $m = \frac{h_2}{h_1} = -\frac{v}{u}$

h_2 = y co-ordinate of image h_1 = y co-ordinate of the object

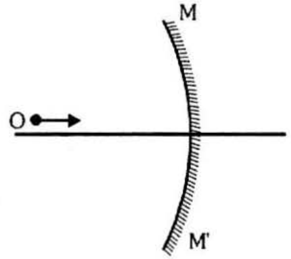
(both perpendicular to the principal axis of mirror)

Longitudinal magnification : m_2 $m_2 = \frac{\text{Length of image}}{\text{Length of object}}$

for small objects $m_2 = -m_t^2$ m_t = transverse magnification.

VELOCITY OF IMAGE OF MOVING OBJECT (SPHERICAL MIRROR)

Velocity component along axis (Longitudinal velocity)



When an object is coming from infinite towards the focus of concave mirror

$\because \frac{1}{v}+\frac{1}{u}=\frac{1}{f}$ $\quad \therefore -\frac{1}{v^2}\frac{dv}{dt}-\frac{1}{u^2}\frac{du}{dt}=0 \Rightarrow \vec{v}_{IM}=-\frac{v^2}{u^2}\vec{v}_{ox}=-m^2\vec{v}_{OM}$

- $v_{IM}=\frac{dv}{dt}=$ velocity of image with respect to mirror
- $v_{OM}=\frac{du}{dt}=$ velocity of object with respect to mirror.

NEWTON'S FORMULA :

Applicable to a pair of real object and real image position only . They are called conjugate positions or foci, X_1, X_2 are the distance along the principal axis of the real object and real image respectively from the principal focus

$$\boxed{X_1X_2=f^2}$$

OPTICAL POWER : Optical power of a mirror (in Diopters) $= -\frac{1}{f}$

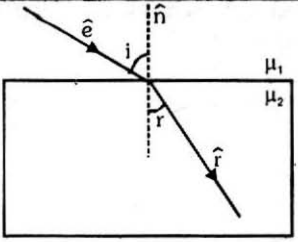
where f = focal length (in meters) with sign .

REFRACTION -PLANE SURFACE

LAWS OF REFRACTION (AT ANY REFRACTING SURFACE)

- **Laws of Refraction**

(i) Incident ray, refracted ray and normal always lie in the same plane .



In vector form $\boxed{(\hat{e} \times \hat{n}).\hat{r} = 0}$

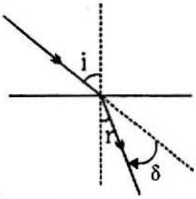
(ii) The product of refractive index and sine of angle of incidence at a point in a medium is constant. μ_1 sin i = μ_2 sin r (Snell's law)

Snell's law :

$$\boxed{\frac{\text{Sin i}}{\text{Sin r}} = {}_1n_2 = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}}$$ In vector form $\boxed{\mu_1 |\hat{\mathbf{e}} \times \hat{\mathbf{n}}| = \mu_2 |\hat{\mathbf{r}} \times \hat{\mathbf{n}}|}$

Note : Frequency of light does not change during refraction .

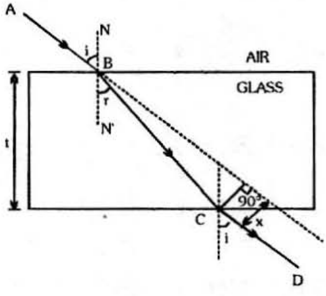
DEVIATION OF A RAY DUE TO REFRACTION



$\boxed{\text{angle of deviation, } \delta = i - r}$

REFRACTION THROUGH A PARALLEL SLAB :

Emerged ray is parallel to the incident ray, if medium is same on both sides.

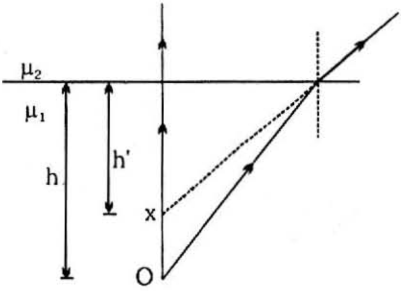


Lateral shift $x = \dfrac{t\sin(i-r)}{\cos r}$; t = thickness of slab

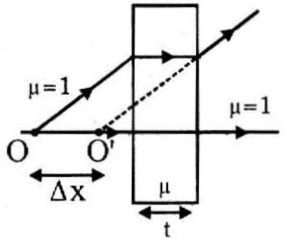
Note : Emerged ray will not be parallel to the incident ray if the medium on both the sides are different.

APPARENT DEPTH OF SUBMERGED OBJECT : ($h' < h$)

$\mu_1 > \mu_2$



For near normal incidence $h' = \frac{\mu_2}{\mu_1} h$

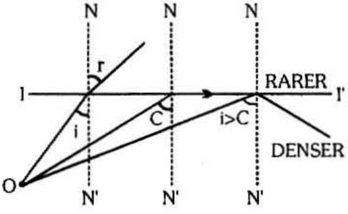


Δx = Apparent shift = $t\left(1-\frac{1}{\mu}\right)$

* always in direction of incidence ray.

Note : h and h' are always measured from surface.

CRITICAL ANGLE & TOTAL INTERNAL REFLECTION (TIR)



Conditions of TIR

- Ray is going from denser to rarer medium
- Angle of incidence should be greater than the critical angle ($i > C$) .

Critical angle $C = \sin^{-1}\frac{\mu_R}{\mu_D} = \sin^{-1}\frac{v_D}{v_R} = \sin^{-1}\frac{\lambda_D}{\lambda_R}$

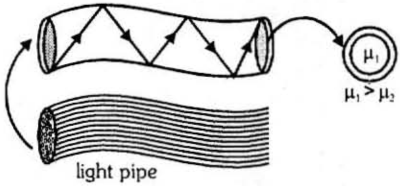
Some Illustrations of Total Internal Reflection

- **Sparkling of diamond**

  The sparkling of diamond is due to total internal reflection inside it. As refractive index for diamond is 2.5 so C= 24°. Now the cutting of diamond are such that i > C. So TIR will take place again and again inside it. The light which beams out from a few places in some specific directions makes it sparkle.

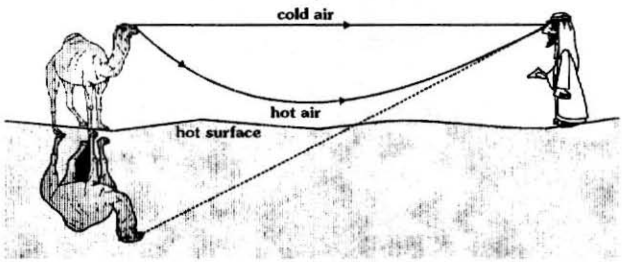
- **Optical Fibre**

In it light through multiple total internal reflections is propagated along the axis of a glass fibre of radius of few microns in which index of refraction of core is greater than that of surroundings (cladding)

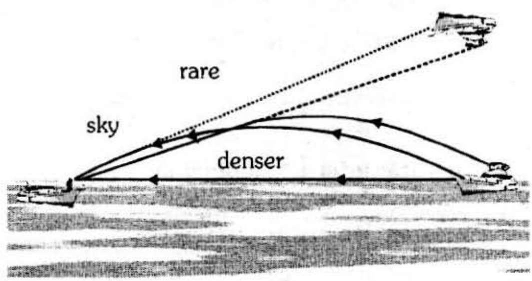


- **Mirage and looming**

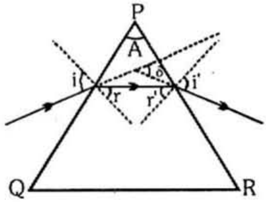
Mirage is caused by total internal reflection in deserts where due to heating of the earth, refractive index of air near the surface of earth becomes lesser than above it. Light from distant objects reaches the surface of earth with $i > \theta_C$ so that TIR will take place and we see the image of an object along with the object as shown in figure.



Similar to 'mirage' in deserts, in polar regions 'looming' takes place due to TIR. Here μ decreases with height and so the image of an object is formed in air if (i>C) as shown in figure.

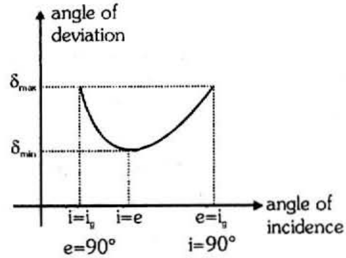


REFRACTION THROUGH PRISM :



• $\delta = (i + i') - (r + r')$ • $r + r' = A$

- Variation of δ versus i

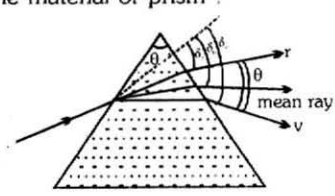


- There is one and only one angle of incidence for which the angle of deviation is minimum. When $\delta = \delta_m$ then $i = i'$ & $r = r'$, the ray passes symetrically about the prism, & then $n = \dfrac{\sin\left[\dfrac{A+\delta m}{2}\right]}{\sin\left[\dfrac{A}{2}\right]}$, where n = absolute R.I. of glass.

  Note : When the prism is dipped in a medium then n = R.I. of glass w.r.t. medium .

- For a thin prism ($A \le 10°$) ; $\delta = (n-1)A$
- **Dispersion Of Light** : The angular splitting of a ray of white light into a number of components when it is refracted in a medium other than air is called ***Dispersion of Light.***
- **Angle of Dispersion :** Angle between the rays of the extreme colours in the refracted (dispersed) light is called Angle of Dispersion. $\theta = \delta_v - \delta_r$.
- Dispersive power (ω) of the medium of the material of prism .

$$\omega = \frac{\text{angular dispersion}}{\text{deviation of mean ray (yellow)}}$$



For small angled prism ($A \le 10°$); $\omega = \dfrac{\delta_v - \delta_R}{\delta_y} = \dfrac{n_v - n_R}{n-1}$; $n = \dfrac{n_v + n_R}{2}$

n_v, n_R & n are R. I. of material for violet, red & yellow colours respectively .

- **Combination Of Two Prisms :**

  Achromatic Combination : It is used for deviation without dispersion . Condition for this $(n_v - n_r)\,A = -(n'_v - n'_r)\,A'$.

  Net mean deviation $= \left[\dfrac{n_v + n_R}{2} - 1\right]A - \left[\dfrac{n'_v + n'_R}{2} - 1\right]A'$ or $\omega\delta + \omega'\delta' = 0$ where

  ω, ω' are dispersive powers for the two prisms & δ , δ' are the mean deviation.

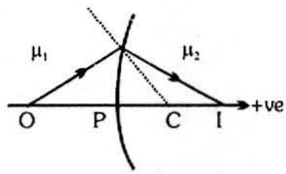
  Direct Vision Combination : It is used for producing disperion without deviation

  condition for this $\left[\dfrac{n_v + n_R}{2} - 1\right]A = -\left[\dfrac{n'_v + n'_R}{2} - 1\right]A'$

  Net angle of dispersion $= (n_v - n_r)\,A - (n_v' - n_r')\,A'$.

REFRACTION AT SPHERICAL SURFACE

(a) $\dfrac{\mu_2}{v} - \dfrac{\mu_1}{u} = \dfrac{\mu_2 - \mu_1}{R}$



v, u & R are to be kept with sign as

$v = PI$

$u = -PO$

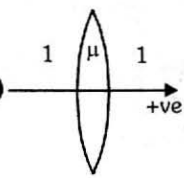
$R = PC$

(Note : Radius is with sign)

(b) $m = \dfrac{\mu_1 v}{\mu_2 u}$

Lens Formula :

(a)



$\dfrac{1}{v} - \dfrac{1}{u} = \dfrac{1}{f}$ **(b)** $\dfrac{1}{f} = (\mu - 1)\left(\dfrac{1}{R_1} - \dfrac{1}{R_2}\right)$ **(c)** $m = \dfrac{v}{u}$

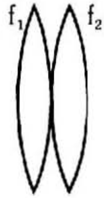
Power of Lenses

Reciprocal of focal length in meter is known as power of lens.

SI unit : dioptre (D) **Power of lens :** $P = \dfrac{1}{f(m)} = \dfrac{100}{f(cm)}$ dioptre

Combination of Lenses

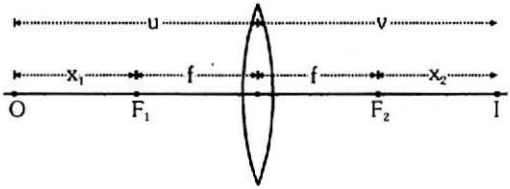
Two thin lens are placed in contact to each other



Power of combination. $P = P_1 + P_2 \Rightarrow \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2}$

Use sign convention when solve numericals

Newton's Formula

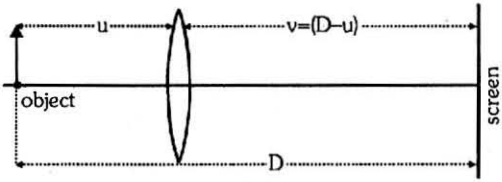


$\boxed{f = \sqrt{x_1 x_2}}$

x_1 = distance of object from focus; x_2 = distance of image from focus.

Displacement Method

It is used for determination of focal length of convex lens in laboratory. A thin convex lens of focal length f is placed between an object and a screen fixed at a distance D apart.



(i) For D<4f: u will be imaginary hence physically no position of lens is possible

(ii) **For D = 4f :** $u = \frac{D}{2} = 2f$ so only one position of lens is possible and since

$v = D - u = 4f - 2f = u = 2f$

(iii) **For D > 4f :** $u_1 = \frac{D - \sqrt{D(D-4f)}}{2}$ and $u_2 = \frac{D + \sqrt{D(D-4f)}}{2}$

So there are two positions of lens for which real image will be formed on the screen.

For two positions of the lens distances of object and image are interchangeable.

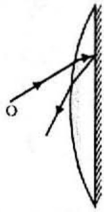
so $u_1 = \frac{D - x}{2} = v_2$ and $v_1 = \frac{D + x}{2} = u_2$

$$m_1 = \frac{I_1}{O} = \frac{v_1}{u_1} = \frac{D+x}{D-x} \text{ and } m_2 = \frac{I_2}{O} = \frac{v_2}{u_2} = \frac{D-x}{D+x}$$

$$\text{Now } m_1 \times m_2 = \frac{D+x}{D-x} \times \frac{D-x}{D+x} \Rightarrow \frac{I_1 I_2}{O^2} = 1 \Rightarrow \boxed{O = \sqrt{I_1 I_2}}$$

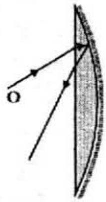
- **Silvering of one surface of lens** [use $P_{eq} = 2P_l + P_m$]

❒ When plane surface is silvered



$$F = \frac{R}{2(\mu - 1)}$$

❒ When convex surface is silvered



$$F = \frac{R}{2\mu}$$

OPTICAL INSTRUMENTS

- **For Simple microscope**
  - ❒ Magnifying power when image is formed at D : MP = 1 + D/f
  - ❒ When image is formed at infinity MP = D/f

- **For Compound microscope** : $MP = -\frac{v_0}{u_0}\left(\frac{D}{u_e}\right)$

❒ Magnifying power when final image is formed at D, $MP = -\frac{v_0}{u_0}\left(1 + \frac{D}{f_e}\right)$

❒ Tube length $L = v_0 + |u_e|$

❒ When final image is formed at infinity $MP = -\frac{v_0}{u_0} \times \frac{D}{f_e}$ and $L = v_0 + f_e$

- **Astronomical Telescope :** $MP = -\frac{f_0}{u_e}$

  - Magnifying power when final image is formed at D: $MP = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)$
  - Tube length : $L = f_0 + |u_e|$
  - When final image is formed at infinity : $MP = -\frac{f_0}{f_e}$ and $L = f_0 + f_e$

- **For terrestrial telescope** : $MP = \frac{f_0}{f_e}$ and $L = f_0 + f_e + 4f$

- **For Galilean telescope** : $MP = \frac{f_0}{f_e}$ & $L = f_0 - f_e$

- **Lens camera** : Time of exposure $\propto \frac{1}{(\text{aperture})^2}$, f – number = $\frac{\text{focal length}}{\text{aperture}}$

- **For myopia or short-sightedness or near sightedness** $\frac{1}{\text{F.P.}} - \frac{1}{\text{object}} = \frac{1}{f} = P$

  $f = -\text{F.P.}$

- **For long - sightedness or hypermetropia** $\frac{1}{\text{N.P.}} - \frac{1}{\text{object}} = \frac{1}{f} = P$

- **Limit of resolution for microscope** $= \frac{1.22\lambda}{2a\sin\theta} = \frac{1}{\text{resolving power}}$

- **Limit of resolution for telescope** $= \frac{1.22\lambda}{a} = \frac{1}{\text{resolving power}}$

KEY POINTS :

- For observing traffic at our back we prefer to use a convex mirror because a convex mirror has a more larger field of view than a plane mirror or concave mirror.
- A ray incident along normal to a mirror retraces its path because in reflection angle of incidence is always equal to angle of reflection.
- Images formed by mirrors do not show chromatic aberration because focal length of mirror is independent of wavelength of light and refractive index of medium.

- Light from an object falls on a concave mirror forming a real image of the object. If both the object and mirror are immersed in water, there is no change in the position of image because the formation of image by reflection does not depend on surrounding medium, there is no change in position of image provided it is also formed in water.
- The images formed by total internal reflections are much brighter than those formed by mirrors and lenses because there is no loss of intensity in total internal reflection.
- A fish inside a pond will see a person outside taller than he is actually because light bend away from the normal as it enters water from air.
- A fish in water at depth h sees the whole outside world in horizontal circle of radius.

$$r = h \tan\theta_C = \frac{h}{\sqrt{\mu^2 - 1}}$$

- Just before setting, the Sun may appear to be elliptical due to refraction because refraction of light ray through the atmosphere may cause different magnification in mutually perpendicular directions.
- A lens have two principal focal lengths which may differ because light can fall on either surface of the lens. The two principal focal lengths differ when medium on two sides have different refractive indices.
- A convex lens behaves as a concave lens when placed in a medium of refractive index greater than the refractive index of its material because light in that case will travel through the convex lens from denser to rarer medium. It will bend away from the normal, i.e., the convex lens would diverge the rays.
- If lower half of a lens is covered with a black paper, the full image of the object is formed because every portion of lens forms the full image of the object but sharpness of image decrease.
- Sun glasses have zero power even though their surfaces are curved because both the surfaces of the Sun glasses are curved in the same direction with same radii.

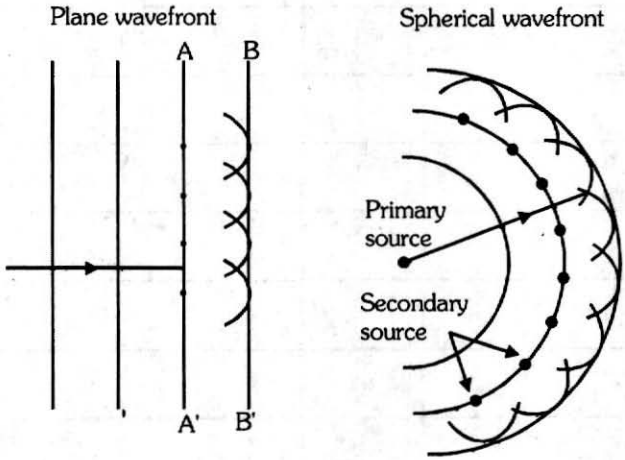
Important Notes

22 Wave Nature of Light and Wave optics

Huygen's Wave Theory :

Huygen's in 1678 assumed that a body emits light in the form of waves.

- Each point source of light is a centre of disturbance from which waves spread in all directions. The locus of all the particles of the medium vibrating in the same phase at a given instant is called a wavefront.
- Each point on a wave front is a source of new disturbance, called secondary wavelets. These wavelets are spherical and travel with speed of light in that medium.
- The forward envelope of the secondary wavelets at any instant gives the new wavefront.
- In homogeneous medium, the wave front is always perpendicular to the direction of wave propagation.



Coherent Sources :

Two sources will be coherent if and only if they produce waves of same frequency (and hence wavelength) and have a constant initial phase difference.

Incoherent sources :

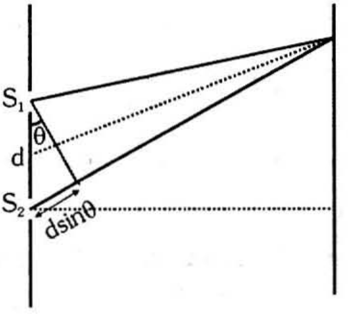
Two sources are said to be incoherent if they have different frequency and initial phase difference is not constant w.r.t. time.

Interference : YDSE

- Resultant intensity for coherent sources $I = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi_0$
- Resultant intensity for incoherent sources $I = I_1 + I_2$
- Intensity $\propto$ width of slit $\propto$ (amplitude)^2

$$\Rightarrow \frac{I_1}{I_2} = \frac{W_1}{W_2} = \frac{a_1^2}{a_2^2} \Rightarrow \frac{I_{max}}{I_{min}} = \frac{\left(\sqrt{I_1}+\sqrt{I_2}\right)^2}{\left(\sqrt{I_1}-\sqrt{I_2}\right)^2} = \left(\frac{a_1+a_2}{a_1-a_2}\right)^2$$

- Distance of n^{th} bright fringe $x_n = \frac{n\lambda D}{d}$



Path difference = $n\lambda$

where n =0, 1, 2, 3, ...

- Distance of m^{th} dark fringe

$$x_m = \frac{(2m+1)\lambda D}{2d}$$

Path difference = $(2m+1)\frac{\lambda}{2}$ where m = 0, 1, 2, 3,.....

- Fringe width $\beta = \frac{\lambda D}{d}$
- Angular fringe width = $\frac{\beta}{D} = \frac{\lambda}{d}$
- Fringe visibility = $\frac{I_{max} - I_{min}}{I_{max} + I_{min}} \times 100\,\%$
- If a transparent sheets of referactive index μ and thickness t is introduced in one of the paths of interfering waves, optial path will becomes 'μt' instead of 't'. Entire fringe pattern is displaced by $\frac{D[(\mu-1)t]}{d} = \frac{\beta}{\lambda}(\mu-1)t$ towards the side in which the thin sheet is introduced without any change in fringe width.

KEY POINTS

- The law of conservation of energy holds good in the phenomenon of interference.
- Fringes are neither image nor shadow of slit but locus of a point which moves such a way that its path difference from the two sources remains constant.
- In YPSE the interference fringes for two coherent point sources are hyperboloids with axis S_1S_2.
- If the interference experiment is repeated with bichromatic light, the fringes of two wavelengths will be coincident for the first time when

$$n(\beta)_{longer} = (n+1)(\beta)_{shorter}$$

- No interference pattern is detected when two coherent sources are infinitely close to each other, because $\beta \propto \frac{1}{d}$
- If maximum number of maximas or minimas are asked in the question, use the fact that value of $\sin\theta$ or $\cos\theta$ can't be greater than 1.

$n_{max} = \frac{d}{\lambda}$ Total maxima $= 2n_{max} + 1$

DIFFRACTION

- **In Fraunhofer diffraction**
  - For minima $\quad a \sin\theta_n = n\lambda$
  - For maxima $\quad a \sin\theta_n = (2n + 1)\frac{\lambda}{2}$
  - Linear width of central maxima $\quad W_x = \frac{2\lambda D}{a}$
  - Angular width of central maxima $\quad W_\theta = \frac{2\lambda}{a}$
  - Intensity of maxima

    Where I_0 = Intensity of central maxima

    $I = I_0\left[\frac{\sin(\beta/2)}{\beta/2}\right]^2$ and $\beta = \frac{2\pi}{\lambda} a \sin\theta$

- **Polarization :**
  - Brewsters' law :-

    $\mu = \tan\theta_p \rightarrow$

    $\theta_p \rightarrow$ polarization of Brewster's angle
  - Here reflecting and refracting rays are perpendirular to each other.
  - Malus law :-

    $I = I_0 \cos^2\theta$

    $I_0 \rightarrow$ Maximum intensity of polarized light.

Important Notes

23 Modern Physics

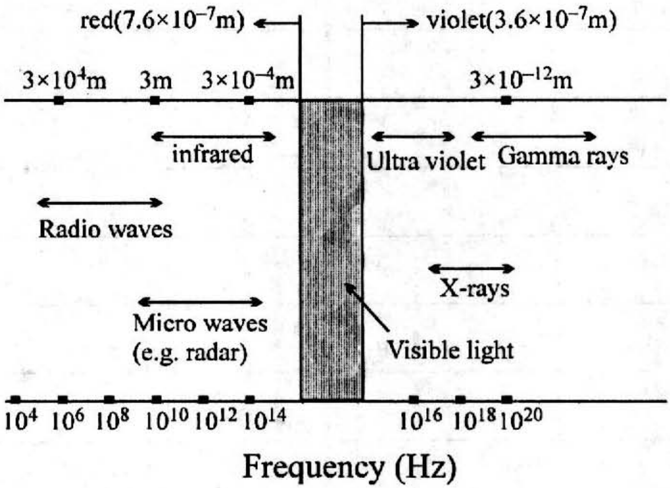
Cathode rays :

- Generated in a discharge tube in which a high vaccum is maintained.
- They are electrons accelerated by high potential difference(10 to 15 kV)
- K.E. of C.R. particle accelerated by a p.d. V is $eV = \frac{1}{2}mv^2 = \frac{p^2}{2m}$
- Can be deflected by Electric & magnetic fields.

Electromagnetic Spectrum :

Ordered arrangement of the big family of electro magnetic waves (EMW) either in ascending order of frequencies or decending order of wave lengths.

Speed of E.M.W. in vacuum : $c = 3 \times 10^8$ m/s = $\nu\lambda$



PLANK'S QUANTUM THEORY

A beam of EMW is a stream of discrete packets of energy called **PHOTONS**; each photon having a frequency ν and energy = $E=h\nu$

where h = planck's constant = 6.63×10^{-34} J-s.

- According to Planck the energy of a photon is directly proportional to the frequency of the radiation.

$$E = \frac{hc}{\lambda} = \frac{12400}{\lambda} eV - \mathring{A} \qquad \left[\because \frac{hc}{e} = 12400(\mathring{A} - eV)\right]$$

- Effective mass of photon $m = \frac{E}{c^2} = \frac{hc}{c^2\lambda} = \frac{h}{c\lambda}$ i.e. $m \propto \frac{1}{\lambda}$

So mass of violet light photon is greater than the mass of red light photon. $(\because \ \lambda_R > \lambda_V)$

- Linear momentum of photon $p = \frac{E}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$

- **Intensity of light** : $I = \frac{E}{At} = \frac{P}{A}$ ...(i)

Here P = power of source, A = Area, t = time taken

E = energy incident in t time = Nhν N = no. of photon incident in t time

Intensity $I = \frac{N(h\nu)}{At} = \frac{n(h\nu)}{A}$ ...(ii) $\left[\because n = \frac{N}{t} = \text{no. of photon per sec.}\right]$

From equation (i) and (ii), $\frac{P}{A} = \frac{n(h\nu)}{A} \Rightarrow n = \frac{P}{h\nu} = \frac{P\lambda}{hc} = 5 \times 10^{24} J^{-1} m^{-1} \times P \times \lambda$

- **Force exerted on perfectly reflecting surface**

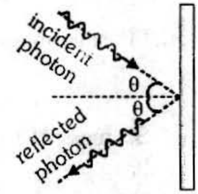
$\therefore \quad F = n\left(\frac{2h}{\lambda}\right) = \frac{2P}{c}$ and Pressure $= \frac{F}{A} = \frac{2P}{cA} = \frac{2I}{c} \left[\because I = \frac{P}{A}\right]$

- **Force exerted on perfectly absorbing surface**

$$F = \frac{P}{c}\left(\because n = \frac{P\lambda}{hc}\right) \text{ and } \text{Pressure} = \frac{F}{A} = \frac{P}{Ac} = \frac{I}{c}$$

- **When a beam of light is incident at angle θ on perfectly reflector surface**

$$F = \frac{2IA\cos^2\theta}{c}$$



- **When a beam of light is incident at angle θ on perfectly absorbing surface** $F = \dfrac{IA\cos\theta}{c}$

PHOTO ELECTRIC EFFECT

The phenomenon of the emission of electrons, when metals are exposed to light (of a certain minimum frequency) is called photo electric effect.

Results :

- Can be explained only on the basis of the quantum theory (concept of photon)
- Electrons are emitted if the incident light has frequency $\nu \geq \nu_0$ (threshold frequency). Emission of electrons is independent of intensity . The wave length corresponding to ν_0 is called threshold wave length λ_0.
- ν_0 is different for different metals.
- Number of electrons emitted per second depends on the intensity of the incident light.

EINSTEINS PHOTO ELECTRIC EQUATION :

Photon energy = KE_{max} of electron + work function

$h\nu = KE_{max} + \phi$

ϕ = Work function = energy needed by the electron in freeing itself from the atoms of the metal $\phi = h\nu_0$

STOPPING POTENTIAL OR CUT OFF POTENTIAL :

The minimum value of the retarding potential to prevent electron emission is

$$eV_{cut\ off} = (KE)_{max}$$

Note: The number of photons incident on a surface per unit time is called photon flux.

WAVE NATURE OF MATTER :

Beams of electrons and other forms of matter exhibit wave properties including interference and diffraction with a de Broglie wave length given by $\lambda = \frac{h}{p}$ (wave length of a praticle).

- **De Broglie wavelength associated with moving particles**

If a particle of mass m moving with velocity v.

Kinetic energy of the particle $E = \frac{1}{2}mv^2 = \frac{p^2}{2m}$

momentum of particle $p = mv = \sqrt{2mE}$

the wave length associated with the particles is $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{h}{\sqrt{2mE}}$

- **De Broglie wavelength associated with the charged particles :-**

- **For an Electron** $\lambda_e = \frac{12.27 \times 10^{-10}}{\sqrt{V}} m = \frac{12.27}{\sqrt{V}} \mathring{A}$ so $\lambda \propto \frac{1}{\sqrt{V}}$

- **For Proton** $\lambda_p = \frac{0.286 \times 10^{-10}}{\sqrt{V}} m = \frac{0.286}{\sqrt{V}} \mathring{A}$

- **For Deuteron** $\lambda_d = \frac{0.202}{\sqrt{V}} \mathring{A}$

- **For α Particles** $\therefore \lambda_\alpha = \frac{0.101}{\sqrt{V}} \mathring{A}$

ATOMIC MODELS :

(a) Thomson model : (Plum pudding model)

- Most of the mass and all the positive charge of an atom is uniformly distributed over the full size of atom (10^{-10} m).
- Electrons are studded in this uniform distribution .
- Failed to explain the large angle scattering α - particle scattered by thin foils of matter.

(b) Rutherford model : (Nuclear Model)

- The most of the mass and all the positive charge is concentrated within a size of 10^{-14} m inside the atom. This concentration is called the atomic nucleus.
- The electron revolves around the nucleus under electric interaction between them in circular orbits.
- An accelerating charge radiates the nucleus spiralling inward and finally fall into the nucleus, which does not happen in an atom. This could not be explained by this model.

(c) Bohr atomic model : Bohr adopted Rutherford model of the atom & added some arbitrary conditions. These conditions are known as his postulates

- The electron in a stable orbit does not radiate energy.
- A stable orbit is that in which the angular momentum of the electron about nucleus is an integral (n) multiple of $\frac{h}{2\pi}$ i.e. $mvr = n\frac{h}{2\pi}$; n=1, 2, 3, ..($n \neq 0$).
- The electron can absorb or radiate energy only if the electron jumps from a lower to a higher orbit or falls from a higher to a lower orbit.
- The energy emitted or absorbed is a light photon of frequency ν and of energy. $\mathbf{E = h\nu}$

For hydrogen atom : (Z = atomic number = 1)

- L_n = angular momentum in the n^{th} orbit = $n\frac{h}{2\pi}$.
- r_n = radius of n^{th} circular orbit = (0.529 Å) $n^2 \Rightarrow r_n \propto n^2$.
- E_n = Energy of the electron in the n^{th} orbit = $\frac{-13.6\text{ eV}}{n^2} \Rightarrow E_n \propto \frac{1}{n^2}$.

  Note : Total energy of the electron in an atom is negative, indicating that it is bound.

  Binding Energy $(BE)_n = -E_n = \frac{13.6\text{ eV}}{n^2}$

- $E_{n2} - E_{n1}$ = Energy emitted when an electron jumps from n_2^{th} orbit to n_1^{th} orbit ($n_2 > n_1$).

$$\Delta E = (13.6\text{ eV})\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

$\Delta E = h\nu$; ν = frequency of spectral line emitted .

$$\frac{1}{\lambda} = \text{wave no. [no. of waves in unit length (1m)]} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right]$$

Where R = Rydberg's constant, for hydrogen $= 1.097 \times 10^7 \text{ m}^{-1}$

- For hydrogen like atom/species of atomic number Z :

$$r_{nz} = \frac{\text{Bohr radius}}{Z} n^2 = (0.529 \text{ Å}) \frac{n^2}{Z};\ E_{nz} = (-13.6) \frac{Z^2}{n^2} \text{eV}$$

$R_z = RZ^2$; Rydberg's constant for element of atomic no. Z .

Note : If motion of the nucleus is also considered , then m is replaced by μ. Where μ= reduced mass of electron - nucleus system = mM/(m+M)

In this case $E_n = (-13.6 \text{ eV}) \dfrac{Z^2}{n^2} \cdot \dfrac{\mu}{m_e}$

Spectral series :

- **Lyman Series :** (Landing orbit n = 1) .

Ultraviolet region $\bar{\nu} = R\left[\dfrac{1}{1^2} - \dfrac{1}{n_2^2}\right]$; $n_2 > 1$

- **Balmer Series:** (Landing orbit n = 2)

Visible region $\bar{\nu} = R\left[\dfrac{1}{2^2} - \dfrac{1}{n_2^2}\right]$; $n_2 > 2$

- **Paschan Series :** (Landing orbit n = 3)

In the near infrared region $\bar{\nu} = R\left[\dfrac{1}{3^2} - \dfrac{1}{n_2^2}\right]$; $n_2 > 3$

- **Bracket Series :** (Landing orbit n = 4)

In the mid infrared region $\bar{\nu} = R\left[\dfrac{1}{4^2} - \dfrac{1}{n_2^2}\right]$; $n_2 > 4$

- **Pfund Series :** (Landing orbit n = 5)

In far infrared region $\bar{\nu} = R\left[\dfrac{1}{5^2} - \dfrac{1}{n_2^2}\right]$; $n_2 > 5$

In all these series $n_2 = n_1 + 1$ is the α line

$= n_1 + 2$ is the β line

$= n_1 + 3$ is the γ line.......etc.

where n_1 = Landing orbit

Total emission spectral lines

From $n_1 = n$ to $n_2 = 1$ state $= \dfrac{n(n-1)}{2}$

From $n_1 = n$ to $n_2 = m$ state $= \left(\dfrac{(n-m)(n-m+1)}{2}\right)$

Excitation potential of atom :

Excitation potential for quantum jump from $n_1 \rightarrow n_2 = \dfrac{E_{n2} - E_{n1}}{\text{electron charge}}$

Ionization energy of hydrogen atom :

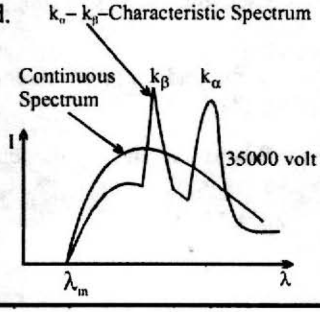
The energy required to remove an electron from an atom. The energy required to ionize hydrogen atom is $= 0 - (-13.6) = 13.6$ eV.

Ionization Potential :

Potential difference through which a free electron is moved to gain ionization energy $= \dfrac{-E_n}{\text{electronic charge}}$

X - RAYS :

- X–rays are produced by bombarding high speed electrons on a target of high atomic weight and high melting point.
- Short wavelength (0.1 Å to 10 Å) electromagnetic radiation.
- Are produced when a metal anode is bombarded by very high energy electrons
- Are not affected by electric and magnetic field.
- They cause photoelectric emission.



Characteristics equation $eV = h\nu_m$

e = electron charge;

V= accelerating potential

ν_m = maximum frequency of X – radiation

- Intensity of X - rays depends on number of electrons hitting the target .
- Cut off wavelength or minimum wavelength, where V (in volts) is the p.d. applied to the tube $\lambda_{min} \cong \frac{12400}{V} \mathring{A}$
- Continuous spectrum due to retardation of electrons .

Characteristic X-rays

For K_α, $\lambda = \frac{hc}{E_K - E_L}$ For K_β, $\lambda = \frac{hc}{E_L - E_M}$

Moseley's law for characteristic spectrum :

Frequency of characteristic line $\sqrt{\nu} = a(Z-b)$

Where a, b are constant, for K_α line b = 1

Z = atomic number of target

ν = frequency of characteristic spectrum

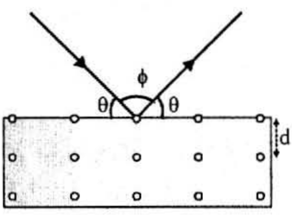
b = screening constant (for K– series b=1, L series b=7.4),

a = proportionality constant

Bohr model	**Moseley's correction**
1. For single electron species	**1.** For many electron species
2. $\Delta E = 13.6Z^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]eV$	**2.** $\Delta E = 13.6\,(Z-b)^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]eV$
3. $\nu = RcZ^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$	**3.** $\nu = Rc(Z-b)^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$
4. $\frac{1}{\lambda} = RZ^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$	**4.** $\frac{1}{\lambda} = R(Z-b)^2\left[\frac{1}{n_1^2}-\frac{1}{n_2^2}\right]$

Diffraction of X–ray

Diffraction of X–ray take place according to Bragg's law $2d\sin\theta = n\lambda$



d = spacing of crystal plane or lattice constant or distance between adjacent atomic plane

θ = Bragg's angle or glancing angle

ϕ = Diffracting angle n = 1, 2, 3 ....

For Maximum Wavelength

$\sin\theta = 1, n = 1 \Rightarrow \lambda_{max} = 2d$

so if $\lambda > 2d$ diffraction is not possible i.e. solution of Bragg's equation is not possible.

KEY POINTS

- Binding energy = – [Total Mechanical Energy]
- Velocity of electron in n^{th} orbit for hydrogen atom $\cong \frac{c}{137n}$; c = speed of light.
- Series limit means minimum wave length of that series.

NUCLEAR COLLISIONS

We can represent a nuclear collision or reaction by the following notation, which means X (a,b) Y

$$\underset{\text{(bombarding particle)}}{a} + \underset{\text{(at rest)}}{X} \rightarrow Y + b$$

We can apply :

(i) Conservation of momentum (ii) Conservation of charge (iii) Conservation of mass–energy

For any nuclear reaction $\underset{K_1}{a} + \underset{K_2}{X} \rightarrow \underset{K_3}{Y} + \underset{K_4}{b}$

By mass energy conservation

(i) $K_1 + K_2 + (m_a + m_x)c^2 = K_3 + K_4 + (m_Y + m_b)c^2$

(ii) Energy released in any nuclear reaction or collision is called Q value of the reaction.

(iii) $Q = (K_3 + K_4) - (K_1 + K_2) = \Sigma K_P - \Sigma K_R = (\Sigma m_R - \Sigma m_P)c^2$

(iv) If Q is positive, energy is released and products are more stable in comparison to reactants.

(v) If Q is negative, energy is absorbed and products are less stable in comparison to reactants.

$$Q = \Sigma(B.E.)_{product} - \Sigma(B.E.)_{reactants}$$

Nuclear Fission

In 1938 by Hahn and Strassmann. By attack of a particle splitting of a heavy nucleus (A > 230) into two or more lighter nuclei. In this process certain mass disappears which is obtained in the form of energy (enormous amount)

$$A + p \longrightarrow \text{excited nucleus} \longrightarrow B + C + Q$$

Nuclear Fusion :

It is the phenomenon of fusing two or more lighter nuclei to form a single heavy nucleus.

$$A + B \rightarrow C + Q \text{ (Energy)}$$

The product (C) is more stable then reactants (A and B) and $m_c < (m_a + m_b)$

and mass defect $\Delta m = [(m_a + m_b) - m_c]$ amu

Energy released is $E = \Delta m$ 931 MeV

The total binding energy and binding energy per nucleon C both are more than of A and B. $\Delta E = E_c - (E_a + E_b)$

RADIOACTIVITY

- **Radioactive Decays :** Generally, there are three types of radioactive decays
  (i) α decay (ii) β^- and β^+ decay (iii) γ decay
- **α decay:** By emitting α particle, the nucleus decreases it's mass number and move towards stability. Nucleus having A>210 shows α decay.
- **β decay** : In beta decay, either a neutron is converted into proton or proton is converted into neutron.
- **γ decay** : When an α or β decay takes place, the daughter nucleus is usually in higher energy state, such a nucleus comes to ground state by emitting a photon or photons.
  Order of energy of γ photon is 100 keV
- **Laws of Radioactive Decay :** The rate of disintegration is directly proportional to the number of radioactive atoms present at that time i.e., rate of decay $\propto$ number of nuclei.

  Rate of decay = λ (number of nuclei) i.e., $\frac{dN}{dt} = -\lambda N$

  where λ is called the decay constant.

  This equation may be expressed in the form $\frac{dN}{N} = -\lambda dt$.

  $$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int_0^t dt \Rightarrow \ell n\left(\frac{N}{N_0}\right) = -\lambda t$$

  where N_0 is the number of parent nuclei at t=0. The number that survives at time t is therefore $N = N_0 e^{-\lambda t}$ and $t = \frac{2.303}{\lambda}\log_{10}\left(\frac{N_0}{N_t}\right)$

  $N = N_0 e^{-\lambda t}$ where λ = decay constant

- Half life $t_{1/2} = \frac{\ell n 2}{\lambda}$

- Average life $t_{av} = \frac{1}{\lambda}$

  - Within duration $t_{1/2} \Rightarrow$ 50% of N_0 decayed and 50% of N_0 remains active
  - Within duration $t_{av} \Rightarrow$ 63% of N_0 decayed and 37% of N_0 remains active

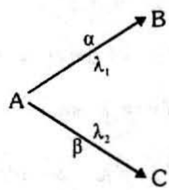
- Activity $R = \lambda N = R_0 e^{-\lambda t}$
- 1Bq = 1 decay/s,
- 1 curie = 3.7×10^{10} Bq,
- 1 rutherford = 10^6Bq

- After n half lives Number of nuclei left $= \frac{N_0}{2^n}$

- Probability of a nucleus for survival of time t $= \frac{N}{N_0} = \frac{N_0 e^{-\lambda t}}{N_0} = e^{-\lambda t}$

- **Parallel radioactive disintegration**

Let initial number of nuclei of A is N_0 then at any time number of nuclei of A, B & C are given by $N_0 = N_A + N_B + N_C$



$$\Rightarrow \frac{dN_A}{dt} = \frac{-d}{dt}(N_B + N_C)$$

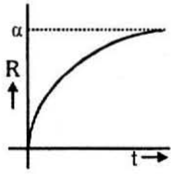
A disintegrates into B and C by emitting α,β particle.

Now, $\frac{dN_B}{dt} = -\lambda_1 N_A$ and $\frac{dN_C}{dt} = -\lambda_2 N_A \Rightarrow \frac{d}{dt}(N_B + N_C) = -(\lambda_1 + \lambda_2) N_A$

$$\Rightarrow \frac{dN_A}{dt} = -(\lambda_1 + \lambda_2) N_A \Rightarrow \lambda_{eff} = \lambda_1 + \lambda_2 \Rightarrow t_{eff} = \frac{t_1 t_2}{t_1 + t_2}$$

Radioactive Disintegration with Successive

Production $\xrightarrow[(\alpha = \text{rate of production})]{\alpha} A \xrightarrow{\lambda} B$



$$\frac{dN_A}{dt} = \alpha - \lambda N_A \text{ ....(i)}$$

when N_A is maximum $\frac{dN_A}{dt} = 0 \Rightarrow \alpha - \lambda N_A = 0$,

$$N_{A\,max} = \frac{\alpha}{\lambda} = \frac{\text{rate of production}}{\lambda}$$

By equation (i) $\int_0^t \frac{dN_A}{\alpha - \lambda N_A} = \int_0^t dt$, Number of nuclei is $N_A = \frac{\alpha}{\lambda}\left(1 - e^{-\lambda t}\right)$

- **Equivalence of mass and energy** $E = mc^2$

  Note :- $1u = 1.66 \times 10^{-27}$ kg $\equiv 931.5$ MeV or $c^2 = 931.5$ MeV/u

- **Binding energy of $_ZX^A$**

  $BE = \Delta mc^2 = [Zm_p + (A-Z)m_n - m_X]c^2 = [Zm_H + (A-Z)m_n - m_X]c^2$

- **Q-value of a nuclear reaction**

  For $a + X \longrightarrow Y + b$ or $X\,(a, b)Y$; $Q = (M_a + M_X - M_Y - M_b)c^2$

- **Radius of the nucleus**

  $R = R_0A^{1/3}$ where $R_0 = 1.3\ f_m = 1.3 \times 10^{-15}$ m

From Bohr Model

$n_1 = 1, \quad n_2 = 2, 3, 4$.......K series

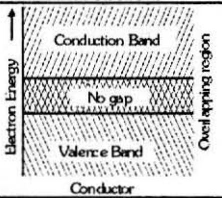
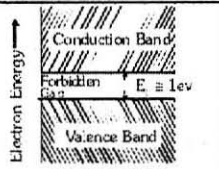
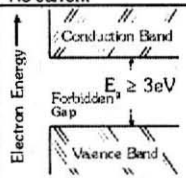
$n_1 = 2, \quad n_2 = 3, 4, 5$.......L series

$n_1 = 3, \quad n_2 = 4, 5, 6$.......M series

Important Notes

24 Semiconductor and Digital Electronics

Comparison between conductor, semiconductor and insulator :

Properties	**Conductor**	**Semiconductor**	**Insulator**
Resistivity	$10^{-2}-10^{-8}$ Ωm	$10^{-5}-10^{6}$ Ωm	$10^{11}-10^{19}$ Ωm
Conductivity	$10^{2}-10^{8}$ mho/m	$10^{5}-10^{-6}$ mho/m	$10^{-11}-10^{-19}$ mho/m
Temp. Coefficient of resistance (α)	Positive	Negative	Negative
Current	Due to free electrons	Due to electrons and holes	No current
Energy band diagram	 Conductor	 Semi conductor	 Insulator
Forbidden energy gap	$\cong 0eV$	$\cong 1eV$	$\geq 3eV$
Example	Pt, Al, Cu, Ag	Ge, Si, GaAs, GaF_2	Wood, plastic, Diamond, Mica

- **Number of electrons reaching from valence band to conduction band**

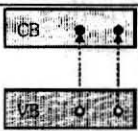
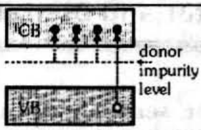
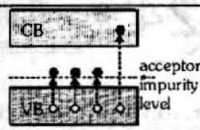
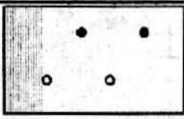
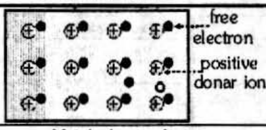
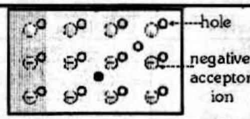
$$n = AT^{3/2}\, e^{-\frac{\Delta E_g}{2kT}}$$

- **Classification of Semiconductors :**

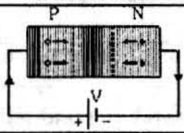
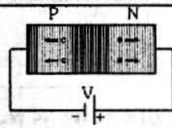
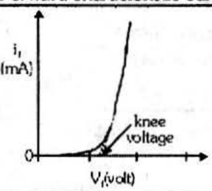
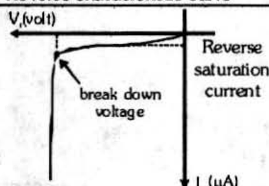
SEMICONDUCTOR

- Intrinsic semiconductor
  - (pure form of Ge, Si) $n_e = n_h = n_i$
- Extrinsic semiconductor (doped semicondutor)
  - N-type: pentavalent impurity (P, As, Sb etc.) donar impurity (N_D) $n_e >> n_h$
  - P-type: trivalent impurity (Ga, B, In, Al) acceptor impurity (N_A) $n_h >> n_e$

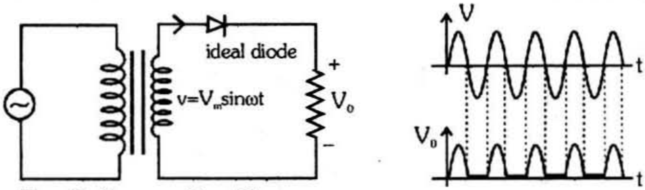
- **Mass-action law** $n_i^2 = n_e \times n_h$
  - ☐ For N-type semiconductor $n_e = N_D$
  - ☐ For P-type semiconductor $n_h = N_A$
- **Conductivity** $n_i e(\mu_e + \mu_h)$

Intrinsic Semiconductor	N-type (Pentavalent impurity)	P-type (Trivalent impurity)
		
		
Current due to electron and hole	Mainly due to electrons	Mainly due to holes
$n_e = n_h = n_i$	$n_h << n_e$ ($N_D \simeq n_e$)	$n_h >> n_e$ ($N_A \simeq n_h$)
$I = I_e + I_h$	$I \simeq I_e$	$I \simeq I_h$
Entirely neutral	Entirely neutral	Entirely neutral
Quantity of electrons and holes are equal	Majority – Electrons Minority – Holes	Majority – Holes Minority - Electrons

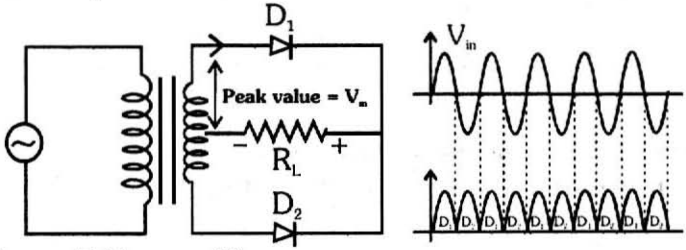
Comparison between Forward Bias and Reverse Bias

	Forward Bias		Reverse Bias
			
1	Potential Barrier reduces	1	Potential Barrier increases.
2	Width of depletion layer decreases	2	Width of depletion layer increases.
3	P-N jn. provide very small resistance	3	P-N jn. provide high resistance
4	Forward current flows in the circuit	4	Very small current flows.
5	Order of forward current is milli ampere.	5	Order of current is micro ampere for Ge or Neno ampere for Si.
6	Current flows mainly due to majority carriers.	6	Current flows mainly due to minority carriers.
7	Forward characteristic curves.	7	Reverse characteristic curve
			
8	Forward resistance : $R_f = \frac{\Delta V_f}{\Delta I_f} \cong 100\Omega$	8	Reverse resistance : $R_r = \frac{\Delta V_r}{\Delta I_r} \cong 10^6\Omega$
9	Order of knee or cut in voltage	9	Breakdown voltage
	Ge→ 0.3 V		Ge → 25 V
	Si → 0.7 V		Si → 35 V
	Special point : Generally $\frac{R_r}{R_f} = 10^3 : 1$ for Ge		$\frac{R_r}{R_f} = 10^4 : 1$ for Si

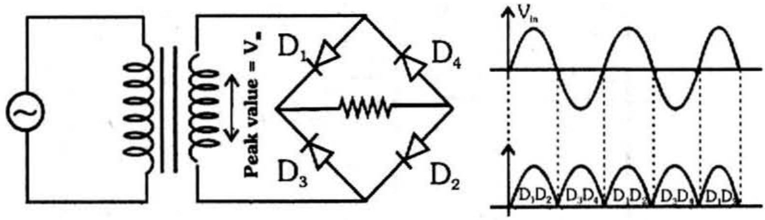
• **Half wave rectifier**



• **Centre – Tap Full wave Rectifier**



• **Full wave Bridge reactifier**

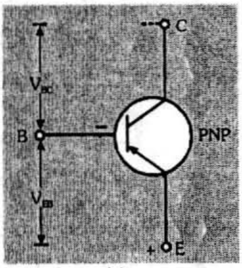


- **Form factor** = $\dfrac{I_{rms}}{I_{dc}}$
  - ☐ For HWR (Half wave rectifier) Form factor = $\dfrac{\pi}{2}$
  - ☐ For FWR (Full wave rectifier) Form factor = $\dfrac{\pi}{2\sqrt{2}}$

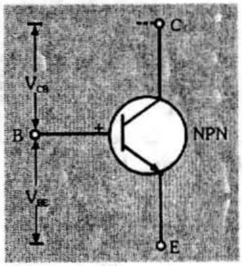
- **Ripple factor** $r = \dfrac{I_{ac}}{I_{dc}}$
  - ☐ For HWR $r = 1.21$ ☐ For FWR $r = 0.48$

- **Rectifier efficiency** $\eta = \dfrac{P_{dc}}{P_{ac}} = \dfrac{I_{dc}^2 R_L}{I_{rms}^2 (R_F + R_L)}$
  - ☐ For HWR $\eta\% = \dfrac{40.6}{1 + \dfrac{R_F}{R_L}}$ & FWR $\eta\% = \dfrac{81.2}{1 + \dfrac{R_F}{R_L}}$

- **For transistor** $I_E = I_B + I_C$



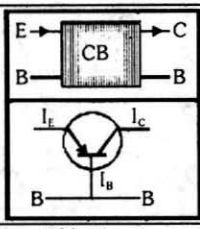
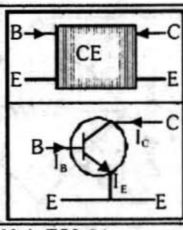
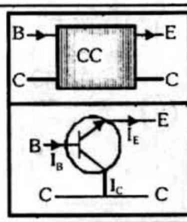
(a)



(b)

Comparative study of transistor configurations

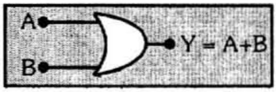
1. Common Base **(CB)** 2. Common Emitter **(CE)**
3. Common Collector **(CC)**

	CB	**CE**	**CC**
			
Input Resistance	Low (100 Ω)	High (750 Ω)	Very High ≅ 750 kΩ
Output resistance	Very High	High	Low
Current Gain	(A_i or α)	(A_i or β)	(A_i or γ)
	$\alpha = \frac{I_C}{I_E} < 1$	$\beta = \frac{I_C}{I_B} > 1$	$\gamma = \frac{I_E}{I_B} > 1$
Voltage Gain	$A_V = \frac{V_o}{V_i} = \frac{I_C R_L}{I_E R_i}$	$A_V = \frac{V_o}{V_i} = \frac{I_C R_L}{I_B R_i}$	$A_V = \frac{V_o}{V_i} = \frac{I_E R_L}{I_B R_i}$
	$A_v = \alpha \frac{R_L}{R_i} \cong 150$	$A_v = \beta \frac{R_L}{R_i} \cong 500$	$A_v = \gamma \frac{R_L}{R_i} < 1$
Power Gain	$A_p = \frac{P_o}{P_i} = \alpha^2 \frac{R_L}{R_i}$	$A_p = \frac{P_o}{P_i} = \beta^2 \frac{R_L}{R_i}$	$A_p = \frac{P_o}{P_i} = \gamma^2 \frac{R_L}{R_i}$
Phase difference (between output and input)	same phase	opposite phase	same phase
Application	For High Frequency	For Audible frequency	For Impedance Matching

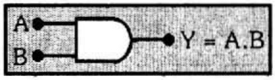
- **Relation between α, β and γ :** $\beta = \dfrac{\alpha}{1-\alpha},\ \gamma = 1+\beta,\ \gamma = \dfrac{1}{1-\alpha}$

- **Logic gates**

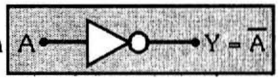
  - OR gate



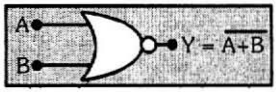
  - AND gate



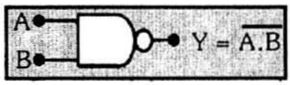
  - NOT gate



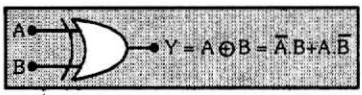
  - NOR gate



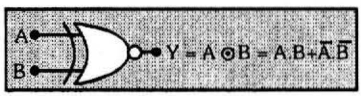
  - NAND gate



  - XOR gate



  - XNOR gate



- **De Morgan's theorem** $\overline{A+B} = \overline{A}\cdot\overline{B},\ \overline{A\cdot B} = \overline{A}+\overline{B}$

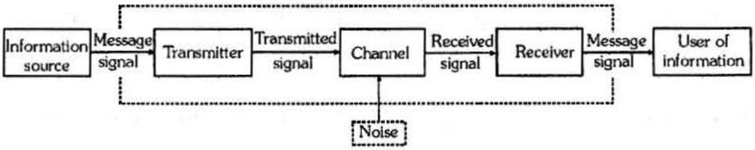
OR	AND	NOT
$A + 0 = A$	$A.\ 0 = 0$	$A + \overline{A} = 1$
$A + 1 = 1$	$A.\ 1 = A$	$A \cdot \overline{A} = 0$
$A + A = A$	$A\ .\ A = A$	$\overline{\overline{A}} \cdot A = A$

Important Notes

25 Communication System

Faithful transmission of information from one place to another place is called communication.

Basic components of a communication system



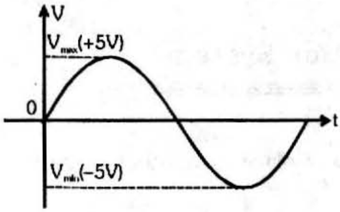
- **Transmitter :** Transmitter converts the message signal produced by information source into a form (e.g. electrial signal) that is suitable for transmission through the channel to the receiver.
- **Communication channel** : Communication channel is a medium (transmission line, an optical fibre or free space etc) which connects a receiver and a transmitter. It carries the modulated wave from the transmitter to the receiver.
- **Receiver** : It receives and decode the signal into original form.

Important terms used in communication

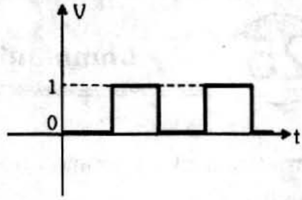
- **Transducer.** Transducer is the device that converts one form of energy into another. Microphone, photo detectors and piezoelectric sensors are types of transducer.
- **Signal** Signal is the information converted in electrical form. Signals can be analog or digital. Sound and picture signals in TV are analog.

  It is defined as a single–valued function of time which has a unique value at every instant of time.

  - **Analog Signal :–** A continuously varying signal (Voltage or Current) is called an analog signal. A decimal number with system base 10 is used to deal with analog signal.
  - **Digital Signal :–** A signal that can have only discrete stepwise values is called a digital signal. A binary number system with base 2 is used to deal with digital signals.



An analog signal



A Digital Signal

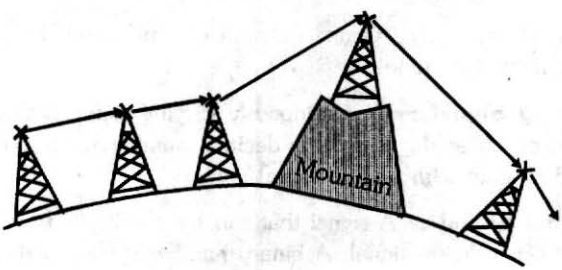
- **Noise :** There are unwanted signals that tend to disturb the transmission and processing of message signals. The source of noise can be inside or outside the system.

- **Attenuation :** It is the loss of strength of a signals while propagating through a medium. It is like damping of oscillations.

- **Amplification :** It is the process of increasing the amplitude (and therefore the strength) of a signal using an electronic circuit called the amplifier. Amplification is absolutely necessary to compensate for the attenuation of the signal in communication systems.

- **Range :** It is the largest distance between the source and the destination upto which the signal is received with sufficient strength.

- **Repeater :** A repeater acts as a receiver and a transmitter. A repeater picks up the signal which is coming from the transmitter, amplifies and retransmits it with a change in carrier frequency. Repeaters are necessary to extend the range of a communication system as shown in figure A communication satellite is basically a repeater station in space.



Use of repeater station to increase the range of communication

BANDWIDTH

- **Bandwidth of signals :** Different signals used in a communication system such as voice, music, picture, computer data etc. all have different ranges of frequency. The difference of maximum and minimum frequency in the range of each signal is called bandwidth of that signal.

  Bandwidth can be of message signal as well as of transmission medium.

  (i) Bandwidth for analog signals : Bandwidth for some analog signals are listed below :

Signal	Frequency range	Bandwidth required
Speech	300-3100 Hz	3100-300 =2800 Hz
Music	High frequencies produced by musical instrument audible range =20 Hz - 20 kHz	20 kHz
Picture	—	4.2 MHz
TV	Contains both voice and picture	6 MHz

  (ii) Bandwidth for digital signal : Basically digital signals are rectangular waves and these can be splited into a superposition of sinusoidal waves of frequencies ν_0, $2\nu_0$, $3\nu_0$, $4\nu_0$, ..$n\nu_0$, where n is an integer extending to infinity. This implies that the infinite band width is required to reproduce the rectangular waves. However, for practical purposes, higher harmonics are neglected for limiting the bandwidth

Bandwidth of Transmission Medium

Different types of transmission media offer different band width of which some are listed below

	Service	Frequency range	Remarks
1	Wire (most common : Coaxial Cable)	750 MHz (Bandwidth)	Normally operated below 18 GHz
2	Free space (radio waves)	540 kHz-4.2 GHz	
	(i) Standard AM	540 kHz to 30 MHz	
	(ii) FM	88-108 MHz	
	(iii) Television	54-72 MHz 76-88 MHz 174-216 MHz 420-890 MHz	VHF (Very high frequencies) TV UHF (Ultra hight frequency) TV
	(iv) Cellular mobile radio	896-901 MHz 840-935 MHz	Mobile to base Station Base station to mobile
	(v) Satellite Communication	5.925-6.425 GHz 3.7 - 4.2 GHz	Uplinking Downlinking
3	Optical communication using fibres	1THz-1000 THz (microwaves- ultra violet)	One single optical fibre offers bandwidth > 100 GHz

Ground Wave Propagation :

(a) The radio waves which travel through atmosphere following the surface of earth are known as ground waves or surface waves and their propagation is called ground wave propagation or surface wave propagation. These waves are vertically polarised in order to prevent short-circuiting of the electric component. The electrical field due to the wave induce charges in the earth's surface. As the wave travels, the induced charges in the earth also travel along it. This constitutes a current in the earth's surface. As the ground wave passes over the surface of the earth, it is weakened as a result of energy absorbed by the earth. Due to these losses the ground waves are not suited for very long range communication. Further these losses are higher for high frequency. Hence, ground wave propagation can be sustained only at low frequencies (500 kHz to 1500 kHz).

(b) The ground wave transmission becomes weaker with increase in frequency because more absorption of ground waves takes place at higher frequency during propagation through atmosphere.

(c) The ground wave propagation is suitable for low and medium frequency i.e. upto 2 MHz only.

(d) The ground wave propagation is generally used for local band broadcasting and is commonly called medium wave.

(e) The maximum range of ground or surface wave propagation depends on two factors :

(i) The frequency of the radio waves and (ii) Power of the transmitter

Sky Wave Propagation :

(a) The sky waves are the radio waves of frequency between 2 MHz to 30 MHz.

(b) The ionoopheric layer acts as a reflector for a certain range of frequencies (3 to 30 MHz). Therefore it is also called has inospheric propagation or short wave propagation. Electromagnetic waves of frequencies higher than 30 MHz penetrate the ionosphere and escape.

(c) The highest frequency of radio waves which when sent straight (i.e. normally) towards the layer of ionosphere gets reflected from ionosphere and returns to the earth is called critical frequency. It is given by $\boxed{f_c = 9\sqrt{N_{max}}}$, where N is the number density of electron/m^3.

Space wave propagation :

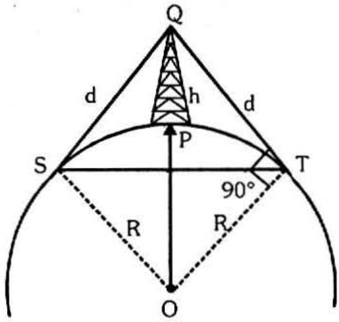
(a) The space waves are the radio waves of very high frequency (i.e. between 30 MHz. to 300 MHz or more).

(b) The space waves can travel through atmosphere from transmitter antenna to receiver antenna either directly or after reflection from ground in the earth's troposphere region. That is why the space wave propagation is also called as tropospherical propagation or line of sight propagation.

(c) The range of communication of space wave propagation can be increased by increasing the heights of transmitting and receiving antenna.

(d) **Height of transmitting Antenna :**

The transmitted waves, travelling in a straight line, directly reach the received end and are then picked up by the receiving antenna as shown in figure. Due to finite curvature of the earth, such waves cannot be seen beyond the tangent points S and T.



$(R+h)^2 = R^2 + d^2$

As $R>>h$, So $h^2 + 2Rh = d^2$

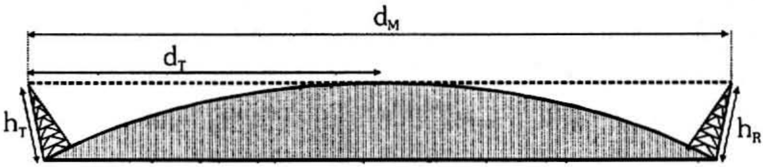
$\Rightarrow d = \sqrt{2Rh}$

Area covered for TV transmission : $A = \pi d^2 = 2\pi Rh$

Population covered = population density × area covered

If height of receiving antenna is also given in the question then the maximum line of sight

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$



Line of sight communication by space waves

where ;

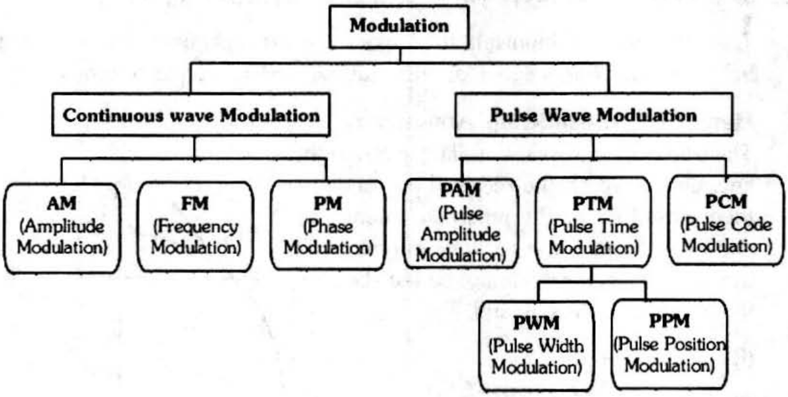
R=radius of earth (approximately 6400 km)

h_T = height of transmitting antenna

h_R = height of receiving antenna

MODULATION

The phenomenon of superposition of information signal over a high frequency carrier wave is called modulation. In this process, amplitude, frequency or phase angle of a high frequency carrier wave is modified in accordance with the instantaneous value of the low frequency information.



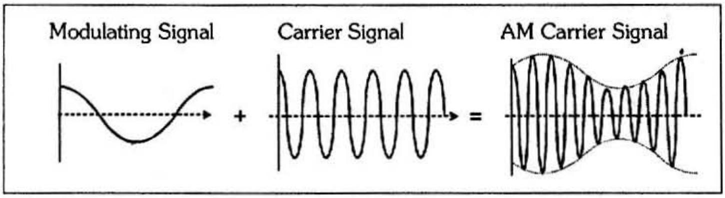
Need for Modulation :

(i) To avoid interference: If many modulating signals travel directly through the same transmission channel, they will interfere with each other and result in distortion.

(ii) To design antennas of practical size : The minimum height of antenna (not of antenna tower) should be $\lambda/4$ where λ is wavelength of modulating signal. This minimum size becomes impracticale because the frequency of the modulating signal can be upto 5 kHz which corresponds to a wavelength of $3 \times 10^8/5 \times 10^3 = 60$ km. This will require an antenna of the minimum height of $\lambda/4 = 15$ km. This size of an antenna is not practical.

(iii) Effective Power Radiated by an Antenna : A theoretical study of radiation from a linear antenna (length ℓ) shows that the power radiated is proportional to (frequency)^2 i.e. $(\ell/\lambda)^2$. For a good transmission, we need high powers and hence this also points out to the need of using high frequency transmission.

Amplitude Modulation :



Modulation factor, $m = \dfrac{\text{amplitude of modulating wave}}{\text{amplitude of normal carrier wave}}$

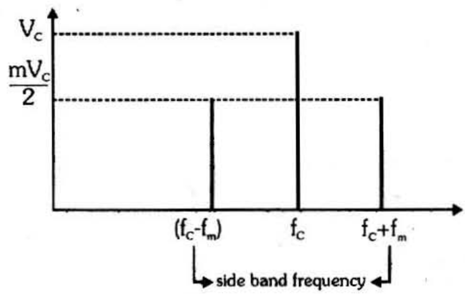
If $v_m = V_m \cos\omega_m t$ and $v_c = V_c \cos\omega_c t$ then $m = \dfrac{V_m}{V_c}$

- As amplitude of the carrier wave varies at signal frequency f_m so the amplitude of AM wave = $V_C + mV_C \cos\omega_m t$ & frequency of AM wave = $\dfrac{\omega_c}{2\pi}$

Therefore $v = \left[V_c(1+m)\cos\omega_m t\right]\cos\omega_c t$

$$\Rightarrow v = V_C \cos\omega_c t + \frac{mV_C}{2}\cos(\omega_C + \omega_m)t + \frac{mV_C}{2}\cos(\omega_C - \omega_m)t$$

Frequency spectrum of AM wave



Power in AM wave :

- Power of carrier wave : $P_C = \dfrac{V_C^2}{2R}$ where R = resistance of antenna in which power is dissipated.

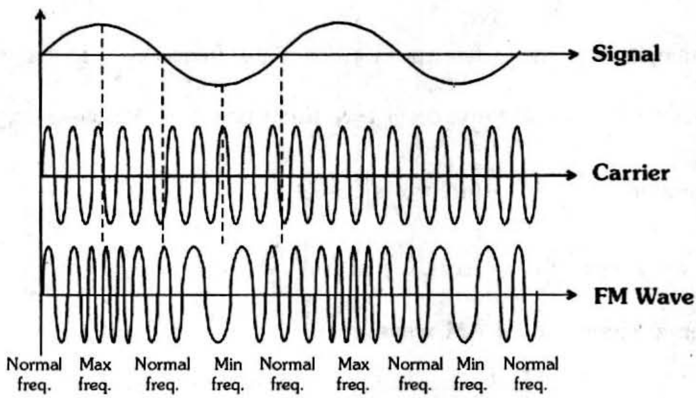
- Total power of side bands : $P_{sidebands} = 2 \times \frac{1}{2R}\left(\frac{mV_C}{2}\right)^2 = \frac{m^2}{2}P_C$

- Total power of AM wave = $P_C\left(1+\frac{m^2}{2}\right)$

- Fraction of total power carried by sidebands = $\frac{m^2}{2+m^2}$

Frequency Modulation (FM) :

When the frequency of carries wave is changed in accordance with the instantaneous value of the modulating signal, it is called frequency modulation.



MODULATION FACTOR OR INDEX AND CARRIER SWING (CS)

- ***Modulation factor*** : $m = \frac{\text{max. frequency deviation}}{\text{Modulating frequency}} = \frac{\Delta f}{f_m}$

$$\Delta f = f_{max.} - f_c = f_c - f_{min.} \; ; \; v_{FM} = V_C \cos[\omega_C t + m_f \cos\omega_m t]$$

- ***Carrier Swing (CS)***

  The total variation in frequency from the lowest to the highest is called the carrier swing $\Rightarrow$ CS = $2 \times \Delta f$

- ***Side Bands***

  FM wave consists of an infinite number of side frequency components on each side of the carrier frequency f_C, $f_C \pm f_m$, $f_C \pm 2f_m$, $f_C \pm 3f_m$, & so on.

	Amplitude Modulation		Frequency Modulation
1	The amplitude of FM wave is constant, whatever be the modulation index.	1	The amplitude of AM signal varies depending on modulation index.
2	It require much wider channel (Band width) [7 to 15 times] as compared to AM.	2	Band width* is very small (One of the biggest advantage).
3	Transmitters are complex and hence expensive.	3	Relatively simple and cheap.
4	Area of reception is small since it is limited to line of sight. (This limits the FM mobile communication over a wide area)	4	Area of reception is Large.
5	Noise can be easily minimised amplitude variation can be eliminated by using limiter.	5	It is difficult to eliminate effect of noise.
6	Power contained in the FM wave is useful. Hence full transmitted power is useful.	6	Most of the power which contained in carrier is not useful. Therefore carrier power transmitted is a waste.
7	The average power is the same as the carrier wave.	7	The average power in modulated wave is greater than carrier power.
8	No restriction is placed on modulation index (m).	8	Maximum m = 1, otherwise over modulation (m > 1) would result in distortion.
9	It is possible to operate several independent transmitter on same frequency.	9	It is not possible to operate without interference.

MODEM :

The name modem is a contraction of the terms Modulator and Demodulator. Modem is a device which can modulate as well as demodulate the signal.

FAX (Facsimile Telegraphy)

FAX is abbreviation for facsimile which means exact reproduction. The electronic reproduction of a document at a distnace place is called Fax.

Important Notes

26 Important Tables

26 (a) SOME FUNDAMENTAL CONSTANTS

Gravitational constant (G)	=	6.67×10^{-11} N m^2 kg^{-2}
Speed of light in vacuum (c)	=	3×10^8 ms^{-1}
Permeability of vacuum (μ_0)	=	$4\pi \times 10^{-7}$ H m^{-1}
Permittivity of vacuum (ε_0)	=	8.85×10^{-12} F m^{-1}
Planck constant (h)	=	6.63×10^{-34} Js
Atomic mass unit (amu)	=	1.66×10^{-27} kg
Energy equivalent of 1 amu	=	931.5 MeV
Electron rest mass (m_e)	=	9.1×10^{-31} kg = 0.511 MeV
Avogadro constant (N_A)	=	6.02×10^{23} mol^{-1}
Faraday constant (F)	=	9.648×10^4 C mol^{-1}
Stefan-Boltzman constant (σ)	=	5.67×10^{-8} W m^{-2} K^{-4}
Wien constant (b)	=	2.89×10^{-3} mK
Rydberg constant (R_∞)	=	1.097×10^7 m^{-1}
Triple point for water	=	273.16 K (0.01°C)
Molar volume of ideal gas (NTP)	=	22.4×10^{-3} m^3 mol^{-1}

26 (b) CONVERSIONS

- 1 year = 365.24 days = 3.16×10^7 s
- 1 day = 24 h = 8.64×10^4 s
- 1 J = 10^7 ergs
- 1 cal = 4.184 J
- 1 eV = 1.6×10^{-19} J
- 1 hp = 0.746 kW
- 1 bar = 10^5 N/m^2
- 1 fm = 10^{-15} m
- 1 atm = 760 mm Hg = 76 cm Hg = 1.013×10^5 N/m^2 = 1.013×10^5 Pa
- 1 light year = 9.46×10^{12} km
- 1 Parsec = 3.26 ly
- 1 Btu = 1055 J = 252 cal
- 1 kWh = 3.6×10^6 J
- 1 T = 1 Wb m^{-2} = 10^4 G

2 (c) Notations for Units of Measurement

- A → ampere
- Å → angstrom
- amu → atomic mass unit
- atm → atmosphere
- Btu → British thermal unit
- C → coulomb
- °C → degree Celsius
- cal → calorie
- deg → degree (angle)
- eV → electronvolt
- F → farad
- fm → femtometer
- ft → foot
- G → gauss
- g → gram
- H → henry
- h → hour
- hp → horse power
- Hz → hertz
- J → joule
- K → kelvin
- m → meter
- min → minute
- Mx → maxwell
- Oe → oersted
- Pa → pascal
- Ω → ohm
- rad → radian
- s → second
- S → siemens
- T → tesla
- V → volt
- W → watt
- Wb → weber

26 (d) Decimal Prefixes for Units of Measurement

- T → tera (10^{12})
- G → giga (10^{9})
- M → mega (10^{6})
- k → kilo (10^{3})
- h → hecto (10^{2})
- da → deca (10^{1})
- d → deci (10^{-1})
- c → centi (10^{-2})
- m → milli (10^{-3})
- μ → micro (10^{-6})
- n → nano (10^{-9})
- p → pico (10^{-12})

27 Dictionary of Physics

- **Abbe number**

  Reciprocal of the dispersive power of a substance.

- **Absorption Coefficient**

  Measure of rate of decrease in intensity of em radiation when it is passes through the given substance.

- **Admittance**

  Reciprocal of impedance. It refers to the measure of the ability of a circuit to conduct an alternating current.

- **Aclinic line**

  The line joining the places of zero dip. This line is also known as magnetic equator and goes nearly side by side with geographical equator.

- **Acoustics**

  Branch of physics that is concerned with the study of sound & sound waves.

- **Actinometer**

  Instruments for measuring the intensity of em radiation.

- **Agonic line**

  The line of zero declination.

- **Albedo**

  Ratio of the amount of light reflected from a surface to the amount of incident light.

- **Alfa-decay**

  A form of radioactive decay where a radioactive nuclei spontaneously emits α-particles (nuclei of $_2He^4$)

- **Alternator**

  Any device that is used to generate an alternating current.

- **Altimeter** An electronic device that indicates altitudue above the surface of earth.

- **Amalgam**

  An alloy (a material consisting of two or more elements e.g. brass is an alloy of Cu and Zn, steel is an alloy of iron & carbon) one of whose constituents is mercury (Hg)

- **Ammeter**

  An instrument used to measure electric current.

- **Ampere-hour**

  A practical unit of electric charge equal to the charge flowing in one hour through a conductor passing one ampere. It is equal to 3600 coulombs.

- **Ampere-rule**

  A rule that relates the direction of the electric current passing through a conductor and the magnetic field associated with it. The rule states that if the electric current is moving away from an observer, the direction of the lines of force of the magnetic field surrounding the conductor is clockwise and that if the electric current is moving towards an observer, the direction of the lines of force is counter clockwise.

- **Amorphous**

  A solid that is not crystalline i.e. one that has no long range order in its lattice. Example : Glass.

- **Amplifier**

  A device that increases the strength of an electrical signal by drawing energy from a separate dc source to that of the signal.

- **Anisotropic**

  Substance showing different physical properties in different directions.

- **Aperture**

  The size of the opening that admit light in an optical instrument. The effective diameter of mirror and lens.

- **Aphelion**

  The farthest point in the orbit of planet, comet and artificial satellite around the sun. The earth is at aphelion on about july 3.

- **Apogee**

  Maximum distance of a satellite from the earth during its orbit around the earth.

- **Asteroids or minor planets**

  Small bodies that revolve around the sun.

- **Astrology**

  Branch of science that is concerned with the study of influence of heavenly bodies on human affairs.

- **Astronomical unit AU**

  A unit of distance in astrology in the solar system. It is equal to the mean distance of sun from earth ($\sim 1.496 \times 10^{11}$ m)

- **Astronomy**

  The study of the universe beyond the earth's atmosphere.

- **Atomic clock**

  A highly accurate clock. It is regulated by the resonance frequency of atoms or molecules of certain substances such as cesium.

- **Atomic mass unit (a.m.u.)**

  A unit of mass used to express "relative atomic masses. It is 1/12 of the mass of an atom of the isotope carbon-12 and is equal to 1.66033×10^{-27} kg.

- **Atomiser**

  A device that is used for reducing liquid to a fine spray.

- **Aurora**

  An intermittent electrical discharge that takes place in rarefied upper atmosphere. Charge particles in the solar wind (or cosmic - rays) becomes trapped in the earth's magnetic field and move in helical paths along the lines of force between the two magnetic poles. The intensity of the aurora is greatest in polar regions although it is seen in temperate zones.

- **Autotransformer**

  A transformer having a single winding instead of two or more independent windings.

- **Avogadro constant**

  Symbol N_A. The number of atoms or molecules in one mole of substance. It has the value $6.0221367 (36) \times 10^{23}$. Formerly it was called Avogadro's number.

- **Avogadro's Law**

  Equal volumes of all gases contain equal numbers of molecules at the same pressure and temperatue. The law, often called Avogadro's hypothesis, is true only for ideal gases. It was first proposed in 1811 by Amadeo Avogadro.

- **Ballistic galvanometer :**

  A device used to measure the total amount of charge that passes through a circuit due to a momentary current.

- **Band spectrum**

  In such a spectrum there appears a number of bands of emitted or absorbed radiations. This type of spectrum are characteristic of molecules.

- **Band width**

  It refers to the width of the range of frequencies.

- **Barn**

  A unit of area & generally used for measuring nuclear cross section (1 barn $= 10^{-28}$ m^2)

- **Barometer**

  A device used to measure atmospheric pressure.

- **Becquerel**

  SI unit of radio-activity (1Bq = 1 disintegration/sec. = $\frac{1}{3.7 \times 10^{10}}$ curie)

- **Bel**

  Ten decibels (10 dB)

- **β-rays**

  A stream of β-particles (fast moving electrons)

- **Betatron**

  A device used to accelerate the electrons.

- **Bevatron**

  An accelerator used to accelerate protons and other particles to very high energies.

- **Binary star**

  A system of two stars which revolve around a common centre of gravity.

- **Binding energy**

  The energy required to separate the nucleons (protons & neutrons) of a nucleus from each other. The binding energy per nucleon is least for very light and very heavy nuclei and nearly constant (~ 8 MeV/nucleon) for medium nuclei.

- **Bipolar transistor**

  A transistor that uses two type of charge carries (electrons & holes) for its operation.

- **Black body**

  A perfectly black body is one that absorbs completely all the radiations falling on it. Its absorptance and emissivity are both equal to 1.

- **Black hole (collapsar)**

  An astronomical body having so high gravitational field in which neither matter particles nor photons can escape (they captured permanently from the outside)

- **Bolometer**

  A device used to measure amount of radiation by means of changes in the resistance of an electric conductor caused due to changes in its temperature.

- **Boson**

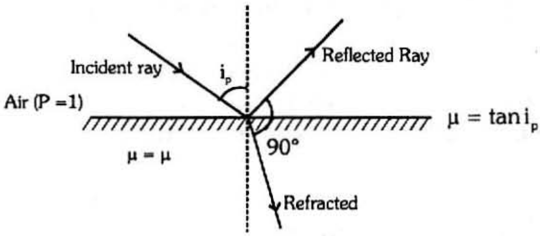
  An elementary particle with integral spin. ex. : photon.

- **Bragg's law**

When an X - ray beam of wavelength λ is incident on a crystal of interplaner spacing d at grazing angle [complement of the angle of incidence] then the direction of diffraction maxima are given by $2d \sin\theta = n\lambda$, which is known as Bragg's law.

- **Brewster's law**

The extent of the polarization of light reflected from a transparent surface is a maximum when the reflected ray is at right angles to the refracted ray. The angle of incidence (and reflection) at which this maximum polarization occurs is called the Brewster angle or polarizing angle.



- **British Thermal Unit (BTU)**

Quantity of heat required to raise the temperature of 1 pound of water thorugh 1°C.

- **Bulk modulus (K)**

$$K = \frac{\text{stress}}{\text{volume strain}} = \frac{\Delta P}{(\Delta V / V)} = \frac{1}{\text{compressibility}}$$

- **Calibration**

It is the process of determining the absolute values corresponding to the graduations on an arbitrary or inaccurate scale on an instrument.

- **Calipers**

An instrument used for measuring internal and external diameters. it is a graduated rule with one fixed and one sliding jaw.

- **Caloric theory**

It regards heat as a weightless fluid. It has now been abandoned.

- **Calorie**

It is equal to the amount of heat required to raise the temperature of 1 gram of water thorugh 1°C. 1 cal = 4.2 Joules.

- **Calorific value**

  The quantity of heat liberated on complete combustion of unit mass of a fuel. The determination is done in a bomb calorimeter and the value is generally expressed in J kg^{-1}.

- **Calorimeter**

  An instrument used for measuring quantity of heat. It consists of an open cylinderical container of copper or some other substance of known heat capacity.

- **Calorimetry**

  It is the study of the measurement of quantities of heat.

- **Canal rays, Anode rays, Positive rays :**

  Positively charged rays produced during the discharge of electricity in gases.

- **Candela**

  It is a S.I. unit of luminous intensity. It is equal to 1/60 of the luminous intensity of a square centimeter of a black body heated to the temperature of solidification of platinum (1773.5°C) under a pressure of 101325 N/m^2 in the perpendicular direction.

- **Cannon**

  A mounted gun for firing heavy projectiles.

- **Capacitor**

  It is a device which is used for storing electric charge. It consists of two metal plates separated by an insulator. It is also known as **condenser**.

- **Capacitive reactance**

  It is the opposition offered by a capacitance to the flow of alternating current.

  $X_C = \frac{1}{2\pi fC}$ Where

  X_c = capacitive reactance in ohms

  f = frequency in cycles/sec

  C = capacitance in farads

- **Capillary action or Capillarity**

  The phenomenon of rise or fall of a liquid in a capillary tube when it is dipped in the liquid. Due to this the portion of the surface of the liquid coming in contact with a solid is elevated or depressed.

- **Carat**

  • A measure of fineness (purity) of gold. Pure gold is described as 24-carat gold. 14-carat gold contains 14 parts in 24 of gold, the remainder usually being copper.

  • A unit of mass equal to 0.200 gram, used to measure the masses of diamonds and other gemstones.

Capillary tube

A tube having a very small internal diameter.

Carbon dating

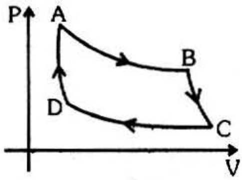
It is a method used to determine the age of materials that contain matter of living organism. It consists of determining the ratio of ${}^{12}_{6}C$ to ${}^{14}_{6}C$.

Carbonize

Means to enrich with carbon.

Carnot cycle

It is a reversible cycle and consists of two isothermal ($A \rightarrow B$ and $C \rightarrow D$) & two adiabatic ($B \rightarrow C$, $D \rightarrow A$) changes.



Carnot theorem

- The efficiency of a reversible heat engine (carnot engine) working between any two temperatures is greater than the efficiency of any heat engine working between the same two temperatures.
- The efficiency of a reversible heat engine depends only on the temperature of the source and the sink and is independent of the working substance.

Cathode

The electrode that emits electrons or gives off negative ions and toward which positive ions move or collect in a voltaic cell, electron or X-ray tube etc.

Cathode ray

The rays emitted in a discharge tube when the pressure falls to about 10^{-4} mm of mercury.

Cathode-ray oscilloscope or CRO

An instrument based on the cathode-ray tube that provides a visual image of electrical signals.

Cathode ray tube

A vacuum tube generating a focussed beam of electrons that can be deflected by electric and magnetic fields.

Cation

A positively charged ion i.e. Na^{+}, Ba^{2+} etc.

- **Cauchy dispersion formula**

  A formula for the dispersion of light of the form : $n = A + \left(\frac{B}{\lambda^2}\right) + \left(\frac{C}{\lambda^4}\right)$,

  where n is the refractive index, λ the wavelength, and A , B, and C are constants. Sometimes only the first two terms are necessary.

- **Centre of buoyancy**

  It is the point through which the resultant of the buoyancy forces on a submerged body act, it coincides with the centre of gravity of the displaced fluid.

- **Centre of gravity**

  It is the point through which the weight of the body acts. It is the point where the whole of the weight of the body may be supposed to be concentrated.

- **Centre of mass**

  For any system it is the point at which the whole of the mass of the body (or system) may be considered to be acting for determining the effect of some external force.

- **Cerenkov radiation**

  Electromagnetic radiation, usually bluish light, emitted by a beam of high-energy charged particles passing through a transparent medium at a speed greater than the speed of light in that medium. It was discovered in 1934 by the Russian physicist Pavel Cerenkov (1904). The effect is similar to that of a sonic boom when an object moves faster than the speed of sound ; in this case the radiation is a shock wave set up in the electromagnetic field. Cerenkov radiation is used in the Cerenkov counter.

- **Chip**

  A very small semi-conductor having a component (transistor, resistor, etc.) or an integrated circuit.

- **Choke**

  It is a coil of high inductance and low resistance which is used to block or reduce the high frequency components of an electrical signal.

- **Chromatic aberration**

  It is a defect of the image formed by a lens (but not a mirror), in which different colours come to focus at different points. It can be corrected by using a suitable combination of lenses.

- **Circuit breaker**

  It is a device that is used for interrupting an electric circuit when the current becomes excessive.

- **Classical physics**

  Refers to the physics that has been developed before the introduction of quantum theory.

- **Classical mechanics**

The branch of mechanics based on Newton's laws of motion. It is applicable to those systems which are so large that in their case Planck's constant can be neglected.

- **Closed end organ pipe**

In these case one end of the pipe is closed. In them first harmonic is given by $\lambda/4$. In such cases only the odd harmonics are produced and even harmonics are missing. Fundamental frequency = $v/4\ell$

- **Coefficient of expansion**

It is the increase in unit length, area or volume per degree rise in temperature.

- **Coefficient of friction** $\mu = \frac{f}{R}$

Where f = Limiting friction . R = Normal reaction

Also $\mu = \tan\theta$; where θ = angle of friction

- **Coefficient of restitution**

The ratio of the relative velocity of two bodies after direct impact to that before impact.

- **Coefficient of mutual inductance**

- It is numerically equal to the magnetic flux linked with one circuit when unit current flows through it. The effective flux N_s linked with secondary circuit is given by N_s=Mi
- It is numerically equal to the e.m.f. induced in one circuit when the rate of change of current in the other is unity. The e.m.f. induced in a secondary coil, when the rate of change of current with time in primary coil is $\frac{di}{dt}$ is given by, $e_s = M\frac{di}{dt}$

- **Coefficient of thermal conductivity (K)**

It is the amount of heat flowing in one second across the 1m^2 area, of a 1 metre rod, maintained at a temperature difference of 1°C.

- **Coefficient of viscosity**

It is the tangential force required to maintain a unit velocity gradient between two layers of unit area. Its units are Nsm^{-2} or poiseulle or decapoise.

- **Coefficient of self - induction**

- It is numerically equal to the magnetic flux linked with the coil when the unit current flows through it. The effective flux N is given by N = Li where i = curent flowing through the circuit.
- It is numerically equal to the e.m.f. induced in the circuit when the rate of change of current is unity.
- It is numerically equal to twice the work done against the induced e.m.f. in establishing unit current in the coil.

- **Coercive force**

  It is the magnetic intenstiy required to reduce the magnetic induction in a previously magnetised material to zero.

- **Complementary colours**

  A pair of colours which, when combined give the effect of white light. A large number of such pairs are possible.

- **Compound microscope**

  A microscope consisting of an objective lens with a short focal length and an eye piece of a longer focal length, mounted in the same tube.

- **Compound pendulum**

  In such a pendulum the moment of the restoring force is τ = mgd sinθ If θ (in radians) is sufficiently small, then $\tau = -$ mgd θ. Time period of such a pendulum is $T=2\pi\sqrt{\frac{I}{Mgd}}=2\pi\sqrt{\frac{\ell}{g}}$

- **Compton effect**

  The phenomenon according to which the wave length of radiation scattered by a particle is greater than that of the original radiation is called compton effect.

- **Condensation**

  A change of state from vapour to liquid. In this state the vapour pressure becomes equal to the saturated vapour pressure (SVP) of liquid state.

- **Conductance**

  It is the reciprocal of resistance. It is the ability of a conductor to transmit current. Its unit is mho, ohm^{-1} or siemens.

- **Conduction**

  A method of heat transfer. In this mode of heat transfer the particles do not move.

- **Conservation of angular momentum**

  In the absence of any external torque the total angular momentum of a system remains unchanged.

- **Conservation of charge**

  For an isolated system the total charge remains constant.

- **Conservation of linear momentum**

  In the absence of any external force the total linear momentum of the system remains constant.

- **Conservation of mass and energy**

The total energy of a closed system, viz., rest mass energy + kinetic energy + potential energy remains constant. This principle treats the rest mass as energy. The rest mass energy of a particle having rest mass m_0 is $m_0 c^2$.

- **Conservative field**

It is that vector field for which the line integral depends on the end points of the path only and is independent of the path. A conservative field can always be expressed as the gradient of a scalar field.

- **Constantan**

An alloy containing about 50% copper and 50% nickel having a comparatively high resistance and low temperature coefficient of resistance.

- **Convection**

A mode of heat transfer. In this mode the movement of particles occur.

- **Corona discharge**

A discharge, generally luminous, at the surface of a conductor or between two conductors of the same transmission line.

- **Corpuscular theory of light** It assumes that light travels as particles or corpuscles. It is useful to explain reflection, refraction etc. It can not explain diffraction, polarisation etc.

- **Cosmic rays**

These are high energy radiations. These consist of protons and some α-particles, electrons and other atomic nuclei and γ-rays reaching the earth from space.

- **Cosmology**

The branch of astonomy that deals with the evolution, general structure, and nature of the universe as a whole.

- **Critical mass**

It is the minimum mass of a fissile material that will sustain a chain reaction.

- **Critical pressure**

It is the saturated vapour pressure of a liquid at its critical temperature.

- **Critical temperature**

It is the temperature above which a gas can not be liquified by increasing the pressure alone.

- **Critical velocity**

The velocity of fluid flow at which the motion changes from laminar to turbulent flow.

- **Critical volume**

The volume of a certain mass of substance measured at critical pressure and temperature.

- **Cryogenics**

The study of the production and effects of very low temperatures. A cryogen is a refrigerant used for obtaning very low temperatures.

- **Cryometer**

A thermometer designed to measure low temperatures.

- **Curie**

A unit to measure the activity of a radioactive substance (see radio activity) It is the quantity of radon in radioactive equilibrium with 1 g of radium. Also defined as that quantity of a radioactive isotope which decays at the rate of 3.7×10^{10} disintegrations per second. Named after Madame Curie (1867-1984).

- **Curie's law**

The value of (χ) susceptibility of a paramagnetic substance is inversely proportional to its absolute temperature $\chi \propto \frac{1}{T}$

- **Cyclotron**

An accelerator in which particles move in a spiral path under the influence of an alternating voltage and a magnetic field.

- **Daughter nucleus**

Refers to the nucleus that results from the radioactive decay of another nucleus known as parent nucleus.

- **Dead beat galvanometer**

A galvanometer which is damped so that its oscillations die away very quickly. In such galvanometer its resistance is less than its critical damping resistance.

- **De broglie wavelength**

The wavelength of the wave associated with a moving particle. The wavelength (λ) is given by $\lambda = h/mv$, where h is the Planck constant, m is the mass of the particle, and v its velocity. The de Broglie wave was first suggested by the French physicist Louis de Broglie (1892-) in 1924 on the grounds that electromagnetic waves can be treated as particles and one could therefore expect particles to behave in some circumstances like waves. The subsequent observation of electron diffraction substantiated this argument and the de Broglie wave became the basis of wave mechanics.

- **Debye length**

It is the maximum distance at which coulombs fields of charged particles in a plasma may be expected to interact.

- **Deca**

  Symbol : The prefix meaning 10, e.g. 1 decameter=10 metres.

- **Deci**

  A prefix measuring 10^{-1}

- **Decibel dB**

  A unit for expressing the intensity of a sound wave. It is measured on a logarithmic scale.

- **Declination**

  The horizontal angle between the directions of true north and magnetic north.

- **Delta-ray**

  A low energy electron emitted by a substance after bombardment by high energy particles (e.g. α-particles)

- **Degrees of freedom**

  The number of independent co-ordinates needed to define the state of a system.

- **Demagnetisation**

  To remove the ferromagnetic properties of a body. It can be done by disordering the domain structure.

- **Deutron**

  Nucleus of deuterium atom. It consists of one proton and one neutron.

- **Dew**

  Water droplets formed due to condensation of water vapour in the air when the temperature of air drops so that the quantity of vapour present at that temperature reaches saturation.

- **Dew point**

  It is the temperature to which air must be cooled for dew to form. At this temperature air becomes saturated with water vapours present in it.

- **Dew point hygrometer**

  It is an instrument used for determination of relative humidity.

- **Diamagnetic substances**

  Refers to those substances that have a negative value of susceptibility. They are repelled when placed in a magnetic field.

- **Diamagnetism**

  Diamagnetic substances when placed in a magnetic field get feebly magnetised in direction opposite to that of magnetising field. This property of diamagnetic substances is known as diamagnetism.

- **Dielectric**

  Refers to an insulator, a non-conducting substance.

- **Dielectric constant (Relative permittivity)**

  Dielectric constant $\dfrac{\text{Absolute permittivity of the medium}}{\text{Absolute permittivity of vacuum}} = \dfrac{\epsilon}{\epsilon_0} = \epsilon_r = K$

- **Dielectric strength**

  Refers to the maximum electric field that a dielectric is capable of withstanding without a break down.

- **Diffraction**

  It refers to the bending of light round an obstacle.

- **Diffraction grating**

  A glass plate with a very large number of closely spaced parallel lines (usually more than 5000 to the inch) scrapped across it. These are used for diffracting light to produce optical spectra.

- **Diffusion length**

  It is the average distance that is travelled by minority carriers between generation and recombination in a semiconductor.

- **Dioptre**

  It is a unit of measurement of the refractive power of a lens. It is equal to the reciprocal of the focal length of a lens expressed in metres.

- **Dip, Inclination (ϕ)**

  The dip at a place is the angle which the earth's field makes with earth's surface at a place.

- **Dip circle**

  It is an instrument that is used to measure the angle of dip at a place. It consists of a magnetic needle mounted in such a way that it can rotate in a vertical plane. The angle is measured on a circular scale.

- **Dipole**

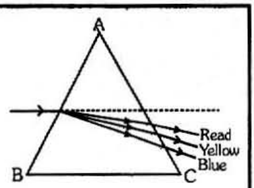
  Refers to two equal and opposite electric charges (or magnetic poles) separated by a distance.

- **Dipole moment**

  It is equal to the product of pole strength and the length of magnetic electric dipole.

Dispersion

The separation of white light into its constituent colours by refraction or other means is called dispersion of light.



Dispersive power (ω)

Dispersive power of the material of the prism is given by

$\omega = \dfrac{\mu_b - \mu_r}{\mu - 1}$ for blue & red rays. Where μ_b and μ_r are the refractive indices of blue and red rays respectively and μ is the refractive index for yellow rays.

Doping

It refers to the process of adding some amount of impurities in semi-conductors to achieve a desired conductivity.

Double refraction

When a beam of light is incident on certain materials, it breaks it into two plane polarised beams with their plane of polarisation perpendicular to each other. The two beams have different velocities in the medium. This phenomenon is called double refraction.

Dry ice

Solid carbon dioxide.

Ductility

Property by which metals are capable of being, drawn in wires.

Dulong and Petit's law

It states, "The product of atomic weight and specific heat of a solid element is approximately 6.4".

Dynamo

An electric generator. It produces direct current by converting mechanical energy into electrical energy. It consists of a strong electromagnet between the poles of which an armature is rotated, consisting of a number of coils suitably wound. It is based on the principle of electromagnetic induction.

Earthing

Refers to connecting an electrical conductor to earth which is assumed to have zero electric potential.

Earth's atmosphere

The gas that surrounds the earth. The composition of dry air at sea level is : nitrogen 78.08%, oxygen 20.95%, argon 0.93%, carbon dioxide 0.03%, neon 0.0018%, helium 0.005%, krypton 0.0001%, and xenon 0.00001% . In addition to water vapour, air in some localities contains sulphur compounds, hydrogen peroxide, hydrocarbons, and dust particles.

- **Eclipse**

  To prevent light from a source reaching an object. It refers to shadowing one heavenly body by another. In **solar eclipse** shadow of the moon falls on the earth when the sun, moon and earth are in line. In **lunar eclipse** shadow of the earth falls on the moon, when the earth is in between the sun and the moon.

- **Efficiency**

  The ratio of the useful energy output to the total energy input in any energy transfer. It is often given as percentage and has no units.

- **Effusion**

  The flow of gas through a small aperture.

- **Einstein's equation**

  Refers to the equation, maximum $KE_{max} = h\nu - \phi_0$ for the kinetic energy of electrons which are emitted in photoelectric effect, ν the frequency of incident radiation and ϕ_0 the work function of the photomaterial upon which the radiation is incident.

- **Einstein's law**

  Mathematically it can be expressed as $E = mc^2$.

- **Electric motor**

  A device that converts electrical energy into mechanical energy.

- **Electrocardiograph (ECG)**

  It is a sensitive instrument that records the voltage and current waveforms associated with the action of the heart. The trace obtained is called electrocardiogram.

- **Electroencephalograph (EEG)**

  A sensitive instrument that records the voltage waveforms associated with the brain. The trace obtained is called electroncephalogram.

- **Electrogen**

  A molecule that emits electrons on being illuminated.

- **Electron microscope**

  It is a type of microscope in which an electron beam is used to study very minute particles.

- **Electromagnet**

  A magnet formed by winding a coil of wire around a piece of soft iron. It behaves as a magnet as long as the current passes through the coil.

- **Electrometer**

  An instrument that is used for determining the potential difference between two charged bodies by measuring the electrostatic force between them.

Electroscope

A device consisting of two pieces of gold leaf enclosed in a glass walled chamber. It is used for detecting the presence of electric charge or for determining the sign of electric charge on a body.

Electrostatic shield

A conducting substance which protects a given apparatus against electric fields. It consists of a hollow conductor and completely surrounds the apparatus to be shielded.

Emissivity

The ability of a surface to emit radiant energy compared to that of a black body at the same temperature and with the same area.

Emissive power

The total energy emitted from unit area from the surface of a body per second.

Enthalpy (H)

$H = E = PV, H = U + PV$

WhereU = Internal energy of the system.

P = Pressure and V = Volume

Entropy (S)

A measure of the degree of disorder of a system. An increase in entropy is accompanied by a decrease in energy availability. When a system undergoes a reversible change then $\Delta S = \frac{\Delta Q}{T}$. The importance of entropy is that in any thermodynamic process that proceeds from one equilibrium state to another, the entropy of system + environment either remains unchanged or increases.

Evaporation

The change of state from liquid to gas which can occur at any temperature upto the boiling point. If a liquid is left in an open container for long enough it will all evaporate.

Extrinsic semi-conductor

A semi-conductor in which the carrier concentration is dependent upon extent of impurities.

Expansion of the universe

The hypothesis, based on the evidence of the *redshift, that the distance between the galaxies is continuously increasing. The original theory, which was proposed in 1929 by Edwin Hubble (1889-1953), assumes that the galaxies are flying aprt like fragments from a bomb as a consequence of the big bang with which the universe originated.

- **Fall-out** (or **radioactive fall-out)**

Radioactive particles deposited from the atmosphere either from a nuclear explosion or from a nuclear accident. Local, fall-out, within 250 km of an explosion, falls within a few hours of the explosion. Tropospheric fall-out consists of fine particles deposited all round the earth in the approximate latitude of the explosion within about one week. Stratospheric fall-out may fall anywhere on earth over a period of years.

- **Faraday's law of electrolysis**

First Law W=Zit

Where

W	=	Wt. of ions liberated from an electrolyte.
Z	=	Electrochemical equivalent (E.C.E.)
t	=	Time in seconds for which current is passed
i	=	Current in amperes

- **Faraday's Law of electromagnetic induction**

• Whenever the number of lines of force linked (flux) with any closed circuit changes and induced current flows through the circuit which lasts only so long as the change lasts.

• The magnitude of induced e.m.f. produced in a coil is directly proportional to the rate of change of lines of force threading the coil $e \propto \frac{d\phi}{dt}$; where ϕ = flux (or number of lines of force threading the circuit)

- **Fahrenheit scale of temperature**

On this scale the melting point of ice is 32°F and the boiling point of water is 212°F The distance between these two points is divided in 180 equal parts, each part being 1°F. It is related to centigrade scale as $\frac{C}{100} = \frac{F-32}{180}$

- **K–capture**

Refers to an absorption of electron from the innermost (K–shell) shell of an atom into its nucleus.

- **Karat (US)**

It is a unit used to specify the purity of gold. a pure gold is 24 Karat gold.

Kepler's law

- The planets move around the sun in elliptical orbits with the sun at one focus of the ellipse
- The radius vector from the planet to the sun sweeps out equal areas in equal intervals of time.
- The ratio of $\frac{T^2}{a^3}$ =constant, where T is the period of the planet's orbit around the sun and a is the semi–major axes of the ellipse.

Kilo watt–hour (kWh)

It is a practical unit of work (or energy). It is equal to the energy supplied by one kilowatt of power in one hour.

$$1 \text{ kWh} = 3.6 \times 10^6 \text{ joule.}$$

Kinetic friction

Refers to the friction that acts on a body when it is moving over a second body.

Kirchhoff's law (Electrostatics)

- **First Law** : It is also known as Junction rule. It states, "The algebraic sum of the currents at a given junction in a circuit is zero". $\Sigma i = 0$. Thus there could be no accumulation of current at any point in the circuit.
- **Second law :** It is also known as loop rule "In a closed circuit, the algebraic sum of the products of the current and the resistances of each part of the circuit is equal to total emf in the circuit."$\Sigma ir = \Sigma E$

Kirchhoff's law (Heat)

For a given temperature and wavelength the ratio of emissive power of a substance to its absorptive power is the same for all substances and is equal to the emissive power of a perfectly black body at that temperature.

Kundt's tube

It is a glass tube whose one end is fitted with a light adjustable piston and its another end is closed by a cap through which passes a metal rod clamped at its centre. A small quantity of lycopodium powder is spread uniformly through out the tube. The free end of the rod is rubbed to and fro along its length. Stationary waves are produced in the air column in the tube. By measuring the wavelength it is possible to calculate the velocity of sound in air in terms of the Young's modulus, length and density of the rod and the wave length of stationary waves.

Lactometer

It is an instrument that is used to find out the specific gravity of milk.

■ **Lambert's law**

The illuminance of a surface that is illuminated by a point source of light normally is proportional to $1/r^2$ where r is the distance between the source and the surfance. If the incident rays make an angle θ with the normal to the ray, then the illuminance is proportional to $\cos\theta$.

■ **Laminar flow**

Refers to the flow of a fluid along a stream lined surface without any turbulance.

■ **Laminated iron**

A piece of iron consisting of thin sheets of iron. Such a piece of iron is used for cores of transformers. It helps to minimize losses due to eddy currents.

■ **Laser**

It stands for light amplification by stimulated emission of radiation. A highly powerful, coherent, monochromatic light source. Such light is of great use in medicine, telecommunications, industry and holography.

■ **Latent heat**

Hidden heat. It is the energy involved in changes of state. In each case, the temperature stays constant while the change of state takes place. A similar situation exists in the changes from liquid to gas and gas to liquid. The quantity of energy transformed from and to the particles during changes of state depends on the nature of the substance and its state.

■ **Lateral inversion**

Refers to the type of inversion produced in the image formed by a plane mirror. The left hand side appears as right hand side and vice versa.

■ **Latitude**

Refers to the angular distance north or south from the equator of a point on the earth's surface, measured on the meridian of the point.

■ **Laws of dynamic friction**

- Dynamic friction is proportional to the normal reaction. It is less than static friction.

- It does not depend on the velocity if the velocity is neither too large nor too small.

■ **Laws of limiting friction**

- The force of limiting friction is directly proportional to normal reaction for the same two surfaces in contact and it takes place in a direction which is opposite to the direction of the force of the pull. Limiting friction is maximum static friction, it is less than static friction. $F \propto R$ (when the body just begins to move $F = \mu R$) Where μ is coefficient of friction.

- Limiting friction is independent of the size and shape of the bodies in contact as long as the normal reaction remains the same.

Law of gravitation

According to it, all bodies and particles in universe exert gravitational force on one another. The force of gravitation between any two bodies is directly proportional to the product of their masses and inversely proportional to the distance between them.

Laws of intermediate temperature

The e.m.f. of a thermocouple between any two temperatures is equal to the sum of the e.m.f. of any number of successive steps in which the given range of temp. is divided. Thus if $E_{t_1}^{t_n}$ is the thermo e.m.f. between two temp. t_1 & t_n, $E_{t_1}^{t_n} = E_{t_1}^{t_2} + E_{t_2}^{t_3} + E_{t_3}^{t_4} + E_{t_{n-1}}^{t_n}$.

Where the given temp. range is divided between the steps $t_1, t_2, t_3 \ldots\ldots t_n$.

Light Emitting Diode (LED)

This is a p–n junction diode and is usually made from gallium arsenide or indium phosphide. Energy is released with in the LED and this is given off as light. The junction is made near to the surface so that the emitting light can be seen. No light is emitted with a reverse bias. LED are generally coloured red, yellow or green. They are widely used in a variety of electronic devices.

Light year

It is a unit used to measure the distance between the earth and stars. 1 light year = $365 \times 86400 \times 3 \times 10^8$ m = 9.46×10^{15} m.

Liquid Crystal

A substance that flows like a liquid but has some order in its arrangement of molecules. Nematic crystals have long molecules all aligned in the same direction, but otherwise randomly arranged. Cholesteric and smectic liquid, crystals also have aligned molecules, which are arranged in distinct layers, In cholesteric crystals the axes of the molecules are parallel to the plane of the layers; in smectic crystals they are perpendicular.

Liquid–Crystal Display (LCD)

A digital display unit used in watches, calculators, etc. It provides a source of clearly displayed digits for a very low power consumption. In the display unit a thin film of liquid crystal is sandwiched between two transparent electrodes (glass with a thin metal or oxide coating). In the commonly used field–effect display, twisted nematic crystals are used. The nematic liquid crystal cell is placed between two crossed polarizers. Polarized light entering the cell follows the twist of the nematic liquid crystal, is rotated through 90°, and can therefore pass through the second polarizer. When an electric field is applied, the molecular alignment in the liquid crystal is altered the polarization of the entering light is unchanged and no light is therefore transmitted. In these circumstances, a mirror placed behind the second polarizer will cause the display to appear black. One of the electrodes, shaped in the form of a digit, will then provide a black digit when the voltage is applied.

- **Lissajou's figures**

  The loci of the resultant displacement of a point subject to two or more simple harmonic motions simultaneously. When the two periodic motions are of the same frequency and are at right angles to each other. The resulting figure varies from a straight line to an ellipse depending on the phase difference between the two motion.

- **Longitude**

  It is the angular distance east or west on earth's surface. It is measured by the angle contained between the meridian of a particular place and some prime meridian.

- **Lumen**

  A unit of luminous flux. One lumen is the luminous flux emitted in a unit solid angle by a point source of one–candle intensity.

- **Lux**

  It is S.I. unit of illuminance. 1 lux = 1 lumen/square meter

- **Mach number**

  It is number that indicates the ratio of the speed of an object to the speed of sound in the medium through which the object is moving.

- **Magic numbers**

  Atomic nuclei with 2, 8, 20, 28, 50, 82, 126 neutrons or protons are quite stable. These number are known as magic numbers.

- **Magnetic axis**

  It is the line joining the two poles of a magnet inside its body.

- **Magnetic elements**

  These are the magnetic declination, magnetic dip and the horizontal component of Earth's magnetic field which completely define the Earth's magnetic field at any point on the Earth's surface.

- **Magnetic equator**

  A line perpendicular to magnetic axis and passing through the middle point of the magnet is called equitorial line or magnetic equator.

- **Magnetic meridian**

  It is that vertical plane which passes through the magnetic axis of a freely suspended magnet.

- **Magnetic storm**

  A temporary disturbance of the earth's magnetic field induced by radiation and streams of charged particles from the sun.

- **Magnetization (M)**

The magnetic moment per unit volume of a magnetised substance.

$$B = \mu_0(H + M) \text{ or } M = \frac{B}{\mu_0} - H$$

Where H is the magnetic field strength, B is the magnetic flux and μ_0 is constant.

- **Malus law**

It states that the intensity of light transmitted through an analyser is proportional to $\cos^2\theta$ where θ is the angle between the transmission planes of the polariser and the analyser.

- **Manganin**

A copper alloy containing 13–18% of manganese and 1–4% of nickel. It has a high electrical resistance, which is relatively insensitive to temperature changes. It is therefore suitable for use as a resistance wire.

- **Maser**

It is a device that is used for amplifying electrical impulses by stimulated emission of radiation.

- **Mass defect (ΔM)**

It is the difference between the actual nuclear mass and the sum of the masses of its constituents nucleons.

- **Mass–Energy equation**

$E = mc^2$.

- **Maxwell Mx.**

It is unit of magnetic flux on C.G.S. system.

$$1 \text{ Mx} = 10^{-8} \text{ Weber}$$

One maxwell is equal to magnetic flux through one square centimetre normal to a magnetic field of one gauss.

- **Maxwell's formula**

A formula that connect the relative permittivity ε_r of a medium and its refractive index n. If the medium is not ferromagnetic the formula is $\varepsilon_r = n^2$.

- **Mayer's relationship** : $C_P - C_V = R$ Where

C_P = Molar specific heat of gas at constant pressure

C_V = Molar specific heat of gas at constant volume

R = Gas constant $= 8.314 \text{ Jk}^{-1} \text{ mol}^{-1}$

- **Mechanical advantage**

It is the ratio of output force to the input force applied to any mechanism.

$P \times AF = W \times BF \qquad \frac{W}{P} = \frac{AF}{BF} = \frac{\text{Power arm}}{\text{Weight arm}}$

- **Meissner effect**

The falling off of the magnetic flux within a superconducting metal when it is cooled to a temperature below the critical temperature in a magnetic field. It was discovered by Walther Meissner in 1933 when he observed that the earth's magnetic field was expelled from the interior of tin crystals below 3.72 K, indicating that as "superconductivity appeared the material became perfectly diamagnetic".

- **Melde's experiment**

It is an experiment carried out for verification of transverse vibrations of strings.

- **Melting point**

The fixed temperature at which a solid changes into the liquid state. The melting point of ice is 0°C. Melting point of a solid depends upon pressure. it is also called fusion temperature of the liquid.

- **Michelson–Morley experiment**

An experiment conducted by Michelson–Morley in 1881 to show that the velocity of light is not influenced by motion of medium through which it passes.

- **Micro**

A prefix denoting 10^{-6}.

- **Micron (μ)**

A unit of length $1\ \mu = 10^{-6}$ m.

- **Micrometer**

Refers to any device used for measuring minute distances, angles etc.

- **Microphone**

An instrument that can transform the air pressure waves of sound into electrical signals and vice–versa. It is used for recording or transmitting sound.

- **Mirage**

An optical phenomenon that occurs as a result of the bending of light rays through layers of air having very large temperature gradients. An inferior mirage occurs when the ground surface is strongly heated and the air near the ground is much warmer that the air above. Light rays from the sky are strongly refracted upwards near the surface giving the appearance of a pool of water. A superior mirage occurs if the air close to the ground surface is much colder than the air above. Light is bent downwards from the object towards the viewer so that it appears to be elevated or floating in the air.

- **Mirror equation**

$$\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$$

u = distance of object
v = distance of image
f = focal length of mirror

- **M.K.S. system**

System of units having the fundamental units metre, kilogram and second for the length, mass and time respectively.

- **Mole**

SI unit of quantity of a substance. Amount of a substance that contains as many atoms (molecules, ions etc.) as there are atoms in 0.012 kg. of carbon–12.

- **Monochromatic**

Having only one colour.

- **Moseley's law**

According to it the frequencies in the X–ray spectrum of elements, corresponding to similar transitions are proportional to the square of the atomic number of elements.

- **Multimeter**

An instrument that can be used for measuring various electrical quantities such as resistance, voltage etc.

- **Mutual inductance**

It refers to the phenomenon by which a current is induced in a coil circuit when current in a neighbouring coil circuit is changed. Direction of current in the secondary coil is opposite to battery current in primary coil (Lenz's law)

- **Myopia**

A defect of vision. Any one suffering with this defect fails to see distant objects clearly. The image of distance object is formed in front of retina and not on retina. It can be corrected by use of concave lens.

- **Natural gas**

It is a mixture of hydrocarbons and is found in deposite under the earth's surface. It contains upto 90% Methane. It is used as a fuel both in industry and home.

- **Nautical mile**

It is a unit of distance used for navigation. 1 nautical mile = 6082.66 feet.

- **Negative crystal**

Refers to that crystal in which the velocity of extra ordinary ray is more than the velocity of ordinary ray e.g. calcite.

- **Negative resistance**

  It is characteristic of certain electronic devices in which the current increases with decrease in voltage.

- **Neel temperature**

  The temperature upto which the susceptibility of antiferromagnetic substances increase with increase in temperature and above which the substance becomes paramagnetic.

- **Nernst heat theorem**

  It is also called the third law of thermodynamics. For a chemical change occuring between pure crystalline solids at absolute zero, there is no change in entropy.

- **Neutrino**

  It is an elementary particle having rest–mass zero and is electrically neutral. It has a spin of 1/2.

- **Neutron bomb**

  It is a nuclear bomb. It releases a shower of life destroying neutrons but has practically little blast and contamination.

- **Newton**

  It is S.I. unit of force. It is equal to the force which produces an acceleration of 1 m/s^2 in a mass of 1 kg.

- **Newton's formula for velocity of sound :**

  $u = \sqrt{\frac{E}{\rho}}$ Where u = velocity of sound E = Elasticity of medium

  ρ = density of medium

- **Newton's law of cooling**

  According to it, the rate of loss of heat from a hot body is directly proportional to the excess of temperature over that of its surroundings, provided the excess of temperature is not very large.

- **Newton's law of gravitation n**

  Every body in this universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

  Mathematically $F \propto \frac{m_1m_2}{r^2}$; $F = G\frac{m_1m_2}{r^2}$

Newton's law of motion

- **Ist Law :** A body continues to remain in its state of rest or of uniform motion in the same direction in a straight line unless acted upon by some external force.
- **IInd Law :** The rate of change of momentum of a body is directly proportional to the implied force & takes place in the direction of the force $F = \frac{dp}{dt} = ma$
- **Third Law :** To every action there is equal and opposite reaction. $\vec{F}_{12} = -\vec{F}_{21}$

Newton's ring

Refers to alternately dark and bright fringes (circular) that can be observed around the point of contact of a convex lens and a plane reflecting surface. These are produced due to interference of light waves reflected at the upper and lower surfaces of the air film separating the lens and the plane surface.

Nichrome

An alloy of nickel, chromium and iron. It has high melting point and large resistivity. It is used for electric resistors and heating element.

Nicol prism

A prism made of calcite. It is used for polarizing light and analysing plane polarised light.

Normal temperature and Pressure (N.T.P.)

These are 273 K and 760 mm of mercury respectively.

Nuclear fission

A nuclear reaction in which an atomic nucleus breaks up into two nearly equal fragments and evolution of a large amount of energy.

Nuclear fusion

A nuclear reaction in which two light nuclei combine to form a heavier nuclei and evolution of a large amount of energy.

Nuclear force

It refers to the strong attractive force that keeps (bind) a large number of nucleons bound together in a very small space. It is a short range attractive force and is charge independent. Its range is a few fermi. (1 fermi = 10^{-15} m)

Nuclear Magnetic Resonance (NMR)

The absorption of electromagnetic radiation at a suitable precise frequency by a nucleus with a nonzero magnetic moment in an external magnetic field. The phenomenon occurs if the nucleus has nonzero "spin, in which case it behaves as a small magnet, In an external magnetic field, the nucleus's magnetic moment vector precesses about the field direction but only certain orientations are allowed by quantum rules. Thus for hydrogens (spin of ½) there are two possible states in the presence of a field, each with a slightly different energy. Nuclear magnetic resonance is the absorption of radiation at a photon energy equal to the difference between these levels causing a transition from a lower to a higher energy state.

- **Nuclear mass**

  It is equal to the sum of masses of protons and neutrons minus the mass defect.

  Mass of nucleus = $Z M_p + (A - Z) M_n - \Delta m$.

  Z = Atomic number = number of protons

  A = Mass no. or = number of protons + no. of neutrons

  M_p = Mass of proton

  M_n = Mass of neutron $\quad\quad$ Δm = Mass defect

- **Nucleons**

  Refers to protons and neutrons which are present in the nucleus. They are collectively called nucleons.

- **Octave**

  The interval between two musical notes whose frequencies are in the ratio of 2 : 1.

- **Octet**

  Group of eight electrons that constitute the outer electron shell in case of an inert gas (except helium) or any other atom/ion.

- **Odd–Odd nucleus**

  A nucleus which contains the odd number of protons and odd number of neutrons.

- **Oersted**

  A C.G.S. unit for magnetic field strength. $\quad 1 \text{ Oersted} = \dfrac{10^3}{4\pi} \text{ A/m}.$

- **Ohm's law**

  It states, "current flowing through a conductor is directly proportional to the potential difference across its ends. If temperature and other physical conditions remain unchanged".

- **Opacity**

  It is the reciprocal of the transmittance of a substance. It is a measure of the extent to which a substance is opaque.

- **Opaque**

  A substance that is not transparent or which does not allow light to pass through it.

- **Optical activity**

  It is the property of certain substance to rotate the plane polarized light when it passes through their solution. The substances are classified as dextro–rotatory or leavo rotatory depending on whether they rotate it towards right (dextro) or left (leavo). The rotation produced depends upon the length of the medium and concentration of the solution. It also depends on the wave length of light used.

- **Optical pyrometer**

  A pyrometer where in the luminous radiation from the hot body is compared with the from a known source. The instrument measures the temperature of a luminous source without thermal contact.

- **Optimum**

  Refers to most favourable conditions for obtaining a given result.

- **Oscillation magnetometer**

  It is an instrument where in a freely suspended magnet is made to vibrate in a magnetic field (of earth). The time period of vibration of this instrument is given by $T = 2\pi\sqrt{\frac{I}{MB_H}}$

- **Overtones**

  Refers to the tones or frequencies emitted by a system besides its fundamental frequency are called overtones. Generally the intensity of overtones is lower than that of the fundamental.

- **Packing fraction**

  The algebraic difference between the relative atomic mass of an isotope and its mass number divided by the mass number.

- **Pair production**

  It refers to the simultaneous production of an electron and its anti–particle (positron) from a gamma ray photon. The minimum energy that such a photon must have in 1.02 MeV.

- **Paramagnetic**

  Refers to the magnetic nature of substances. Paramagnetic substances are those substances in which the magnetic moments of the atoms have random directions until placed in a magnetic field. When placed in a magnetic field they possess magnetisation in direct proportion to the magnetic field and are weakly magnetised. If placed in a non–uniform magnetic field, they move from weaker parts to stronger parts of the field.

- **Paraxial rays**

  Refers to those incident rays which are parallel and close to the axis of a lens.

- **Parent nucleus**

  Any nucleus that undergoes radioactive decay to form another nucleus. The nucleus resulting by radioactive decay of the parent nucleus is called daughter nucleus.

- **Parsec**

  It is an astronomical unit of distance 1 parsec = 3.0857×10^{16} m. or 3.2616 light years. It corresponds to a parallel of one second of arc. The distance at which the mean radius of the earth's orbit subtends an angle of one second of arc.

- **Pascal (Pa)**

  The S.I. unit of pressure. 1 Pa = 1 Newton/metre^2

- **Pascal's law**

  In a confined fluid, externally applied pressure is transmitted uniformaly in all directions.

- **Pauli's exclusion principle**

  It states, "No two electrons in an atom can have all the quantum numbers same."

- **Peak value of inverse voltage (PIV)**

  It is the maximum instantaneous voltage that is applied to a device, particularly rectifiers, in the reverse direction.

- **Penumbra**

  The partial shadow that surrounds the complete shadow of an opaque body.

- **Perfect gas**

  An ideal gas that obeys the gas laws at all temperatures and pressure. It consists of perfectly elastic molecules. The volume of molecules is zero and the intermolecular forces of attraction between them is also zero.

- **Perigee**

  It is the shortest distance of a satellite from the earth.

- **Perihelion**

  The point in the orbit of a planet, comet, or artificial satellite in solar orbit at which it is nearest to the sun. The earth is at perihelion on about 2 January.

- **Periscope**

  An optical device used to view objects that are above the level of direct sight or are in an obstructed field of vision. In its very simple form it is made up of two mirrors inclined at 45° to the direction being viewed.

- **Permalloys**

  A group of alloys of high magnetic permeability consisting of iron and nickel (usually 40–80%) often with small amounts of other elements (e.g. 3 – 5% molybdenum, copper, chromium or tungsten. They are used in thin foils in electronic transformers, for magnetic shielding and in computer memories.

- **Permanent magnet**

  A magnet that retains its magnetism even after the removal of external magnetic field.

- **Permeability (μ)**

When a magnetic substance is placed in a uniform magnetic field (where lines of force are parallel) number of lines of force are seen to be crowded through the substance. The conducting power of the substance for the lines of force is called permeability.. It is taken as unity for air. $B = \mu H$. It is measured in Henry/metre. The relative permeability of a substance is equal to the ratio of its absolute permeability to the permeability of the free space. Thus $\mu_r = \mu/\mu_0$ where μ_0, the permeability of free space has the value $4\pi \times 10^{-7}$ henry metre

- **Persistence of vision**

The impression of an image on the retina of the eye for some time after its withdrawl is known as persistence of vision. The impression on human eye lasts for $1/16^{th}$ of a second. Successive images at the rate of 16 per second of the same scene give the impression of continuity.

- **Phonon**

The phonon is a quantum of thermal energy. It is given by hf, where h is the Planck constant and f the vibrational frequency. It refers to lattice vibration of crystals.

- **Photodiode**

A Semiconductor diode used to detect the presence of light or to measure its intensity. It usually consists of a p–n junction device in a container that focuses any light in the environment close to the junction. The device is usually biased in reverse so that in the dark the current is small; when it is illuminated the current is proportional to the amount of light falling on it.

- **Photo–electric effect**

When light of suitable wavelength falls on a metal plate, such as ultra violet light on zinc, slow moving electrons are emitted from the metal surface. This phenomenon is known as photoelectric effect and the electrons emitted are known as photoelectrons.

- **Photo fission**

A nuclear fission that is caused by a gamma–ray photon.

- **Photon**

Each quantum of light energy is known as photon. The energy of photon is given by $E = \dfrac{hc}{\lambda}$, where λ is the wavelength associated with the photon, c is velocity of light and h is Planck's constant.

- **Photonuclear reaction**

A nuclear reaction that is initiated by a (gamma–ray) photon.

- **Photo sphere**

  It refers to highly luminous and visible portion of the sun. The approximate temperature existing in photosphere is estimated to be about 6000 K.

- **Piezo electric effect**

  The production of a small e.m.f. across the opposite faces of non conducting crystals when they are subjected to mechanica stress between their faces external pressure is known as piezoelectric effect or piezoelectricity.

- **Planck's formula for black–body radiation**

  The energy radiated per unit time per unit area at a given wavelength λ, is

  given by $$E = \frac{2\pi hc^2}{\lambda^5}\frac{1}{\left(e^{\frac{hc}{\lambda kT}} - 1\right)}$$

  where c is the speed of light, h is Planck's constant and T is the absolute temperature of the black body, k is the Boltzmann's constant.

- **Plane of polarisation**

  It is a plane that is perpendicular to the plane of vibration and containing the direction of propagation of light. It is also the plane containing the direction of propagation and the electric vector of the electromagnetic light wave.

- **Plasma**

  A highly ionized gas in which the number of free electrons is approximately equal to the number of positive ions. Sometimes described as the fourth state of matter, plasmas occurs in interstellar space, in the atmospheres of stars (including the sun), in discharge tubes and in experimental thermonuclear reactors.

- **Poises**

  It is a unit of viscosity in C.G.S. system.

  1 Poise = 0.1 Ns/m^2.

- **Poiseuille's formula**

  It gives the volume per unit time flowing through a cylinderical tube carrying a laminar flow. $Q = \dfrac{\pi R^4 \Delta P}{8\eta\ell}$

where; Q = Volume per unit of time

R = Radius of pipe

ℓ = Length of the pipe

ΔP = Pressure difference across each end of pipe

η = Coefficient of viscosity

- **Poisson's ratio**

  The ratio of the lateral strain to the longitudinal strain in a stretched rod. If the original diameter of the rod is d and the contractiono f the diameter under stress is Δd, the latral strain $\Delta d/d = s_d$; if the original length is ℓ and the extension under stress $\Delta\ell$, the longitudinal strain is $\Delta\ell/\ell = s_\ell$. Poisson's ratio is then s_d/s_ℓ.

- **Polaroid**

  Synthetic materials that are used for producing polarized light from unpolarised light by dichroism.

- **Positive crystals**

  Doubly refracting crystals in which the ordinary ray travels faster as compared to an extra ordinary ray e.g. quartz.

- **Positron**

  An elementary particle having a mass equal to that of an electron and carrying a unit positive charge.

- **Positronium**

  An unstable assembly of a positron and an electron. It decays into a photon.

- **Potentiometer**

  It is a device that is used for measuring electromotive force or potential difference by comparing it with a known voltage.

- **Pound**

  A unit of mass of FPS system 1 pound = 453.59 g

- **Poundal**

  A unit of force of FPS system 1 poundal = 0.138 N

- **Power of a lens**

  It is the ability of a lens to bend the rays passing through it. Power of convex lens is positive and that of concave lens is negative. Units of power of lens = Diopter. $\text{Power} = \dfrac{1}{\text{Focal length in meters}}$

- **Power reactor**

  A nuclear reactor designed to produce electrical power.

- **Presbyopia**

  It is a defect of vision. Any one suffering with this defect cannot see the near objects. This defect is generally observed in older people. It can be corrected with the help of convex lenses.

- **Pressure gauge**

  It is an instrument that is used for measuring the pressure of a gas or a liquid.

- **Prime meridian**

  The Greenwich meridian. It is used as standard for reckoning longitude east or west.

- **Principle of floatation**

  A body floats as a liquid when the weight of the liquid displaced by it is equal to its weight.

- **Prompt neutrons**

  The neutrons emitted during a nuclear fission process within less than a microsecond of fission.

- **Proton–Proton cycle**

  It refers to a chain of nuclear fusion reactions which are thought to be responsible for production of energy in the sun. Hydrogen gets converted into helium.

$$ {}_1^1H + {}_1^1H + {}_1^1H + {}_1^1H \longrightarrow {}_1^2H + \nu + e^+ $$

$$ {}_1^2H + {}_1^1H \longrightarrow {}_2^3He + \nu $$

$$ {}_2^3He + {}_2^3He \longrightarrow {}_2^4He + 2{}_1^1H $$

- **Pulsar**

  A celestial source of radiation emitted in brief (0.03 second to 4 seconds) regular pulses. First discovered in 1968, a pulsar is believed to be a rotating neutron star. The strong magnetic field of the neutron star concentrates charged particles in two regions and the radiation is emitted in two directional beams. The pulsing effect occurs as the beams rotate. Most pulsars are radio sources (emit electromagnetic radiation of radio frequencies) but a few that emit light or X–rays have been detected. Over 300 pulsars are now known, but is estimated that there are over one million in the Milky way.

- **Pyrometer**

  It is an instrument that is used for measurement of very high temperatures. The measurement is done by observing the colour produced by a substance by heating or by thermoelectric means.

- **Quality of sound**

  Majority of musical notes contain more than one frequency. Quality of sound is a characteristic of a musical note that depends on frequencies present in the note. In each note there is one fundamental frequency and a number of overtones. The frequencies of overtones are integral multiples of the fundament frequency but intensity is much low. The quality of sound changes with the number of overtones present and their intensity.

- **Quark**

  Hypothetical fundamental particles which are postulated to be building blocks of elementary particles.

- **Quartz**

  The most abundant and common mineral, consisting of crystalline silica (sillicon dioxide, SiO_2).

- **Quartz clock**

  A clock based on a piezoelectric crystal of quartz.

- **Quasars**

  A class of astronomical objects that appear on optical photographs as star like but have large redshifts quite unlike those of stars.

- **Quenching**

  The rapid cooling of a metal by immersing it in a bath of liquid in order to improve its properties.

- **Q–Value**

  It is the amount of energy produced in a nuclear reaction. It is expressed in MeV.

- **Rad**

  The unit of absorbed radiation. One rad = absorption of 10^{-2} joule of energy in one kilogram of material.

- **Radiology**

  It is the branch of science that deals with X-rays or rays from radioactive substances.

- **Radioscopy**

  It involves the examination of opaque objects with the help of X-rays.

- **Radius of curvature (R)**

  In case of a mirror or a lens it is the radius of the sphere of which a mirror or lens surface is a part.

- **Radius of gyration (K)**

  It is the distance, from the axis of rotation of a body to a point where the whole mass of a body may be considered to be concentrated.

  It is given by $K = \sqrt{\frac{I}{m}}$ Where I is the moment of inertia of body of mass m about the axis of rotation.

- **Rainbow**

  An arc of seven colours that appears in the sky due to splitting of sunlight into its constituent colours by the water droplets present in air because of refraction and internal reflection of sunlight by them.

- **Raman effect**

  When monochromatic light is allowed to pass through a transparent medium it gets scattered and the scattered light contains original wave length as well as lines of larger wave length than the original lines. These lines of larger wave lengths are known as Raman lines and this effect is known as Raman effect. This is quite useful in the study of molecular energy levels of liquids.

- **Rayleigh's criterion**

  Two sources are just resolvable by an optical instrument if the central maximum of the diffraction pattern of one coincides in position with the first minimum of the diffraction pattern of the other.

- **Receiver**

  Any device or apparatus that receives electric signals, waves etc.

- **Recoil**

  Means to fly back

- **Rectifier**

  A device that allows the current to flow through it in one direction only. It can convert a.c. into d.c. The commonly used rectifiers are a p-n junction, a diode valve etc.

- **Red giant**

  It is a type of cool giant star that emits light in red region of the spectrum. A normal star expands to red giant as it exhausts its nuclear fuel.

- **Red shift :**

  Because of **Doppler effect** a shift of spectrum lines in the spectra of some celestial objects towards the red end of the visible spectrum with an increase in wave length of the lines.

- **Reflectance**

  It is the ratio of the reflected light to the incident light on a surface.

- **Reflecting power**

  It is the ratio of the quantity of energy reflected to the quantity of energy falling on a body per unit time.

- **Refrigerator**

  It is the device that is used for producing low temperature and keeping items at low temperature.

- **Relative humidity**

The amount of water vapour in the air, expressed as a percentage of the maximum amount that the air could hold at a given temperature.

- **Relativistic mass**

It is the mass of an object which is moving with a velocity v.

It is given by the relation $m = \dfrac{m_0}{\sqrt{1-\dfrac{v^2}{c^2}}}$

where m_0 is the rest mass of the same object.

- **Relativistic particle**

A particle moving with a velocity close to the velocity of light, say greater than 0.1 c, c being the velocity of light.

- **Remanence**

The magnetic flux which remains in a magnetic circuit even after the applied magnetomotive force is removed.

- **Remote sensing**

The gathering and recording of information concerning the earth's surface by techniques that do not involve actual contact with the object or area under study. These techniques include photography (e.g. aerial photography), multispectral imagery, infrared imagery, and radar. Remote sensing is generally carried out from aircraft and increasingly, satellites. The techniques are used, for example, in cartography (map making).

- **Resistance**

It is the property of a material by virtue of which it opposes the flow of current through it. $R = V/I$

- **Resistance box**

It is a box containing a set of combination of resistance coils arranged in such a way that any desired value of resistance may be obtained using one or a combination of these.

- **Resistivity (ρ)**

It is also known as specific resistance. It is defined as the resistance offered by 1 m length of the conductor having an area of cross-section of 1 square meter.

Units of ρ are ohm-meter or ohm-cm.

- **Resolving power:**

  It gives the measure of the ability of an optical instrument to form separate and distinguishable images of two objects very close to each other. The resolving power of a telescope is given by

  $$\text{Resolving power} = \frac{1.22\,\lambda}{a}$$

  Where λ is the wavelength of light used and a is the aperture.

- **Retentivity**

  It is the ability to retain magnetisation even after the magnetising force is removed.

- **Reverberation**

  Refers to the persistence of sound even after the source has stopped emitting the sound.

- **Reverberation time**

  It is the time taken by a sound made in a room to diminish by 60 decibels.

- **Reynold number**

  It determines the state of flow of liquid through a pipe. According to Reynold number the critical velocity (v_c) is given by $v_c = \frac{R_n \eta}{\rho D}$ where ρ is the density of liquid, R_n is Reynold number and D is the diameter of the pipe thorugh which liquid is flowing –

  If R_n is upto 1000 the flow is streamline or laminar.

  If R_n lies between 1000-2000, flow is unstable.

  If R_n is more than 2000, flow is turbulant.

- **Richter scale**

  A logarithmic scale devised in 1935 by C.F. Richter (1900) to compare the magnitude of earthquakes. The scale ranges from 0 to 10. On this scale a value of 2 can just be felt as a tremor and damage to buildings occurs for values in excess of 6. The largest shock recorded hand a magnitude of 8.9.

- **Roentgen (R)**

  It is a unit of ionising radiation. One, Roengten induces 2.58×10^{-4} C of charge per kilogram of dry air.

- **Roentgen rays**

  X-rays

- **Rutherford**

  It is defined as the amount of radioactive substance which gives rise to 10^6 disintegrations per sec.

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

■ **Rydberg constant**

The wavelengths of lines of an atomic spectra are given by $\frac{1}{\lambda} = R\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$

where n_1 and n_2 are integers, R is called Rydberg's constant $R = \frac{2\pi^2 me^4}{ch^3}$

■ **Scattering**

It is the phenomenon of spreading out or diffusion of a beam of radiation when it is incident on some matter surface. The intensity of scattered light varies as $1/\lambda^4$ (Rayleigh scattering)

■ **Schwartzchild radius**

It is equal to $2GM/c^2$, where G is the gravitational constant, c is the speed of light, and M is the mass of the body. If the body collapse to such an extent that its radius is less than the Schwartzchild radius the escape velocity becomes equal to the speed of light and the object becomes a black hole.

■ **Scintillated**

To twinkle like stars

■ **Scintillation**

Refers to the twinkling effect of the light of stars.

■ **Second pendulum**

A simple pendulum having a time period of two seconds.

■ **Seeback effect**

When the juctions of two metallic conductors are maintained at different temperatures and e.m.f. is produced across these junctions. The production of such an e.m.f. is known as seeback effect.

■ **Segre chart**

A graph wherein the number of protons in nuclides is plotted against the number of neutrons

■ **Seismograph**

An instrument that records ground oscillations. e.g. those caused by earthquakes, volcanic activity, and explosions.

■ **Semi–conductor**

A substance having conductivity more than an insulator but less than that of a conductor. The conductivity of a semiconductor increases with temperature. Pure semi–conductors are also known as intrinsic semi–conductors. It is possible to increase the conductivity of a semi–conductor by adding suitable impurities in them. Such semi–conductors are known as extrinsic semi–conductors.

- **Semipermeable membrane**

  A membrane that is permeable to molecules of the solvent but not the solute in osmosis. Semipermeable membranes can be made by supporting a film of material (e.g. cellulose) on a wire gauze of porous pot.

- **Sextant**

  It is an optical instrument. It is used for the determination of the dimensions and distances of distant objects. It is based on the principle that if the angle subtended by two ends of an object at the observer's eye is known (measured by the sextant), the distance and dimensions of the object can be determined with the help of a trignometric formula.

- **Shadow**

  It refers to the dark shape cast on a surface by an object through which light, a form of radiation, can not pass, as radiations, travel in a straight line through a given medium. If one of the sources of radiations is small and the object is large, a sharp shadow is formed.However if the sources is larger than the object the shadow formed is not sharp and shows two distinct regions. The umbra, or full shadow, at the centre, surrounded by penumbra or partial shadow, no radiation reaches umbra but some radiation reaches penumbra.

- **Short wave**

  Refers to an electromagnetic wave of 60 meters or less.

- **Side band**

  Range of frequencies on either side of the carrier frequency of a modulated signal. The width of a side–band both above and below the modulated wave is equal to the highest modulating frequency.

- **Siemens (Mho)**

  It is S.I. unit of electrical conductance 1 Siemen (1 Mho) = 1 A/V.

- **Significant figures**

  The number of digits used in a number specify its accuracy. The number 6.532 is a value taken to be accurate to four significant figures. The number 7320 is accurate only to three significant figures. Similarly 0.0732 is also only accurate to three significant figure. In these cases the zeros only indicate the order of magnitude of the number, whereas 7.065 is accurate to four significant figures as the zero in this case is significant in expressing the value of the number.

- **Silicon chip**

  A single crystal of a semiconducting silcon material, typically having micrometer dimensions, fabricated in such a way that it can perform a large number of independent electronic functions.

- **S.I. units**

This is international system of units comprising of seven basic units. These are:

Physical Quantity	Unit	Symbol
Length	Metre	m
Mass	Kilogram	kg
Time	Second	s
Temp.	Kelvin	K
Electric current	Ampere	A
Light Intensity	Candela	cd
Amount of substance	mole	mol

- **Skin effect**

It is the phenomenon wherein an alternating current tends to concentrate in the outer layer of a conductor.

- **Skip distance**

The minimum distance at which a sky wave can be received. This arises due to a minimum angle of incidence at the ionosphere below which a sky wave is not reflected. This minimum angle is a function of the frequency.

- **Sky wave**

Refers to a radio wave that is propagated upwards from the earth and such a wave reaches a point after reflection from the ionosphere and not directly from the transmitter.

- **Snell's law**

$$\mu = \frac{\sin i}{\sin r} \text{ (or } \mu\sin\theta = \text{constant)}$$

- **Soft iron** It refers to iron that contains small quantities of carbon. Since it can be easily magnetised and demagnetised easily so it is used in transformers, electric bells etc.

- **Solar battery**

It is device for converting solar energy into electricity by means of photo voltaic cells.

- **Solar constant**

It refers to the average rate at which solar energy is received from the sun by the earth. It is equal to 1.94 small calories per minute per square centimeter of area perpendicular to the sun's rays. It is equal to 1400 J/s–m^2.

- **Solar day**

The time interval that elapses between two successive appearances of the sun at the meridian.

- **Solar system**

  The sun, the nine major planets (Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto) and their natural satellites, the asteroids, the comets and meteoroids. Over 99% of the mass of the system is concentrated in the sun. The solar system as a whole moves in an approximately circular orbit about the centre of the galaxy, taking about 2.2×10^8 years to complete its orbit.

- **Solar wind**

  A continuous outward flow of charged particles, mostly protons and electrons, from the sun's corona into interplanetary space. The particles are controlled by the sun's magnetic field and are able to escape from the sun's magnetic field and are able to escape from the sun's gravitational field because of their high thermal energy. The average velocity of the particles in the vicinity of the earth is about 450 km s^{-1} and their density at this range is about 8×10^6 protons per cubic metre.

- **Solenoid**

  It refers to a coil of wire wound over a cylinderical frame uniformly. Its diameter is small as compared to its length. When a current is passed through it, a magnetic field is produced inside the coil and parallel to its axis. It can also be used as an electromagnet by introducing a core of soft iron inside it.

- **Sonic boom:**

  Refers to a loud noise.

- **Sonometer**

  It is an instrument that is used for studying the vibrations of a fixed wire or string. It consists of a hollow wooden box with a wire stretched across its top. The wire is fixed at one end while the other end passes over a pulley and a load can be suspended from it. Any length of wire can be set into vibration by placing two inverted v–shaped bridges at the ends, by placing vibrating tunning fork on the sonometer. resonance is produced when the natural frequency of the vibrating wire given by $\left(f = \frac{1}{2\ell}\sqrt{\frac{T}{m}}\right)$ is equal to the frequency of the tunning fork. T is the tension in the wire and m is its mass per unit length.

- **Space–charge**

  A region in a vacuum tube or semi–conductor having some net electric charge because of excess or deficiency of electrons.

- **Specific gravity**

  It is the ratio of density of any substance to the density of some other substance taken as standard. e.g. the density of water at 4°C is taken as 1.

Specific heat

It is the amount of heat required to raise the temperature of 1 kg of substance by 1°C or 1 K.

It is expressed in J/g/K or J Kg^{-1} K^{-1}.

The specific heat of water is maximum.

Spectrograph

An instrument where in a photograph of the spectrum can be obtained.

Spectrometer

It is an instrument that is used for analysing the spectrum of a source of light.

Spherical aberration

A defect of image due to the paraxial and marginal rays which are coming to focus at different point on the axis of the lens. It can be corrected by using parabolic surfaces as reflectors and refractors.

Spontaneous fission

Nuclear fission that occurs independently of external circumstances and is not initiated by the impact of a neutron, an energetic particles or a photon.

Spring balance

Any instrument with which a force is measured by the extension produced in a helical spring. It is used in weighing. The extension produced is directly proportional to the force (weight).

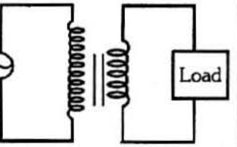
Stable equilibrium

A body is said to be in stable equilibrium if it tends to return to its original state when it is slightly disturbed from its state.

Steam point

It is the temperature at which water boils under a pressure of one atmosphere.

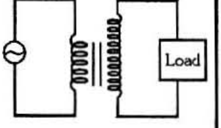
Step–down transformer



It helps in stepping down the voltage. In it $N_S < N_P$ and so $\frac{N_S}{N_P} < 1$.

The e.m.f. of secondry coil is less than that of primary $E_S < E_P$.

Step–up transformer



It helps in stepping up the voltage.

In it $N_S > N_P$ and the ratio $\frac{N_S}{N_P} > 1$ The e.m.f. of secondary coil is greater than that of primary $E_S > E_P$.

- **Stokes (St)**

  It is a unit of viscosity in C.G.S. system.

- **Stoke's law**

  When a spherical body falls through a viscous medium, it drags the layer of fluid in contact. Due to relative motion between layers, the falling body feels a viscous force F given by $F = 6\pi\eta rv$

  Where r = radius of body

  v = velocity of body

  η = Coefficienat of viscosity

- **Sublimation**

  Change from solid to gaseous state without passing through liquid state.

- **Subsonic**

  Speed less than the speed of sound.

- **Sunspots**

  Dark patches observed on the sun's surface that are regions of cool gas. Their presence is connected with local changes in the sun's magnetic field. They appear in cycles having a period of about 11 years.

- **Super conductivity**

  Refers to complete disappearance of electrical resistance. It has been observed in some substances when they are cooled to very low temperatures (very close to absolute zero). This phenomenon can be used for producing large magnetic fields.

- **Surface tension**

  It is the force per unit length of an imaginary line drawn in the liquid surface in equilibrium acting perpendicular to it at every point and tending to pull the surface apart along the line. It can also be defined as the work done in increasing the surface area of a liquid film by unity. Units of surface tension are dynes/cm or N/m.

- **Susceptibility**

  If a bar of iron is placed in a magnetic field, it gets magnetised and the pole strength or magnetisation depends upon the strength of magnetic field. Thus if $\vec{H}$ is magnetic intensity or magnetizing field intensity and $\vec{I}$ is intensity of magnetization then $\frac{I}{H} = \chi$ is the susceptibility of the specimen. The value of χ (susceptibility) and μ (permeability) are high for ferromagnetic substances.

- **Synchronous orbit or geosynchronous orbit**

An orbit of the earth made by an artificial satellite with a period exactly equal to the earth's period of rotation on its axis, i.e. 23 hours 56 minutes 4·1seconds. If the orbit is inclined to the equatorial plane the satellite will appear from the earth to trace out a figure–of–eight track once every 24 hours. If the orbit lies in the equatorial plane and is circular, the satellite will appear to be stationary. This is called a stationary orbit (or geostationary orbit) and it occurs at an altitude of 35900 km. Most communication satellites are in stationary orbits, with three or more spaced round the orbit to give worldwide coverage.

- **Telestar**

It refers to one of a series of low altitude, active communication satellites for broad band microwave communication and satellite tracking in space.

- **Temperature gradient**

Rate of change of temperature with distance.

- **Temperature scale**

Any temperature scale consists of two fixed points which generally correspond to two easily reproducible systems. These are assigned certain definite values and the interval between them is divided into an equal number of parts. The celsius scale is most commonly used and the fixed points in it are the ice point (0 °C) and steam point (100 °C). Interval between them is divided into 100 equal parts, each part being equal to 1° C, other scales used are, Fahrenheit, Romer and Kelvin. These are related to celsius scale as –

$$\frac{C}{100} = \frac{F-32}{180} = \frac{R}{80} = \frac{K-273}{100}$$

- **Tempering**

It refers to the process used for increasing the toughness of an alloy by heating it to a predetermined temperature, maintaining it at this temperature for predetermined time and then cooling it to room temperature at a predetermined rate.

- **Tensile strength**

The resistance of a material to longitudinal stress. It is measured by minimum amount of longitudinal stress needed to break the material.

- **Terminal speed**

The constant speed finally attained by a body moving through a fluid under gravity when there is a zero resultant force acting on it. See Stokes's law.

$$v_0 = \frac{2r^2(\rho-\rho')g}{9\eta}$$

Where ρ= Density of spherical body and ρ' = Density of fluid
If $\rho > \rho' \Rightarrow$ The body will move downward
If $\rho < \rho' \Rightarrow$ The body will move upward

- **Thermal capacity or Heat capacity**

  It is the amount of heat required to raise the temperature of a body by 1 °C. It is equal to the product of mass of the body and the specific heat. It is expressed in J/°C or J/K.

- **Thermal diffusion**

  It refers to the diffusion that occurs in a fluid due to temperature gradient. It is used to separate heavier gas molecules from lighter ones by maintaining a temperature gradient over a volume of gas containing particles of different masses. This method is also used to separate gaseous isotopes of an element.

- **Thermal neutrons**

  Refers to neutrons of very low speed and energy ($\simeq 0.1$ eV)

- **Thermal reactor**

  It is a type of nuclear reactor in which the nuclear fission reactions are caused by thermal neutrons.

- **Thermion**

  Refers to an ion that is emitted by an incandescent material.

- **Thermionic current**

  It refers to the electric current that is produced due to flow of thermions.

- **Thermionic emission**

  It refers to the emission of electrons from the surface of a substance when it is heated. It forms the basis of the thermionic valve and the electron gun in cathode ray tubes. The emitted current density is given by Richardson – Dushman equation $J = AT^2e^{-\phi/kT}$

  Where T = Thermodynamic temp. of the emitter

  ϕ = Work function

  k = Boltzmann constant

  A = Some constant

- **Thermistor**

  It refers to a semi–conductor, whose electrical resistance changes rapidly with change in temperature. It is used to measure temperature very accurately.

- **Thermocouple**

  It consists of two metallic junctions of different metals whose junctions are kept at different temperatures, an e.m.f. develops across these which is proportional to the temperature difference. A measurement of e.m.f. enables one to calculate the temperature so it is used for measurement of temperatures.

- **Thermo e.m.f.**

  Seebeck discovered that if two dissimilar metals are joined together to form a closed circuit and their two junctions are maintained at different temperatures an e.m.f. is developed and an electric current flows in the circuit. This e.m.f. developed is known as thermo e.m.f. is given by $E = \alpha t + \frac{1}{2}\beta t^2$

  Where t = temperature difference of hot and cold junction in °C, α and β are constants which are characteristic of metals forming the thermocouple and are known as seebeck coefficients.

- **Thermoelectricity**

  The electricity produced due to thermo e.m.f. is called thermoelectricity.

- **Thermoelectric power**

  It refers to the rate of change of the thermo e.m.f. of the thermocouple with the temperature of the hot junction.

- **Thermopile**

  It is an arrangement of thermocouple in series. Such an arrangement is used to generate thermoelectric current or for detecting and measuring radiant energy.

- **Thermostat**

  A device which is used to keep the temperature in a place within in a particular range. Thermostats are present in a number of common household devices such as cookers, refrigerators, irons, freezers and heating boilers. Many thermostats are **bimetallic strips**.

- **Threshold**

  It refers to the minimum value of a parameter that will produce a specified effect.

- **Threshold of hearing**

  That minimum intensity level of a sound wave which is audible. It occurs at a loudness of about 4 phons.

- **Timbre**

  The characteristic quality of sound. It is independent of pitch and loudness but depends upon the relative strength of components of different frequencies, determined by resonance. It depends on the number and intensity of the overtones present.

- **Tomography**

  The use X–rays to photograph a selected plane of a human body with other planes eliminated. The CAT (computerised axial tomography) scanner is a ring–shaped X–ray machine that rotates through 180° around the horizontal patient, making numerous X–ray measurements every few degress. The vast amount of information acquired is built into a three–dimensional image of the tissues under examination by the scanner's own computer. The patient is exposed to a dose of X–rays only some 20% of that used in a normal diagnostic X–ray.

- **Ton**

  It is a unit of weight 1 ton = 2000 pounds = 907.18 kg.

- **Tone**

  It refers to a sound considered with reference to its quality, strength, source etc.

- **Tonne (Metric Ton)**

  A unit of mass 1 Tonne = 10^3 kg.

- **Torr**

  A unit of pressure. 1 torr = 1333.2 microbars. One torr is equal to the pressure of 1 mm of mercury.

- **Torricelli's theorem**

  It gives us the velocity of a fluid, coming out of a vessel, at a point at a height h below its surface. According to it. $v = \sqrt{2gh}$

- **Torsion**

  It refers to the twisting of an object by two equal and opposite torques.

- **Torsional pendulum**

  In such a pendulum moment of restoring forces, $\tau = -k\theta$

  Time period $T = 2\pi\sqrt{\frac{I}{K}}$ Where

  K = Constant torsion in the thread

  I = Moment of inertia of the rotating body about the thread

- **Torsional balance**

  An instrument for measuring very weak forces. It consists of a horizontal rod fixed to the end of a vertical wire or fibre or to the centre of a taut horizontal wire. The forces to be measured are applied to the end or ends of the rod. The turning of the rod may be measured by the displacement of a beam of light reflected from a plane mirror attached to it.

- **Total internal reflection**

  For such a reflection the ray must pass from a denser to a rarer medium. When a ray of light travels from a more refractive medium to a less refractive medium it undergoes total internal reflection, if angle of incidence is greater than critical angle θ, which can be defined as

$$\sin\theta = \frac{n_1}{n_2} = {}^1n_2$$

- **Transmitter**

  • The equipment used to generate and broadcast radio–frequency electromagnetic waves for communication purposes. It consists of a carrier–wave generator, a device for modulating the carrier wave in accordance with the information to be broadcast, amplifiers, and an aerial system.

  • The part of a telephone system that converts sound into electrical signals.

- **Trajectory**

  It is the path traversed by a projectile, rocket etc.

- **Trans–conductance**

  It is the ratio of change in plate current to change in grid voltage at constant plate voltage. It is expressed in mhos.

- **Transducer**

  Refers to a device that receives energy from one source and retransmit it in a different form to another system or media.

- **Transformer**

  It is a device that is used to convert a large alternating current at low voltage into a small alternating current at high voltage or vice–versa.

- **Transients**

  It refers to the non-periodic portion of a wave or signal transient modulation i.e. a modulation of temporary nature.

- **Transmutation**

  The process in which one nuclide is converted into another nuclide.

- **Transponder**

  Refers to a radio or radar receiver, that automatically transmits a reply promptly on reception of a certain signal.

- **Triangle law of vectors**

  It states, "if two vectors can be represented in magnitude and direction by two sides of triangle taken in order, then the resultant vector can be represented in magnitude and direction by the third side of the triangle taken in opposite order." where $\vec{a}$, $\vec{b}$ are two vectors and $\vec{c}$ is the resultant vector. $\vec{c} = \vec{a} + \vec{b}$

- **Triple point**

  It is the temperature at which the gas, liquid and solid phase of a substance can coexist. Triple point of water is 273.16 K and 0.46 cm of mercury. All the three phases of water (solid, liquid and gas) coexist at this temperature and pressure and all the phases are equally stable.

- **Triton**

  Nucleus of tritium ($_1^3H$) atom.

- **Troposphere**

  It is the region of atmosphere which extends upto a height of about 16 km above the earth's surface at the equator and to a height of about 8 km at the poles. The temperature in this region decreases with increase in height.

- **Tunnel diode**

  A semiconductor diode, based on the tunnel effect. It consists of a highly doped p–n semiconductor junction, which short circuits with negative bias and has negative resistance over part of its range when forward biased. Its fast speed of operation makes it a useful device in many electronic fields.

- **Tunnel effect**

  An effect in which electrons are able to tunnel through a narrow potential barrier that would constitute a forbidden region if the electrons were treated as classical particles.

- **Turbulent flow**

  Flow of liquid wherein the speed of the fluid changes rapidly in magnitude and direction. The motion of a fluid becomes turbulent when its speed increases beyond a certain typical speed.

- **Twilight**

  The soft diffused light from the sky when the sun is below the horizon.

- **Tyndall effect**

  It refers to the scattering of light by particles in its path and the beam of light becomes visible.

- **Umbra**

  It is the region of complete shadow.

- **Uncertainty principle**

  It states, "It is not possible to find accurately and simultaneously both the position and velocity of a moving particle." Mathematically $\Delta x.\Delta p = \frac{h}{4\pi}$

  Where Δx = Uncertainty in position, Δp = Uncertainty in momentum

- **Unipolar transistor**

  A transistor wherein current flow is due to the movement of majority carriers only.

- **Upthrust**

  Refers to the upward force that acts on an object when it is immersed in a fluid. It is equal to the mass of the fluid displaced by the object.

- **Vacuum**

  A space that is totally devoid of matter. Generally it refers to a space from which air has been removed and where the pressure is very low.

- **Valence band**

  Range of energies in a semi–conductor which corresponds to energy state that can be occupied by the valency electrons in the crystal.

- **Van–de–graff accelerator**

  It is a machine that is used to accelerate charged particles.

- **Vander wall's equation of state**

  It is an equation of state for real gases.

  $$\left(P+\frac{n^2a}{V^2}\right)(V-nb) = nRT$$

  Where V = Volume of gas

  R = Gas constant

  T = Absolute temperature

  n = Number of moles of gas

  a, b = constant called Vander Wall's constant.

- **Vander wall forces :** These are very weak attractive forces that exist between the atoms and molecules of all the substances. These are short range forces and arise due to molecular dipoles.

- **Venturimeter**

  It is an apparatus used to find the rate of flow of liquids when the motion of fluid is steady and non–turbulent.

- **Vernier**

  A small movable device having graduated scale running parallel to the fixed graduated scale of a sextant. It is used for measuring a fractional part of one of the fixed division of the fixed scale. The smallest measurement which can be made using a vernier instrument is equal to the difference between 1 main scale division (smallest) and 1 vernier scale division.

- **Vernier caliper**

  A caliper made up of two pieces sliding across one another, one having a graduated scale and the other a vernier.

- **Viscosity**

  It is the property of the fluid by virtue of which it opposes the relative motion between its different layers. It is also called internal friction of the fluid.

- **Visible radiation**

  Radiation in the wave length range of 3800–7600 Å. It is visible to human eye.

- **Visual–Display Unit (VDU)**

  The part of a computer system or word processor on which text or diagrams are displayed. It consists of a cathode–ray tube and usually has its own input keyboard attached.

- **Voltage stabilizer**

  A device or circuit to maintain a voltage at its output terminals that is the substantially constant and independent of other changes in the input voltage or in the load current.

- **Voltaic Cell**

  A cell having two electrodes of different metals dipped in the solution of their soluble salts and arranged in such a way that they produce an electromotive force.

- **Voltameter**

  It is an electrolytic cell and is used to carry out the process of electrolysis.

- **Voltmeter**

  It is an instrument that is used for measuring the potential difference across two points in a circuit. It is always connected in parallel across the desired points in an electrical circuit.

- **Volume**

  It refers to the space occupied by a body.

- **Volumetric**

  Refers to measurement by volume.

- **Watt-meter**

  It is an instrument that is used for measuring power consumed in an electric circuit.

- **Wavelet**

  A small wave

- **Water equivalent of a substance**

  It is the amount of water that would need the same quantity of that for being heated through the same range of temperature as required by the substance for being heated through a given range of temperature.

- **Wave-particle duality**

  According to dual nature of matter, there is wave associated with every moving particle and vice-versa. The wave length of a wave associated with a moving particle having a momentum, p, is given by $\lambda = h/p$ where h is Plank's constant.

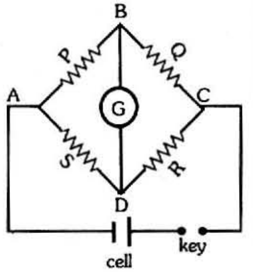
- **Weber**

  One weber is the magnetic flux linked with a surface of magnetic field one Tesla over an area of 1 sq metre. $1\ Wb = 1\ Tm^2$.

- **Weightlessness**

It refers to the state, experienced by a person in an orbiting space craft, of loss of weight.

- **Wheatstone bridge**



It is an electrical circuit that is used to measure the electrical resistance. It consists of resistances connected in four arms. A galvanometer (G) is connected across two opposite junctions, and a source of e.m.f. is connected across the remaining two junctions as shown in the diagram. If three of the resistances P, Q, R are known, the fourth (S) can be determined. Keeping the resistance P, Q fixed the resistance R is varied till the glavanometer shows zero deflection. When this is achieved $\frac{P}{Q}=\frac{R}{S}$. For maximum sensitivity all the four resistances should be of the same order.

- **White dwarf**

Refer to any of a large size of very faint stars that are considered to be in the last stage of stellar evolution. Its nuclear fuel is completely exhausted and it collapses, under its own gravitation, into a small but very dense body.

- **Wiedemann–Franz law**

It states that for all metals, the ratio $\frac{k}{\sigma T}$ = constant, where k is the thermal conductivity. σ is electrical conductivity and T is the absolute temperature of the substance.

- **Wien's displacement law**

According to it, for a black-body radiation $\lambda_m T$ = constant

Where λ_m = wavelength corresponding to maximum energy radiation. T = Absolute temperature of the body.

- **Wireless**

Means having no wire

- **Work Function (ϕ)**

It is the minimum energy that is required to overcome the surface force so as to liberate the electrons from the metal surface. It is measured in electron volts.

- **X-ray**

It is a form of electromagnetic radiation of shorter wavelength as compared to visible light. X-ray can penetrate through solid and can ionise gases.

- **X-ray Diffraction**

the diffraction of X-rays by a crystal. The wavelengths of X-rays are comparable in size to the distances between atoms in most crystals, and the repeated pattern of the crystal lattice acts like a diffraction grating for X-rays.

- **Yard**

The former Imperial standard unit of length. In 1963 yard was redefined as 0.9144 metre exactly.

- **Yield point**

When a rod or wire of certain material is subjected to a slowly increasing tension, the point at which a small increase in tension produces a sudden and large increase in length is called the yield point.

- **Zeeman effect**

It refers to the splitting up of single lines in a spectrum into a group of closely spaced lines. this effect is observed when the substance emitting the spectrum is placed in a strong magnetic field. The study of this effect is used in the study of atomic structure.

- **Zener diode**

It is a semi-conductor diode where in each side of junction is highly doped. When the junction is reverse biased, a sharp increase in the current occurs at well defined potential. Such a diode is used as a voltage regulator.

- **Zero-gravity**

It refers to the condition wherein the apparent effect of gravity becmes zero as on a body in orbit.

- **Zero point energy**

It is the energy possessed by atoms or molecules of a substance at absolute zero of temperature. It can not be explained by classical physics but has been accounted for as a quantum effect.

- **Zeroth law of thermodynamics**

According to it, whenever two bodies A and B are in thermal equilibrium with another body C then bodies A and B will also be in thermal equilibrium with each other.

- **Zero vector or Null vector**

A vector whose magnitude is zero is known as a zero vector. The direction of zero vector is not defined.