Physics 3 Hours

PHYSICS

Units & Measurements

If Q is the quantity, n is the numerical value and u is the unit then;

Q = nu

$n_1u_1 = n_2u_2$ (bigger the unit, smaller is the value)

Systems of Measurement

(a) **C.G.S** (Centimeter-Gram-Second) system.

(b**) F.P.S.** (Foot-Pound-Second) system.

(c) **M.K.S.** (Meter-Kilogram--Second) system.

(d) **M.K.S.A.** (Meter-Kilogram-Second-Ampere) unit.

Fundamental Units

These units are independent of other units, thus called as fundamental units.

PHYSICAL QUANTITY	SYMBOL	DIMENSION	MEASUREMENT UNIT
Length	S	L	Meter – m
Mass	M	M	Kilogram – kg
Time	T	T	Second – s
Electric charge	I	A	Current – A
luminous intensity	I	C	Candela – Cd
Temperature	T	K	Kelvin - K
Angle **Solid Angle**	Θ ω	None None	Radian - rad Steradian

- **Dimensional Formula:-**

Dimensional formula of a physical quantity is the formula which tells us how and which of the fundamental units have been used for the measurement of that quantity.

- **How to write dimensions of physical quantities:-**

(a) Write the formula for that quantity, with the quantity on L.H.S. of the equation.

(b) Convert all the quantities on R.H.S. into the fundamental quantities mass, length and time.

(c) Substitute M, L and T for mass, length and time respectively.

(d) Collect terms of M,L and T and find their resultant powers (a,b,c) which give the dimensions of the quantity in mass, length and time respectively.

Uses of Dimensional Analysis :

1. To check the correctness of an equation
2. To find the conversion factor
3. To find the dimensions by comparison method

Significant Figures

There are three rules on determining how many significant figures are in a number:

1. Non-zero digits are always significant.
2. Any zeros between two significant digits are significant.
3. A final zero or trailing zeros in the decimal portion ONLY are significant.
4. If the last digit to be rounded off is 5 or greater than 5 , then the last significant digit is increased by 1 .

Order of Magnitude

Order of Magnitude is the power to which 10 is raised to ; to indicate the size of the quantity .

To find out order of magnitude :

1. The number should be in units place . e.g. 2.15×10^4 has the order 4 .
2. If the number in units place is 5 or greater than 5 , then increase the order by 1 .
   e.g. 7.4×10^6 has the order 7 .

Types of Errors

Personal Error

Error occurring due to human errors.

Random Error

Error occurring due to random changes in the environment of the experiment.

Systematic Error

Error occurring due to a constant error in the readings of instrument. This is caused due to the faulty calibration of instrument.

Instrumental Error

Error occurring due to faulty construction of instrument.

Error Analysis

Mean Value: Average of All readings

Absolute Error : Individual Reading - Mean Value

Mean Absolute Error : Average of all Absolute values

Relative Error : Mean Absolute Error / Mean Value

Percentage Error : Relative Error x 100

Rules for Error Analysis :

1) If dx is the error in x , then Error in x^n is n dx.

2) If dx is the error in x and dy is the error in y , then the Error in x + y , x – y , xy , x/y , is dx + dy

Scalars & Vectors

Scalars and Vectors

Scalar Quantities can be denoted by a number and a unit, i.e. Magnitude. Vector Quantities are denoted by magnitude and direction.

Tensor Quantities

Tensor Quantities are those quantities whose magnitude changes based upon the direction in which you measure it. (e.g. Moment of Inertia)

Types of Vectors

Equal Vectors: Vectors having same direction and magnitude.

Parallel Vectors: Vectors having same direction.

Anti-Parallel Vectors: Vectors having opposite directions.

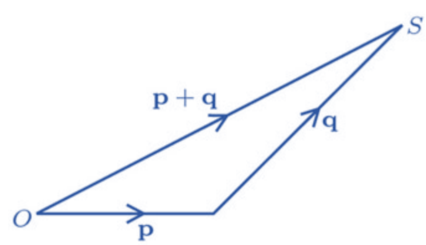
Position Vector: Vector drawn from the origin to a point.

Zero Vector: Vector of magnitude zero.

Free Vector: Vector which can be moved through space, without changing its direction.

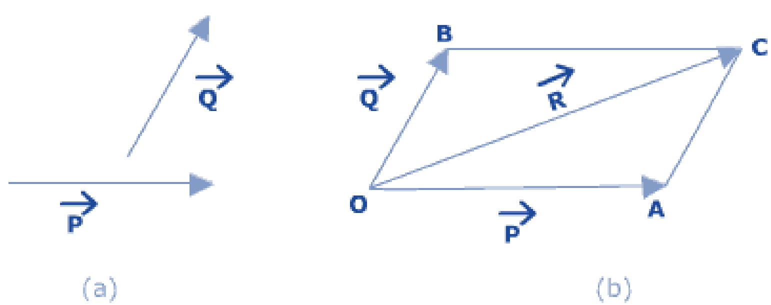
Triangle Law

If two vectors exist such that their directions are taken in order, then their resultant is equal to the third of the triangle formed; & the direction is from head of first to tail of second.



Parallelogram Law

The parallelogram law of Vectors states that if two vectors originate or meet at a common point, then their resultant is given by the diagonal of parallelogram formed.



Magnitude: $\bar{R} = \sqrt{\bar{P}^2 + \bar{Q}^2 + 2\bar{P}\bar{Q}cos\theta}$

Direction: $\theta = tan^{-1}\frac{Qsin\theta}{P+Qcos\theta}$

Scalar Multiplication

Scalar multiplication refers to the multiplication of a vector with a number.

In Scalar Multiplication, the number is multiplied to all components of the vector. Thus, scalar multiplication does not change the direction of the vector, it only affects the magnitude.

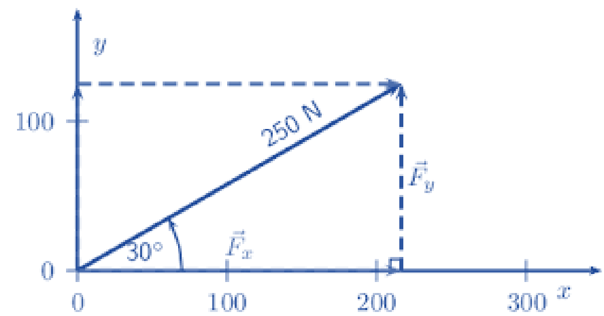
Resolution of Vectors

for co-ordinate system, we know that:

x = rcosθ y = rsinθ

for 3-d coordinate system, we resolve using direction cosines :

r = acosα + acosβ + acosγ



Scalar Product

a.b = abcosθ

Scalar Product gives us a Scalar result.

Vector Product

axb = absinθ

Vector product gives us a vector result.

Unit Vector

A unit vector has unit magnitude and any direction. If we divide a vector by its magnitude, we get an unit vector.

Kinematics & Projectile Motion

- The average speed v_{av} and average velocity $\vec{V}_{av}$ of a body during a time interval is defined as,

  V_{avg} = *Total Distance / Total Time*

  $$\vec{V}_{av} = \text{average velocity} = \frac{\Delta \vec{r}}{\Delta t}$$

- Instantaneous speed and velocity are defined at a particular instant and are given by

  $$v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} = \frac{ds}{dt} \text{ and } \vec{V} = \lim_{\Delta t \to 0} \frac{\Delta \vec{r}}{\Delta t} = \frac{d\vec{r}}{dt}$$

Note:

(a) A change in either speed or direction of motion results in a change in velocity

(b) A particle which completes one revolution, along a circular path, with uniform speed is said to possess zero velocity and non-zero speed.

(c) It is not possible for a particle to possess zero speed with a non-zero velocity.

- Average acceleration is defined as the change in velocity $\Delta \vec{V}$ over a time interval *t*.

  $$\vec{a}_{av} = \frac{\Delta \vec{V}}{\Delta t}$$

The instantaneous acceleration of a particle is the rate at which its velocity is changing at that instant.

$$\vec{a}_{ins} = \lim_{\Delta t \to 0} \frac{\Delta \vec{V}}{\Delta t} = \frac{d\vec{V}}{dt}$$

Kinematical Equations:

- The three equations of motion for an object with constant acceleration are given below.

  (a) $v = u + at$

  (b) $s = ut + \frac{1}{2}at^2$

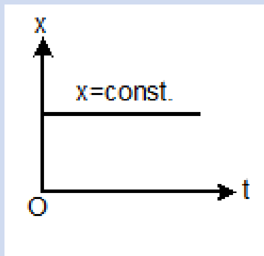
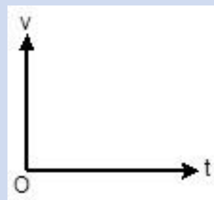
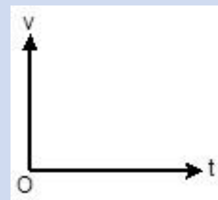
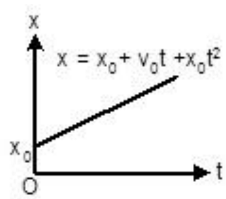
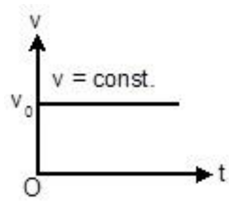
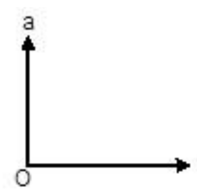
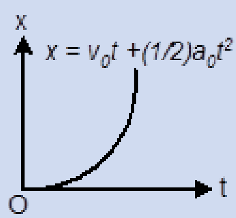
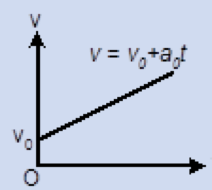
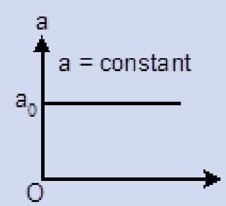
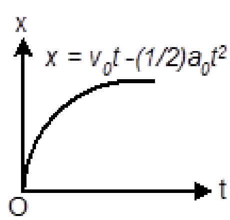
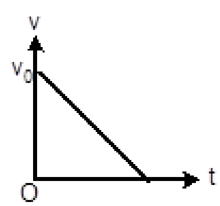
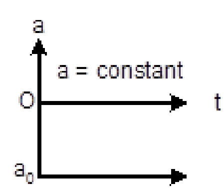
  (c) $v^2 = u^2 + 2as$

Here *u* is the initial velocity, *v* is the final velocity, *a* is the acceleration, *s* is the displacement travelled by the body and *t* is the time.

Note: Take '+ve' sign for a when the body accelerates and takes '–ve' sign when the body decelerates.

- The displacement by the body in n^{th} second is given by, $s_n = u + \frac{a}{2}(2n - 1)$

All Graphs from Kinematics

	Displacement(x)	Velocity (v)	Acceleration (a)
(a) At rest			
(b) Motion with constant velocity			
(c) Motion with constant acceleration			
(d) Motion with constant deceleration			

Relative Velocity

Relative Velocity is the velocity of a moving body with respect to another moving body

1) Bodies moving in the same direction; a - b
2) Bodies moving in opposite directions; a + b
3) Bodies moving and inclined at an angle θ to each other, then:

$$Relative\ Velocity = \sqrt{a^2 + b^2 - 2abcos\theta}$$

Motion in Straight Line: Moves along one co-ordinate axis

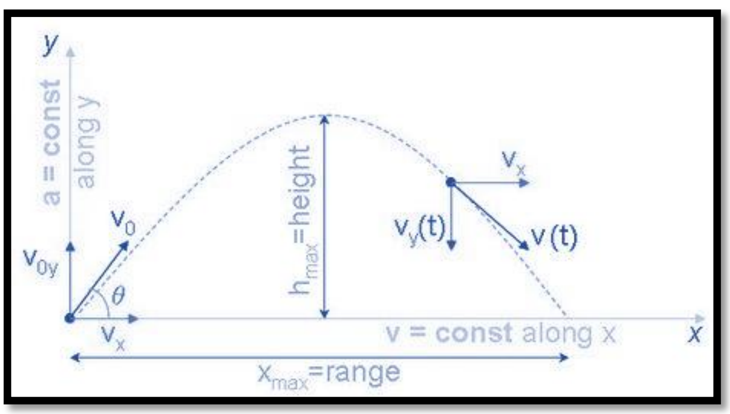
Motion in a Plane: Moves in a plane with 2 d co-ordinate axis.

Motion in Space: Moves in Space with 3 d co-ordinate axis.

Projectile Motion, Motion in 2 Dimensions / Motion in a Plane

Projectile motion in a plane:

If a particle having initial speed u is projected at an angle θ (angle of projection) with x-axis, then,



Equation of trajectory, $y = xtan\alpha - (\frac{gx^2}{2u^2cos\,2\alpha})$

Time of Flight, $T = \frac{2u\ sin\alpha}{g}$

Horizontal Range,$R = \frac{u^2 sin\,2\alpha}{g}$

Maximum Height, $H = \frac{u^2 sin\,2\alpha}{2g}$

Motion on an inclined plane:

(i) Perpendicular vector: At the top of the inclined plane (t = 0, u = 0 and $a = g \sin \theta$), the equation of motion will be,

(a) $v = (g \sin\theta)t$

(b) $s = ½ (g \sin\theta) t^2$

(c) $v^2 = 2(g \sin\theta) s$

(ii) If time taken by the body to reach the bottom is t, then $s = ½ (g \sin\vartheta) t^2$

$t = \sqrt{(2s/g \sin\vartheta)}$

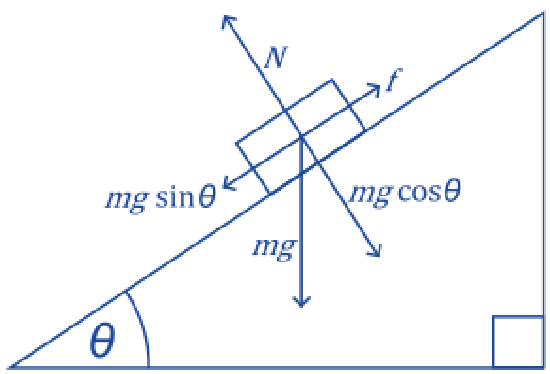
But $\sin\vartheta = h/s$ or $s = h/\sin\vartheta$

So, $t = (1/\sin\vartheta) \sqrt{(2h/g)}$

(iii) The velocity of the body at the bottom

$v = g(\sin\vartheta)t$

$= \sqrt{2gh}$



Force

Newton's Laws of Motion

First Law of Motion

An object continues to be in its state of rest or uniform motion, until and unless an external unbalanced force acts on it.

Second Law of Motion

Force acting on an object is directly proportional to the rate of change of Momentum with respect to time.

Third Law of Motion

For every action, there is an equal and opposite reaction. This reaction is limiting and acts in opposite direction as long as it is capable of withstanding the force.

Force

Force = Mass x Acceleration

Forces in Nature

Gravitational Force

Force of attraction between two bodies having mass.

Electromagnetic Force

Forces involved in electric and magnetic fields.

Strong Nuclear Force:

A nucleus contains protons and neutrons. Protons being positively charged exert repulsive force on each other. But, this force is not enough to break the nucleus. This is because there exists a strong interaction inside the nucleus. This is called as strong nuclear force.

Weak Nuclear Force:

Forces associated with radioactive reactions are called as Weak Nuclear Forces.

Law of Conservation of Momentum

The law of conservation of momentum states that the total momentum of a system of objects is always conserved.

Impulse is the amount of force acting on a body in given time. Impulse and Momentum have the same dimensions.

$$Impulse = J = F.t$$

Frame of Reference

A Frame of reference is a fixed co-ordinate system, with respect to which the position and motion of an object is determined.

Inertial

Inertial frame of reference is a frame of reference in which Newton's First Law of Motion holds good. i.e. it is an unaccelerated frame of reference.

Non-Inertial

Non-Inertial Frame of reference is a frame of reference in which Newton's First Law of Motion does not hold good. i.e. It is an accelerated frame of reference. Since it is an accelerated frame of reference, even if no force is acting on the object, the object will be set in motion . e.g. A person sitting in train.

Conservative and Non Conservative Force

The Forces that conserve Total Energy, Kinetic Energy and Momentum are called as **Conservative Forces.**

The Forces that conserve Total Energy and Momentum but not Kinetic Energy are called **Non Conservative Forces**.

Moment of Force

Moment of Force = Force x Moment arm

Moment Arm is the distance through which the Force is acting.

Couple & Torque

Torque = Force x Distance between the two forces.

Centre of Mass

The fixed point of an object at which the entire mass of the object is supposed to be concentrated is called Centre of Mass.

$$Centre\ of\ Mass\ = \frac{m_1r_1\ +\ m_2r_2\ +\ m_3r_3 + \ldots + m_nr_n}{m_1 + m_2 + m_3 + \cdots + m_n}$$

Centre of Gravity

The fixed point through which the entire weight of the object is supposed to act in the downward direction is called as Centre of Gravity.

Conditions of Equilibrium of Forces

The resultant force should be 0; i.e. it should not produce acceleration. Thus, the vector sum of all forces acting on the body should be 0.

If the Forces in Equilibrium prevent rectilinear motion, it is called as translational equilibrium. If the forces in equilibrium prevent rotational motion, it is called rotational equilibrium.

Important for solving Problems:

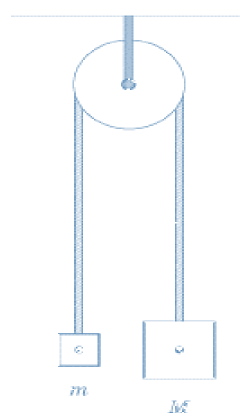
Apparent weight of a man inside a lift:

(a) The lift possesses zero acceleration: **W = mg**

(b) The lift moving upward with an acceleration a: **W = mg + ma**

(c) The lift moving downward with an acceleration a: **W = mg – ma**

Connected motion (Pulley problem):



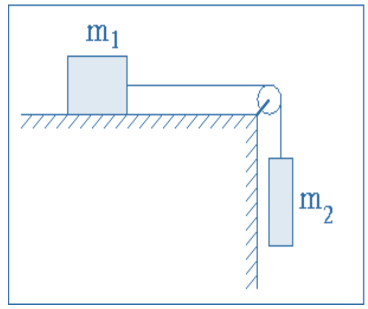
(a) Driven body moving vertically:

Acceleration of the system, $a\ =\ (M - m/M + m)\ g$

Tension in the string, $T\ =\ (2Mm/M + m)\ g$

The force on the pulley, $F\ =\ (4Mm/M + m)\ g$

(b) Driven body moving horizontally:



Acceleration of the system, $a = (\frac{Mm}{M+m})\ g$

Tension in the string, $T = \left(\frac{Mm}{M+m}\right)\ g$

The force on the pulley, $F = \sqrt{\left[\frac{2(Mm)}{M+m}\right]}\ g$

Work, Energy & Power

Work: Work done W is defined as the dot product of force F and displacement s.

Work = F.s = Fs cos θ

Here θ is the angle between Force and displacement.

Work done by a variable force:

If applied force F is not a constant force, then work done by this force in moving the body from position A to B will be,

$$W = \int_a^b F \, . \, ds$$

Here ds is the small displacement.

Units: The unit of work done in S.I is joule (J) and in C.G.S system is erg.

1J = 1 Nm | 1 erg = 1 dyn.cm

1J = 10^7 erg

Power:

The rate at which work is done is called power and is defined as,

P = W/t = F.s/v = F.v

Here s is the distance and v is the speed.

Instantaneous power in terms of mechanical energy: $P = \frac{dE}{dt}$

Units: The unit of power in S.I system is J/s (watt) and in C.G.S system is erg/s.

Energy

Energy is the ability of the body to do some work. The unit of energy is same as that of work.

Kinetic Energy (KE): It is defined as,

$$KE = \frac{1}{2} mv^2$$

Here m is the mass of the body and v is the speed of the body.

Potential Energy (U): Potential energy of a body is defined as,

$$U = mgh$$

Relation between Kinetic Energy (K) and momentum (p):

$$K = \frac{p^2}{2m}$$

Work-Energy Theorem:

It states that work done on the body or by the body is equal to the net change in its Kinetic Energy.

For constant force,

$$W = \frac{1}{2}mv^2 - \frac{1}{2} mu^2$$

$$= Final\ K.E - Initial\ K.E$$

Law of conservation of Energy:

It states that, "Energy can neither be created nor destroyed. It can be converted from one form to another. The sum of total energy, in this universe, is always same".

The sum of the kinetic and potential energies of an object is called mechanical energy. So, E = K+U

In accordance to law of conservation of energy, the total mechanical energy of the system always remains constant.

Coefficient of restitution (e):

It is defined as the ratio between magnitude of impulse during period of restitution to that during period of deformation.

$$e = \frac{relative\ velocity\ after\ collision}{relative\ velocity\ before\ collision}$$

$$e = \frac{v_2 - v_1}{u_1 - u_2}$$

Case (i) For **perfectly elastic collision**, e = 1. Thus, v2 – v1 = u1 – u2. This signifies the relative velocities of two bodies before and after collision are same.

Case (ii) For **inelastic collision**, e<1. Thus, v2 – v1 < u1 – u2. This signifies, the value of e shall depend upon the extent of loss of kinetic energy during collision.

Case (iii) For **perfectly inelastic collision**, e = 0. Thus, v2 – v1 =0, or v2 = v1. This signifies the two bodies shall move together with same velocity. Therefore, there shall be no separation between them.

Elastic collision: In an elastic collision, both the momentum and kinetic energy conserved.

Elastic collision in One Dimension:

After collision, the velocity of two body will be,

$$v_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right) u_1 + \left(\frac{2m_2}{m_1 + m_2}\right) u_2$$

and

$$v_2 = \left(\frac{m_2 - m_1}{m_1 + m_2}\right) u_2 + \left(\frac{2m_1}{m_1 + m_2}\right) u_1$$

Friction in Solids

Types of Friction

Static Friction: Friction acting on an object so as to keep it static.

Kinetic Friction: Friction acting on a moving object so as to reduce its velocity. The direction of Kinetic Frictional Force is in opposite direction to its motion.

Rolling Friction: Friction acting on Rolling objects.

Law of Static Friction

$F_S \leq \mu_S N$

Law of kinetic Friction

$F_k \leq \mu_k N$

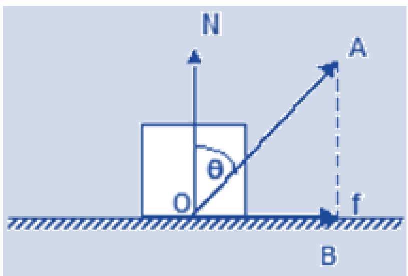
Law of Rolling Friction

$F_R \leq \mu_R N$

Angle of Friction:-

The angle made by the resultant reaction force with the vertical (normal reaction) is known as the angle of the friction.

Now, in the triangle OAB



AB/OB = cotθ

So, $OB = AB/\cot\vartheta$

$= AB \tan\vartheta$

Or, $\tan\vartheta = OB/AB$

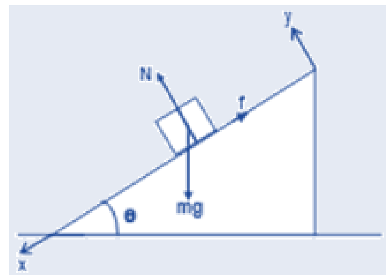
$= f / N$

So, $\tan\vartheta = f / N = \mu_s$

Angle of Repose:

It is the angle which an inclined plane makes with the horizontal so that a body placed over it just begins to slide of its own accord.

Consider a body of mass *m* resting on an inclined plane of inclination*q*. The forces acting on the body are shown – F_f being the force of friction. If friction is large enough, the body will not slide down.



along x: $mg \sin\theta - f = 0$ …(1)

Along y: $N - mg \cos\theta = 0$ …(2)

i.e. $N = mg \cos\theta$ and $f = mg \sin\theta$

Thus, $f \leqslant \mu_S N$ gives,

$mg \sin\theta \leq \mu_S\, mg \cos\theta$

So, $\tan\theta \leq \mu_S$. This signifies, the coefficient of static friction between the two surfaces, in order that the body doesn't slide down.

When *q* is increased, then $\tan\theta > \mu$. Thus sliding begins, and the angle $\theta_r = \tan^{-1}\mu$. This angle is known as the angle of repose.

Fluid Mechanics

- Stream line flow:- Flow of a liquid fluid is said to be streamlined if the velocity of a molecule, at any point, coincides with that of the preceding one.
- Laminar flow:- It is a special case of streamline flow in which velocities of all the molecules on one streamline is same throughout its motion.
- Turbulent flow:- Whenever the velocity of a fluid is very high or it rushes past an obstacle so that there is a sudden change in its direction of motion, the motion of fluid becomes irregular, forming eddies or whirlpools. This type of motion of fluid is called turbulent flow.

Rate of flow (Equation of continuity):-

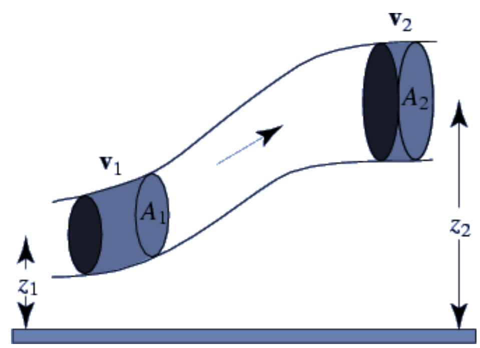
AV = Constant , A – Area , V - velocity

$A_1V_1=A_2V_2$

Equation of continuity can be considered to be a statement of conservation of mass.

So, $V \propto 1/A$

Velocity of flow of liquid varies inversely as the area of cross-section of the opening from where the liquid comes out.



- Total energy of a liquid:-

(a) Kinetic energy:- It is the energy possessed by a liquid by virtue of its velocity.

$$K.E = \frac{1}{2}mv^2$$

$$K.E\ per\ unit\ mass = \frac{1}{2}v^2$$

$$K.E\ per\ unit\ volume = \frac{1}{2}\left[\frac{mv^2}{V}\right] = \frac{1}{2}\rho v^2$$

Here, ρ is the density of liquid.

(b) Potential energy:- It is the energy possessed by a liquid by virtue of its position.

$$Potential\ energy = mgh$$

$$P.E\ per\ unit\ mass = \frac{mgh}{m} = gh$$

$$P.E\ per\ unit\ volume = \frac{mgh}{V} = \rho gh$$

(c) Pressure energy:- It is the energy possessed by a liquid by virtue of its pressure.

$$Pressure\ energy\ = P \times V\ = m\,(\frac{P}{\rho})$$

$$Pressure\ energy\ per\ unit\ mass\ = \frac{P}{\rho}$$

$$Pressure\ energy\ per\ unit\ volume\ = \frac{P \times V}{V} = p$$

- **Total energy:-** Total energy of a liquid is the sum total of kinetic energy, potential energy and pressure energy.

$$E = \frac{1}{2}\, mv^2\ + mgh + \frac{mP}{\rho}$$

$$Total\ energy\ per\ unit\ mass\ = \frac{1}{2} v^2\ + gh + \frac{P}{\rho}$$

$$Total\ energy\ per\ unit\ volume\ = \frac{1}{2}\, \rho v^2\ + \rho gh + P$$

- **Bernoulli's Equation:-**

It states that the total energy of a small amount of an incompressible non-viscous liquid flowing without friction from one point to another, in a streamlined flow, remains constant throughout the displacement.

(a) $\frac{1}{2}\, mv^2\ + mgh + \frac{mP}{\rho} = Constant$

(b) $\frac{1}{2} v^2\ + gh + \frac{P}{\rho} = Constant$

(c) $\frac{1}{2}\, \rho v^2\ + \rho gh + P\ = Constant\ \ or\ \frac{v^2}{2g}\ +\ h\ + \frac{P}{\rho g}\ = Constant$

The term $\frac{v2}{2g}$ is called **velocity head**, h is called gravitational head and $\frac{p}{\rho g}$ is called **pressure head**.

Therefore Bernoulli's theorem states that in case of an incompressible, non-viscous fluid, flowing from one point to another in a streamlined flow, the sum total of velocity head, gravitational head and the pressure head is a constant quantity.

Torricelli's theorem (velocity of efflux)

It states that the velocity of efflux of a liquid (V), from an orifice, is equal to the velocity acquired by a body, falling freely (v), from the surface of liquid to the orifice.

So, $v = \sqrt{2gh}$

- **Viscosity**:- Viscosity is the property of fluids by virtue of which they tend to destroy any relative motion between their layers.
- **Velocity gradient:**- Velocity gradient is defined as the rate of change of velocity with respect to distance.

  Velocity gradient = dv/dr

Newton's law of Viscosity

In accordance to Newton's law of viscosity, the viscous drag force depends upon the nature of fluid along with following factors:-

(a) $F \propto A$ (common area of two layers)

(b) $F \propto \frac{dv}{dr}$ (velocity gradient)

(c) So, $F = \eta A \left(\frac{dv}{dr}\right)$

Unit of η:-

S.I:- η = 1 deca poise = 1 N sec/m^2

C.G.S:- η = 1 poise = 1 dyne sec/cm^2

1 deca-poise = 10 poise

Fluidity:- Reciprocal of coefficient of viscosity of a fluid is called its fluidity.

$$Fluidity = \frac{1}{\eta}$$

Unit of fluidity: $poise^{-1}$

Kinematic viscosity:- Kinematic viscosity of a fluid is defined as the ration between its coefficient of viscosity to the density of fluid.

$$Kinematic\ viscosity = \frac{\eta}{\rho}$$

Units of kinematic viscosity:- C.G.S : 1 stoke = $cm^2\,s^{-1}$

Kinetic viscosity of a fluid having its dynamic viscosity one poise and density one g cm^{-3} is said to be 1 stoke.

Critical velocity (Reynold's Number)

Critical velocity (v_c) is the maximum velocity of the flow of liquid flowing in a streamlined flow.

$$v_c = \frac{N_R \eta}{\rho D}$$

Here η is the coefficient of viscosity of liquid, ρ is the density of liquid and D is the diameter of the tube.

Reynold's Number, $N_R = \frac{\rho v_c D}{\eta}$

Stokes Law:- In accordance to Stokes' law, force of viscosity F depend upon, force of viscosity, $F = 6\pi \eta r v$

- Terminal velocity:- $v = \frac{2}{9} [\frac{r^2 (\rho - \sigma)}{\eta}]$
- $\eta = \frac{2}{9} [\frac{r^2 (\rho - \sigma) g}{v}]$

(a) Effect of temperature on η:- $\eta = A / (1 + Bt)^c$

Here A, B and C are constants.

Again, $\eta v^{\frac{1}{2}} = Ae^{\frac{c}{vt}}$

Here, A and C are constants and v is the relative velocity.

(b) Effect of pressure on η:

Co-efficient of viscosity of liquids increases due to an increase in pressure but there is no relation, so far, to explain the effect.

Change in viscosity of gases:-

(a) Effect of temperature:- Co-efficient of viscosity of a gas at a given temperature is given by,

$$\eta = \eta_0 A T^{\frac{1}{2}}$$

Here T is the absolute temperature of gas.

Modified formula, $\eta = [\eta_0 A T^{\frac{1}{2}}] / [1 + \left(\frac{S}{T}\right)]$

(b) Effect of pressure:- At low pressure, co-efficient of viscosity of a gas varies directly with pressure.

- Rate of flow of liquid through a liquid through a capillary tube of radius r and length l,

$$V = \frac{\pi P r^4}{8\eta l} = \frac{P}{\frac{8\eta l}{\pi r^4}} = \frac{P}{R}$$

Pressure exerted by a column of liquid of height h:- $P = h\rho g$

Here, ρ is the density of liquid.

- Pressure at a point within the liquid:-

$$P = P_0 + h\rho g$$

Here, P_0 is the atmospheric pressure and *h* is the depth of point with respect to free surface of liquid.

Circular Motion

Uniform Circular Motion:-Circular motion is said to the uniform if the speed of the particle (along the circular path) remains constant.

Angular Displacement:-

$$\theta = \frac{s}{r}$$

Angular Velocity:-

$$\boldsymbol{\omega} = \frac{\boldsymbol{\theta}}{\boldsymbol{t}}$$

Relation between linear velocity (v) and angular velocity (ω):-

$$v = r\omega$$

Angular Acceleration:-

$$\alpha = \frac{\omega}{t}$$

Relation between linear velocity (v) and angular velocity (ω):-

$$a = r\alpha$$

- **Centripetal force:-** The force, acting along the radius towards the centre, which is essential to keep the body moving in a circle with uniform speed is called centripetal force. It acts always along the radius towards the centre. A centripetal force does no work.

$$F = \frac{mv^2}{r} = mr\omega^2$$

- **Centrifugal force:-** Centrifugal force is the fictitious force which acts on a body, rotating with uniform velocity in a circle, along the radius away from the centre. Magnitude of centrifugal force is,

$$F = \frac{mv^2}{r}$$

- Centripetal and centrifugal forces are equal in magnitude and opposite in direction. They cannot be termed as action and reaction since action and reaction never act on same body.

- **Banking of Roads:-**

Road offering no frictional resistance, $\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$

Road offering frictional resistance, $v_{max} = \sqrt{rg\left(\frac{□+tan\theta}{1-□tan\theta}\right)}$

- **Bending of Cyclist:-** $\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)$

  (a) Velocity of the cyclist:- Greater the velocity, greater is his angle of inclination with the vertical.

  (b) Radius of curvature:- Smaller the radius, greater is the angle with the vertical.

- **Time period of conical pendulum:-** $T = 2\pi\sqrt{\frac{l\cos\theta}{g}}$

Motion in a vertical circle

	Tension	Velocity	Total Energy
Highest Point	$\frac{mv^2}{r} - mg$	$\sqrt{gr}$	$\frac{5}{2}mgr$
Mid Point	$\frac{mv^2}{r}$	$\sqrt{3gr}$	$\frac{5}{2}mgr$
Lowest Point	$\frac{mv^2}{r} + mg$	$\sqrt{5gr}$	$\frac{5}{2}mgr$

(a) For lowest point A and highest point B, $T_A - T_B = 6\,mg$

(b) Condition for oscillation:- $VA < \sqrt{2gl}$

(c) Condition for leaving circular path:- $\sqrt{2gl} < V_A < \sqrt{5gl}$

- **Non-uniform circular motion:-**

  (a) The velocity changes both in magnitude as well as in direction.

  (b) The velocity vector is always tangential to the path.

  (c) The acceleration vector is not perpendicular to the velocity vector.

  (d) The acceleration vector has two components.

(i) **Tangential acceleration** a_t changes the magnitude of velocity vector and is defined as, $a_t = dv/dt$

(ii) **Normal acceleration** or centripetal acceleration a_c changes the direction of the velocity vector and is defined as, $a_c = \frac{v^2}{r}$

(iii) The total acceleration is the vector sum of the tangential and centripetal acceleration.

So, $a = \sqrt{a_t^2 + a_c^2}$

Gravitation

Universal Law of Gravitation

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

Gravitational Force is independent of the medium . The gravitational force inside a body is zero .

Gravitational Constant

G = 6.67 x 10^{-11} Nm^2/kg^2

Acceleration due to Gravity

Variation with Height

$$g = G\frac{M}{(R+h)^2}\Big| g_h = g\left(\frac{R}{(R+h)^2}\right)\Big| g_h = g\left(1 - \frac{2h}{R}\right)$$

Variation with Depth

$$g = g_h\left(1 - \frac{d}{R}\right)$$

for every percentage decrease in radius , with mass constant ; there is 2 % increase in acceleration due to gravity

Variation with Latitude

$$g' = g - R\omega_2 \cos_2 \Phi$$

Relation between Variation of height and depth

If acceleration due to gravity is same at a certain height and depth ;

then d = 2h

Gravitational Field Intensity

Gravitational field is the field of attraction around a mass . Gravitational Field Intensity is the amount of Force experienced by an object of unit mass in a gravitational Field .

$$\therefore \ Intensity = \frac{Force}{mass}$$

Gravitational Potential Energy

Gravitational Potential Energy is the work done in bringing a charge of unit mass from infinity to a point against the gravitational field .

$$Potential\ Energy\ (U) = Force\ x\ Displacement$$

$$= -\frac{GMm}{r}$$

$$\therefore U = Vm$$

Gravitational Potential

Gravitational potential is the amount of work done per unit mass in a gravitational field .

$$Potential(V) = -\frac{GM}{r}$$

$\therefore V = \frac{U}{m}$

Gravitational Potential is always directed opposite to Gravitational Field .

Cases of Potential :

1. **Due to point mass :** $V = -\frac{GM}{r}$ $\therefore$ at r = 0 , Z is negative infinite . The graph will be negative , curved and parallel to V and r axes .
2. **Inside a Solid Sphere :** $V = -GM\frac{\left(\frac{3}{2}R^2 - \frac{1}{2}r^2\right)}{R^3}$. At r=R ,V = - GM/R . At r = 0 ,V = $-\frac{1}{2}\frac{GM}{R}$ The graph is negative , parabolic .
3. **Outside a Solid Sphere :** $V = -\frac{GM}{r}$, at r = infinity , V = 0 ; On surface , V = -GM/R
4. **Due to a Spherical Shell :** Outside $V = -\frac{GM}{r}$. Inside V = - GM/r
5. **On the Axis of a Ring :** $V = -\frac{GM}{\sqrt{R^2+x^2}}$

Kepler's Laws

Law of Orbits

Kepler's Law of Orbits states that all planets revolve around the sun in elliptical orbits with sun as the focus .

Law of Areas

Kepler's Law of Areas states that a planet sweeps equal Areas in equal intervals of time around the sun .

Law of Periods

Kepler's Law of Periods states that the square of Time Period is directly proportional to the cube of Distance .

$\therefore T^2 \alpha r^3$

Critical Velocity

$$v_c = \sqrt{\frac{GM}{r}}$$

$$v_c = \sqrt{g_h r}$$

Time Period

$$T = 2\pi \sqrt{\frac{r^3}{GM}}$$

Binding Energy

$$B.E. = -T.E.$$

$$B.E. = G\frac{Mm}{r} \text{ \{At rest\}}$$

$$B.E. = G\frac{Mm}{2r} \text{ \{in orbit\}}$$

Escape Velocity

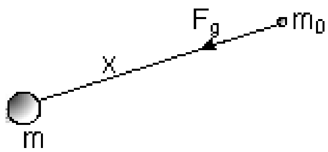
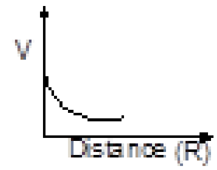
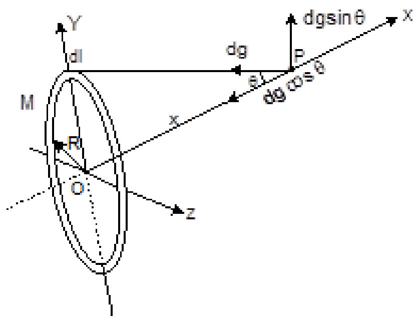
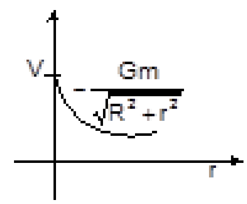
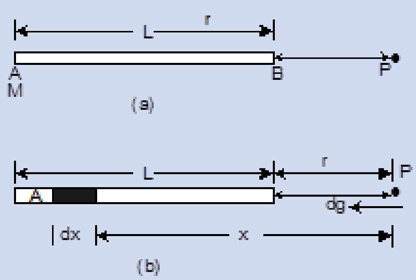
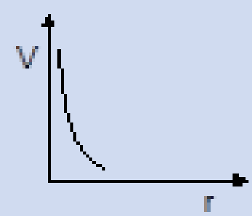
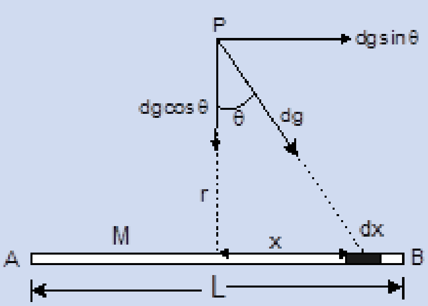
$$v_e = \sqrt{2g_h r}$$

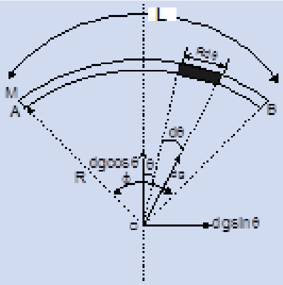
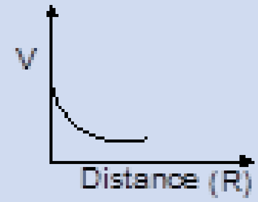
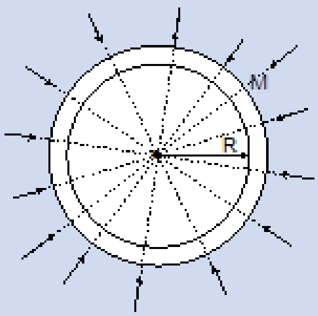
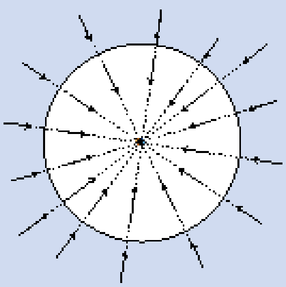
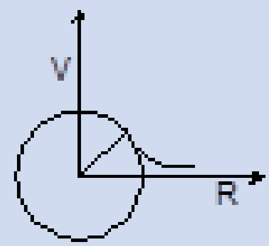
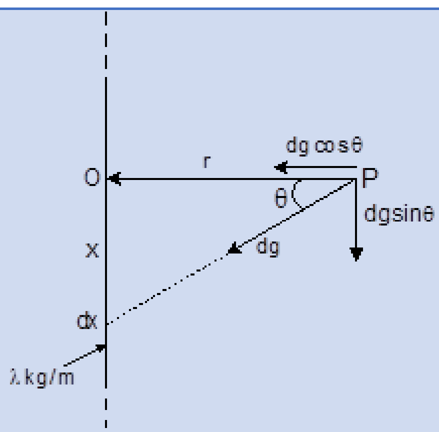
$$v_e = \sqrt{\frac{2GM}{r}}$$

The escape velocity remains independent of angle of projection.

Escape Velocity for an object on earth is 11.2 km/s

GRAVITATIONAL POTENTIAL & FIELD DUE TO VARIOUS OBJECTS

Causing Shape	Gravitational Potential (V)	Gravitational Field (I or E)	Graph V vs R
POINT MASS			
	$V = \frac{-GM}{R}$	$I \text{ or } E = \frac{GM}{R^2}$	
AT A POINT ON THE AXIS OF RING			
	$V = \frac{-GMr}{\sqrt{R^2 + r^2}}$ $0 \leq r \leq \infty$	$E(r) = \frac{-GMr}{(R^2 + r^2)^{3/2}}$	
ROD			
1. AT AN AXIAL POINT			
	$V = -\frac{GM}{L}\ln\left(1 + \frac{L}{r}\right)$	$E = \frac{GM}{r^2}\left(\frac{1}{1 + \frac{L}{r}}\right)$	
2. AT AN EQUATORIAL POINT			
	$V = \frac{2GM}{r\sqrt{l^2 + 4r^2}}$	$E = -\frac{dv}{dr}$	

CIRCULAR ARC			
	$V = \frac{2\pi GM}{L}$	$E = \frac{2\pi GM}{L^2}$	
HOLLOW SPHERE			
	$V(r) = \frac{-GM}{r}$ $(r \geq R)$ $V(r) = \frac{-GM}{R}$ $(r = R)$	$E(r) = \frac{GM}{r^2}$ $(r \geq R)$ $E(r) = \frac{GM}{R^2}$ $(r = R)$	
SOLID SPHERE			
	$V(r) = \frac{-GM}{r}$ $(r \geq R)$ $V(r) = \frac{-GM}{R^3}(1.5R^3 - 1.5R^2)$ $(r \leq R)$	$E(r) = \frac{GM}{r^2}$ $E(r) = \frac{GMr}{R^3}$ $(r \leq R)$	
LONG THREAD			
	$V = \infty$	$E = \frac{2Gl}{r}$	

Rotational Motion

Rigid Body: A rigid body consists of a number of particles such that the distance between any pair of particles always remains constant.

- **Moment of Inertia (Rotational Inertia) *I*:-**

$$I = MR^2$$

(i) Mass of body

(ii) Distribution of mass about the axis of rotation

(iii) Moment of inertia of a body should always be referred to as about a given axis, since it depends upon distribution of mass about that axis.

(iv) It does not depend upon the state of motion of rotating body. It is same whether the body is at rest, rotating slowly or rotating fast about the given axis.

$I = \sum mr^2$

- **Rotational Kinetic Energy:-** $K_r = \frac{1}{2} I\omega^2 = \frac{1}{2} mr^2\omega^2$

So, $I = 2K_r/\omega^2$

- **Radius Gyration:-** Radius of gyration of a body about a given axis is that distance, at which if whole of the mass of the body were concentrated, it would have same moment of inertia as that of body.

$I = MK2$

So, $K = \sqrt{\frac{I}{M}}$

Again, Radius of gyration of a body about a given axis is defined as the square root of the mean of the squares of distances of various particles of the body from the axis of rotation.

So, $K = \sqrt{}[r12 + r22 + r32 + \cdots./n]$

(a) $x_{CM} = \frac{m_1x_1 + m_2x_2}{m_1 + m_2}$

(b) $v_{CM} = \frac{m_1v_1 + m_2v_2}{m_1 + m_2}$

(c) $a_{CM} = \frac{m_1a_1 + m_2a_2}{m_1 + m_2}$

(d) $v_{CM} = \frac{dx_{CM}}{dt}$

(e) $a_{CM} = \frac{dv_{CM}}{dt} = \frac{d_2x_{CM}}{dt^2}$

System of mass for many particle system:-

$$xCM = \sum mixi / \sum mi$$

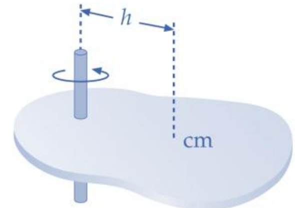
- **Perpendicular axes theorem:-**

$$I_z = Ix + Iy$$

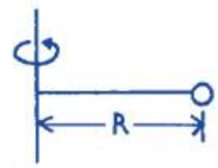
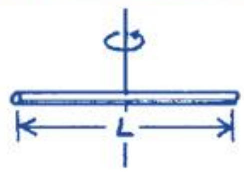
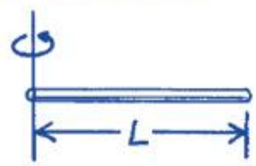
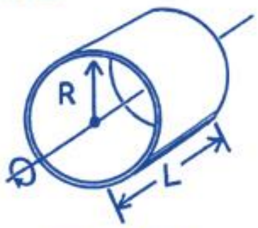
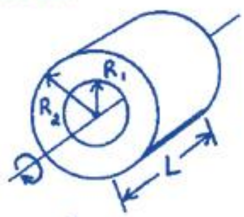
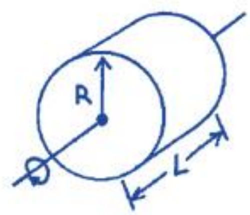
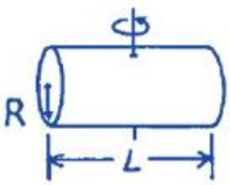
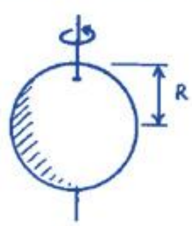
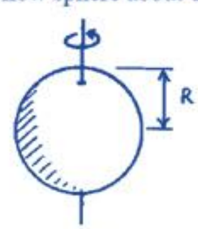
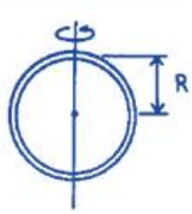
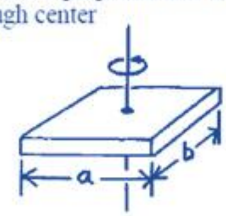
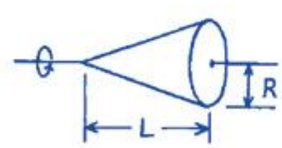
- **Parallel axes theorem:-**

  $I = I_g + Mh^2$

  Here, I_g is the moment of inertia of the body about an axis through its center of gravity *G*.



Moments of Inertia of Various Objects:-

Point mass at a radius R  $I = MR^2$	Thin rod about axis through center perpendicular to length  $I = \frac{1}{12}ML^2$	Thin rod about axis through end perpendicular to length  $I = \frac{1}{3}ML^2$
Thin-walled cylinder about central axis  $I = MR^2$	Thick-walled cylinder about central axis  $I = \frac{1}{2}M(R_1^2 + R_2^2)$	Solid cylinder about central axis  $I = \frac{1}{2}MR^2$
Solid cylinder about central diameter  $I = \frac{1}{4}MR^2 + \frac{1}{12}ML^2$	Solid sphere about center  $I = \frac{2}{5}MR^2$	Thin hollow sphere about center  $I = \frac{2}{3}MR^2$
Thin ring about diameter  $I = \frac{1}{2}MR^2$	Slab about perpendicular axis through center  $I = \frac{1}{12}M(a^2 + b^2)$	Cone about central axis  $I = \frac{3}{10}MR^2$

- **Moment of inertia of a ring about an axis passing through its center and perpendicular to its plane:-**
  (a) About one of its diameters:- $I_d = ½ (MR^2)$
  (b) About a tangent
    (i) Tangent lying in the plane of ring:-I = 3/2 (MR^2)
    (ii) Tangent perpendicular to the plane of ring:-$I = 2MR^2$

- **Moment of inertia of a solid disc:-**
  (a) About an axis passing through its center and perpendicular to its plane:- I = ½ MR^2
  (b) About one of its diameters:- I_d = ¼ (MR^2)
  (c) About a tangent:-
    (i) Tangent lying in the plane of disc:-I = 5/4 (MR^2)
    (ii) Tangent perpendicular to the plane of disc:- $I = 3/2 (MR^2)$

- **Moment of inertia of an annular disc:-**
  (a) About an axis passing through the center and perpendicular to the plane:-
    (i) For a solid disc:- I = ½ MR^2
    (ii) For ring:- I = MR^2
  (b) About any of its diameter:-
    (i) For a solid disc:- I_d = ¼ (MR^2)
    (ii) For ring:- I_d = ½ MR^2
  (c) About a tangent:-
    (i) Tangent lying in the plane of disc:-
      (1) For a solid disc:-I = 5/4 MR^2
      (2) For a ring:-I = 3/2 MR^2
    (ii) Tangent perpendicular to the plane of the disc:-
      (1) For a solid disc:- I = 3/2 MR^2
      (2) For a Ring:- I = $2MR^2$

- **Torque (τ) in vector form:-**

$$\vec{\tau} = \vec{r} \times \vec{F}$$
$$= rF sin\theta$$

- **Moment of inertia (*I*) and Torque :-**$\tau = I\alpha$

  Here α is the angular acceleration.

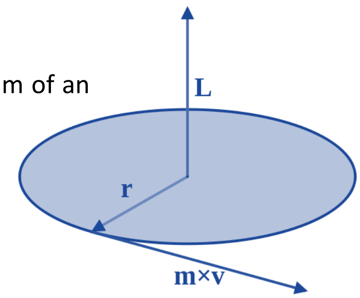
- **Angular Momentum (*L*):-**

$$\vec{L} = \vec{r} \times \vec{p}$$
$$= rp \sin\theta$$

- **Moment of Inertia (*I*) and Angular momentum (*L*):-**

  $\vec{L} = I\vec{\omega}$

- **Law of conservation of angular momentum:-** The net angular momentum of an isolated system (no external torque), always remains constant.



  $$\frac{d\vec{L}}{dt} = 0$$

  $$\text{So, } \vec{L} = I\vec{\omega} = \text{constant}$$

  $I_1\omega_1 = I_2\omega_2$

- **Motion of a point mass attached to a string would over a cylinder capable of rotating about its axis of symmetry:-**

  $$Tension, T = \frac{mg}{\left[1 + \left(\frac{mR^2}{I}\right)\right]}$$

- **Motion of a body rolling down an inclined plane without slipping:-**

  The maximum allowed angle for rolling without slipping.

  (a) A cylinder rolling down the plane,

  $\vartheta_{max} = \tan^{-1}(3\mu)$

  (b) A sphere rolling down the inclined plane,

  $\vartheta_{max} = \tan^{-1}[7/2\ (\mu)]$

  (c) A ring rolling down the inclined plane,

  $\vartheta_{max} = \tan^{-1}(2\mu)$

  Here μ is the coefficient of sliding friction.

- **Angular impulse:-** $\Delta\vec{L} = \vec{\tau}\,\Delta t$

- **Rotational work done:-** $W = \tau_{av}\vartheta$

- **Rotational power:-** $P = \vec{\tau} \cdot \vec{\omega}$

Oscillations

(a) Simple harmonic motion (SHM):- Simple harmonic motion is the motion in which the restoring force is proportional to displacement from the mean position and opposes its increase.

- **Simple harmonic motion (SHM):-** A particle is said to move in SHM, if its acceleration is proportional to the displacement and is always directed towards the mean position.

- **Conditions of Simple Harmonic Motion**

  For SHM is to occur, three conditions must be satisfied.

  (a) There must be a position of **stable equilibrium**
  At the stable equilibrium potential energy is minimum.
  So, $dU/dy = 0$ and $d^2U/dy^2 > 0$

  (b) There must be no dissipation of energy

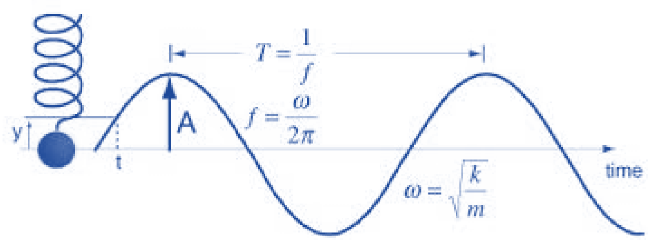
  (c) The acceleration is proportional to the displacement and opposite in direction.
  That is, $a = -\omega^2 y$

- **Equation of SHM**

  (a) $F = -kx$

  (b) $\frac{d_2 y}{dt^2} + \omega^2 x = 0$

  Here $\omega = \sqrt{k/m}$ (k is force constant)



- **Displacement (y)**

  Displacement of a particle vibrating in SHM, at any instant , is defined as its distance from the mean position at that instant.

  $y = r \sin(\omega t + \delta)$

  Here δ is the phase and r is the radius of the circle.

- **Amplitude (r):-**

  Amplitude of a particle, vibrating in SHM, is defined as its maximum displacement on either side of mean position.

  As the extreme value of value of $\omega t = \pm 1$, thus, $y = \pm r$

- **Velocity (V):-** $V = \frac{dx}{dt} = r\omega cos(\omega t + \delta) = v cos(\omega t + \delta) = \omega\sqrt{r^2 - y^2}$

- **Acceleration (a):** $a = \frac{dV}{dt} = -\frac{v^2}{r} sin\omega t = -\omega^2 x$

- **Time period (*T*):** It is the time taken by the particle to complete one vibration.

  (a) $T = 2\pi/\omega$

  (b) $T = 2\pi\sqrt{(\text{displacement}/\text{acceleration})}$

  (c) $xT = 2\pi\sqrt{\frac{m}{k}}$

- **Frequency (*f*):** It is the number of vibrations made by the body in one second.

  (a) $f = \frac{1}{T}$

  (b) $f = \frac{1}{2}\pi\sqrt{\frac{k}{m}}$

- **Angular frequency (*ω*)**

  (a) $\omega = \frac{2\pi}{T}$

  (b) $\omega = \sqrt{\frac{acceleration}{displacement}}$

- **Relation between Angular frequency (*ω*) and Frequency (*f*):-** $\omega = 2\pi f = \sqrt{\frac{k}{m}}$

- **Phase:**
  (a) Phase of a particle is defined as its state as regards its position and direction of motion.
  (b) It is measured by the fraction of time period that has elapsed since the particle crossed its mean position, last, in the positive direction.
  (c) Phase can also be measured in terms of the angle, expressed as a fraction of 2π radian, traversed by the radius vector of the circle of reference while the initial position of the radius vector is taken to be that which corresponds to the instant when the particle in SHM is about to cross mean position in positive direction.

- **Energy in SHM:**

  (a) Kinetic Energy (E_k): $Ek = \frac{1}{2} m\omega^2(r^2 - y^2) = \frac{1}{2} m\omega^2 r^2 \cos^2 \omega t$

  (b) Potential Energy (E_p): $Ep = \frac{1}{2} m\omega^2 r^2 = \frac{1}{2} m\omega^2 r^2 \sin^2 \omega t$

  (c) Total Energy (*E*): $E = Ek + Ep = \frac{1}{2} m\omega^2 r^2 = conserev ed$

  $$E = (Ek)max = (Ep)max$$

- **Average Kinetic Energy**:-$\langle E_k \rangle = \frac{1}{4} m\omega^2 r^2$

- **Average Potential Energy**:-$\langle E_p \rangle = \frac{1}{4} m\omega^2 r^2$

- **Spring-mass system:**

  (a) $mg = kx$

  (b) Time period, $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{x_0}{g}}$

Cutting a spring:

(a) Time period, $T' = T_0/\sqrt{n}$

(b) Frequency, $f' = \sqrt{(n)}\, f_0$

(c) Spring constant, $k' = nk$

(d) If spring is cut into two pieces of length l_1 and l_2 such that, $l_1 = nl_2$, then,

$k_1 = (n+1/n)k$,

$k_2 = (n+1)k$

and

$k_1 l_1 = k_2 l_2$

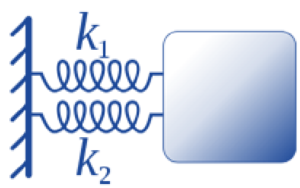
- **Spring in parallel connection:**

(a) Total spring constant, $k = k_1 + k_2$

(b) Time period, $T = 2\pi\sqrt{[m/(k_1+k_2)]}$

(c) If $T_1 = 2\pi\sqrt{m/k_1}$ and $T_2 = 2\pi\sqrt{m/k_2}$, then,

$T = T_1T_2/\sqrt{T_1^2 + T_1^2}$ and $\omega^2 = \omega_1^2 + \omega_2^2$



- **Spring in series connection:**

(a) Total spring constant, $1/k = 1/k_1 + 1/k_2$ or, $k = k_1k_2/\ k_1+k_2$

(b) Time period, $T^2 = T_1^2 + T_2^2$

(c) $T = 2\pi\sqrt{[m(k_1+k_2)/k_1k_2]}$

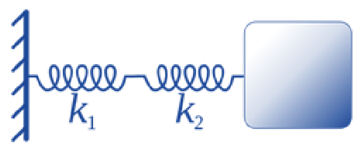
(d) $1/\omega^2 = 1/\omega_1^2 + 1/\omega_2^2$

(e) $f = 1/2\pi\ \sqrt{[k_1k_2/m(k_1+k_2)]}$

(h) **Equation of motion:-**$d^2\vartheta/dt^2 + (g/l)\vartheta = 0$

(i) **Frequency,** $f = 1/2\pi\ \sqrt{(g/l)}$

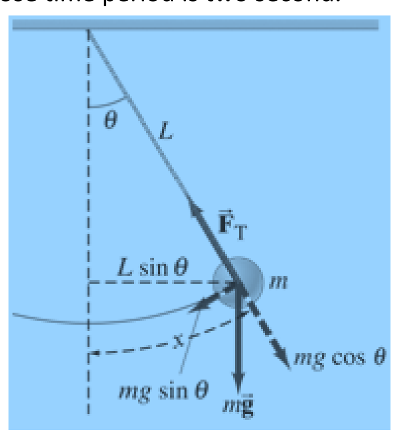
(j) **Angular frequency,** $\omega = \sqrt{(g/l)}$



- **Second Pendulum:-**A seconds pendulumis that pendulum whose time period is two second.

(a) $T = 2$ sec

(b) $l = 0.9925$ m



- **Mass-less loaded spring in the horizontal alignment:-**

Force, $F = -kx$

Acceleration, $a = -kx/m$

Time period, $T = 2\pi\sqrt{m/k}$

Frequency, $f = 1/2\pi\sqrt{k/m}$

- **Time period of mass-less loaded spring in the vertical alignment:-**

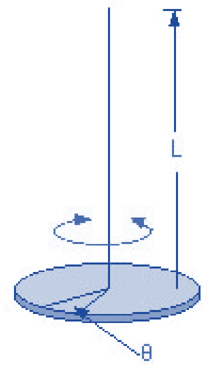
$T = 2\pi\sqrt{m/k}$ and $T = 2\pi\sqrt{l/g}$

- **Time period of bar pendulum:-**

  $T = 2\pi\sqrt{I/mgl}$

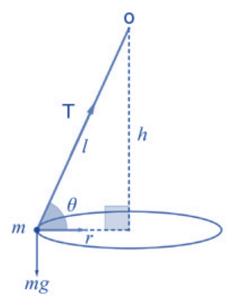
  Here I is the rotational inertia of the pendulum.
  and
  $T = 2\pi\sqrt{L/g}$
  Here, $L = (k^2/l)+l$

- **Time period of torsion pendulum:-**



  (a) $T=2\pi\sqrt{I/C}$
  Here I is the rotational inertia of the pendulum and C is the restoring couple per unit angular twist.
  (b) Equation of motion:-$d^2\vartheta/dt^2+(C/I)\vartheta = 0$
  Here, $\vartheta = \vartheta_0 \sin(\omega t+\delta)$
  (c) Angular frequency, $\omega = \sqrt{C/I}$
  (d) Frequency, $f = 1/2\pi\sqrt{C/I}$

- **Conical Pendulum:-**



  Time period, $T = 2\pi\sqrt{(L\cos\vartheta/g)}$

  Velocity, $v = \sqrt{(gR\tan\vartheta)}$

- **Restoring couple (τ):-**

  $\tau = C\vartheta$

  Here C is the restoring couple per unit angular twist and ϑ is the twist produced in the wire.

- **Free vibrations:-** Vibrations of a body are termed as free vibrations if it vibrates in the absence of any constraint.
- **Damped Vibrations:-**

  Equation:$d^2y/dt^2 + 2\mu dy/dt+\omega^2 y = 0$

  Here amplitude, $R = Ae^{-\mu t}$
  And
  $\omega' = \sqrt{\omega^2-\mu^2}$
  (a) $\mu<<\omega$ signifies the body will show oscillatory behavior with gradually decreasing amplitude.
  (b) $\mu>>\omega$ signifies the amplitude may decrease from maximum to zero without showing the oscillatory behavior.
  (c) In between the above two cases, the body is in the state of critically damped.
  (d) Time period of oscillation, $T' = 2\pi/\omega' = 2\pi/\sqrt{\omega^2-\mu^2}$. Thus, presence of damping factor μ in the denominator indicates an increase of time period due to damping.

- **Forced vibrations:-** Forced vibrations is the phenomenon of setting a body into vibrations by a strong periodic force whose frequency is different from natural frequency of body.

  Equation: $d^2y/dt^2+2\mu dy/dt+\omega^2 y = (F_0/m) \cos\omega\, t$

  Here, $\mu = r/2m$ and $\omega=\sqrt{k/m}$

  Amplitude:- $A = F_0/m\sqrt{4\mu^2p^2+(p^2-\omega^2)^2}$ and $A_{max} = F_0/2\mu m\sqrt{\omega^2-\mu^2}$

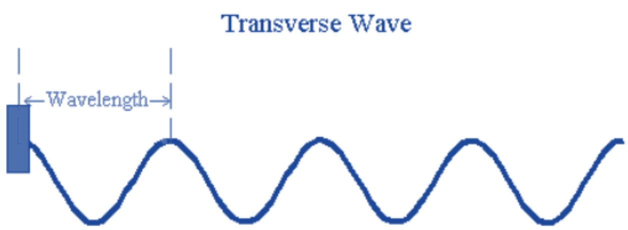
  This state of forced vibrations in which the amplitude reaches a maximum value is known as amplitude resonance.

  Amplitude vibration depends upon value of $\omega = \sqrt{k/m}$. Greater the value of stiffness (k), smaller is the amplitude.

- **Resonance:-** Resonance is the phenomenon of setting a body into vibrations by a strong periodic force whose frequency coincides with the natural frequency of the body.

Waves
Progressive & Stationary

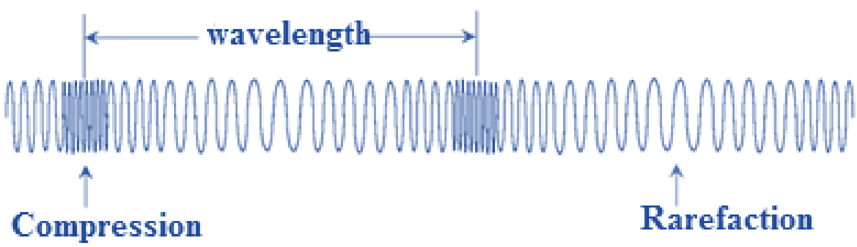
- **Wave motion:-**



- **Wave Equation:-** $d^2y/dt^2 = v^2\ (d^2y/dx^2)$

- **Transverse wave motion:-**It is the type of wave motion in which the particles of the medium are vibrating in a direction at right angles to the direction of propagation of wave.
  (a) Velocity of transverse wave,$V_t = \sqrt{T/m} = \sqrt{T/\pi r^2\rho}$
  (b) Vibrations of the particles of medium are normal to the direction of wave propagation.

- **Longitudinal wave motion:-**It is the type of wave motion in which the particles of the medium vibrate in the direction of propagation of wave.



  (a) Velocity of longitudinal wave**,** $V_l = \sqrt{E/\rho}$
  (b) Vibrations of the particles are parallel to the direction of wave propagation.

- **Relation between phase difference (*?*) and path difference (*λ*):-**
  Phase Difference = $(2\pi/\lambda)\times$(path difference)

- **Simple Harmonic Motion:-**A wave which originates from a source, undergoing simple harmonic motion, is called a simple harmonic wave.
  Equation:-$y = r\sin\omega t$

  $= r \sin 2\pi ft$

  $= r\sin 2\pi(v/\lambda)t$

  $= r \sin 2\pi x/\lambda$

- **Equation of progressive wave:-** A relation between the instantaneous displacement of a particle executing SHM and time is called equation of progressive wave.
  $y = r \sin 2\pi (\omega t \pm \delta)$
  $y = r \sin [(\omega t \pm (2\pi/\lambda)x]$
  $y = r \sin (\omega t \pm kx)$
  $y = r \sin 2\pi (t/T \pm x/\lambda)$
  $y = r \sin 2\pi/\lambda (vt \pm x)$

- **Angular wave number (*k*):** $k = 2\pi/\lambda$

- **Relation between particle velocity (*V*) and wave velocity (*v*):-**

  $V = (2\pi r/\lambda)\, v\cos[(2\pi/\lambda)(vt \pm x)]$

  $V_{max} = (2\pi r/\lambda)\, v$

- **Energy transmission in a progressive wave:-**$E = ½\, m\omega^2 r^2$

- **Energy per unit volume:-** $E = ½\, \rho r^2\omega^2$ Here ρ is the density of medium.

- **Intensity of a wave:-**

  $I = 2\pi^2\rho v f^2 r^2$

  Intensity of a wave varies directly as the square of its amplitude.

  So, $I \propto r^2$

- **Velocity of transverse wave in stretched string:-**$v = \sqrt{(T/m)}$, Here,T is the tension in the string.

- **Interference:-** Interference is the phenomenon by virtue of which there is a modification in the distribution of energy due to super position of two or more waves.

  $y_1 = a_1\sin\omega t$, $y_2 = a_2\sin(\omega t+\delta)$

  $y = y_1+y_2$

  Amplitude, $A = \sqrt{[a_1^2+a_2^2+2\, a_1\, a_2\cos wt]})$
  Intensity, $I = kA^2$ and $I = I_1+I_2+2(\sqrt{I_1 I_2}) \cos wt$
  Here, $I_1 = ka_1^2$ and$I_2 = ka_2^2$

Angle, ϑ = $\tan^{-1}[a_2 \sin wt/(a_1+a_2\cos wt)]$

- **Constructive interference:-**
  Phase difference = $2n\pi$, $n = 0,1,2,3\ldots$

  $\boldsymbol{A} = a_1+a_2$

  $\boldsymbol{I}_{\max} = [\sqrt{I_1}+\sqrt{I_2}]^2$

  Path difference, *x* = $2n(\lambda/2)$

- **Destructive interference:-**
  Phase difference = $(2n+1)\pi$, $n = 0,1,2,3\ldots$

  $A = 2a\cos wt/2$

  $I = 4a^2k \cos^2 wt/2$

  $\boldsymbol{I}_{\max} = 4a^2k$

  $\boldsymbol{I}_{\min} = 0$

  Path difference, *x* = $(2n+1)(\lambda/2)$

- **Stationary Wave:-**
  Wave equation, *y* = $2a\cos(2\pi/\lambda)\, x \sin(2\pi/\lambda)\, vt$
  Amplitude, *A* = $2a\cos(2\pi/\lambda)\, x$
  Condition for maxima (anti-nodes), *x* = $k(\lambda/2)$
  Condition for minima (nodes), *x* = $(2k+1)(\lambda/4)$

- **Frequency of transverse vibrations in stretched string:-**

  $f = (1/2l)\sqrt{(T/m)}$, Here l is the length, T is the tension and m is the mass.

  $f = (1/lD)\sqrt{(T/\pi\rho)}$, Here l is the length, T is the tension, D is the diameter and ρ is the density.

- **Harmonics in stretched strings:-**

  (a) First harmonic (fundamental frequency), $f_0=(1/2l)\sqrt{(T/m)}$

  (b) Second harmonic (first overtone), $f_1 = 2f_0=(2/2l)\sqrt{(T/m)}$

  (c) Third harmonic (second overtone), $f_2 = 3f_0=(3/2l)\sqrt{(T/m)}$

  (d) p^{th} harmonic (p-1 overtone), $f_{p-1} = pf_0=(p/2l)\sqrt{(T/m)}$

  Here, p=1,2,3…

- **Frequency of tuning fork:-**

  $f \propto (t/l)\sqrt{(E/\rho)}$

  Here, t is the thickness, l is the length, E is the elastic constant and ρ is the density.

- **Phenomenon of Beats:-** Periodic variations of amplitude resulting from the superposition of two waves of slightly different frequencies is known as phenomenon of beats.

  If m is the number of beats per second, then, $m = f_1 - f_2$. Here f_1 and f_2 are the frequencies of the two waves.

  $y_1 = a\sin 2\pi f_1 t$, $y_2 = a\sin 2\pi f_2 t$

  $y = y_1 + y_2 =$ Asin$2\pi ft$

  Amplitude, $A = 2a\cos 2\pi(f_1 - f_2/2)t$, Frequency, $F = f_1 - f_2/2$

  (a) **Maxima**:- $t = f/f_1 - f_2$
  (b) **Minima**:- $t = 2f + 1/2(f_1 - f_2)$

- **Beat period (t_b):-** It is defined as the time interval between consecutive beats or it is the time between two consecutive maxima or minima of intensity of sound.

  $t_b = 1/f_1 - f_2$

  If m is the number of beats per second, then,

  m = 1/beat period = $f_1 - f_2$

  This signifies, the number of beats per second is equal to the difference in frequencies of two waves.

Elasticity

The property of a body , by the virtue of which material bodies regain their original dimensions (size, shape or both) after removal of deforming forces is called elasticity .

Plasticity

Plasticity is the property of a body to undergo permanent deformation even after the removal of deforming forces .

Rigidity

Deformation α Deforming Force

Strain α Stress

Stress / Strain = Constant

Stress And Strain

1) **Longitudinal Stress & Strain (along length)**

   Longitudinal Stress = Applied Force / Cross Section Area

   Longitudinal Strain = $(l - l_0) / l_0 = \Delta L / L$

2) **Volume Stress & Strain (with Volume)**

   Volume Stress = Applied Force / Volume

   Volume Strain = $\Delta V / V$

3) **Shearing Stress & Strain (with shape)**

   Shearing Stress = Tangential Applied Force / Area

   Shearing Strain = θ

Elasticity Modulus (Hooke's Law)

(Young's Modulus and Hooke's Law for JEE)

Deformation α Deforming Force

Strain α Stress

Stress / Strain = M; where M is a constant , called as Modulus of Elasticity .

Young's Modulus

(for longitudinal strain and stress)

Y = Longitudinal Stress / Longitudinal Strain

Bulk Modulus

(for Volume Strain and Strain)

K = Volume Stress / Volume Strain

Compressibility = 1 / Bulk Modulus

Modulus of Rigidity

(for Shearing Strain and Stress)

η = Shearing Stress / Shearing Strain

Poisson's Ratio

σ = lateral strain / longitudinal strain

Determination of Elasticity Modulus

Elastic Energy

Strain Energy = 1/2 load x extension

Strain Energy per unit volume = 1/2 x $(\text{Strain})^2$

Strain Energy is defined as an elastic potential energy gained by a wire during elongation by stretching force

Surface Tension

- **Force of cohesion:-** It is force between two molecules of similar nature.
- **Force of adhesion:**- It is the force between two molecules of different nature.
- **Molecular range:**- The maximum distance between two molecules so that the force of attraction between them remains effective is called molecular range.
- **Sphere of influence:**- Sphere of influence of any molecule is the sphere with molecule as its center and having a radius equal to molecular range (=10^{-7} cm).
- **Surface film:**- Surface film of a liquid is defined as the portion of liquid lying on the surface and caught between two parallel planes situated molecular range apart.
- **Surface tension:**-
  Surface tension is the property of a liquid by virtue of which its free surface behaves like a stretched membrane and supports, comparatively heavier objects placed over it. It is measured in terms of force of surface tension.
- **Force of surface tension:**- It is defined as the amount of force acting per unit length on either side of an imaginary line drawn over the liquid surface.
  (a) T = Force/length = F/l
  (b) T = Surface energy/Surface area = W/A
  Units:- S.I – Nm^{-1}
  C.G.S- dyne cm^{-1}
- **Additional force:-**
  (a) For a cylindrical rod:- $F = T\times 2\pi r$ (Here r is the radius of cylindrical rod)
  (b) For a rectangular block:- $F = T\times 2(l+d)$ (Here l is the length and d is the thickness of the rectangular block)
  (c) For a ring:- $F = T\times 2\times 2\pi r$ (Here r is the radius of cylindrical rod)

- **Surface energy:-**

  Potential energy per unit area of the surface is called surface energy.

  (a) Expansion under isothermal condition:-

  To do work against forces of surface tension:-

  W= $T \times A$ (Here A is the total increase in surface area)

  To supply energy for maintaining the temperature of the film:-

  $E = T+H$

  (b) Expansion under adiabatic conditions:-

  $E = T$

  Force of surface tension is numerically equal to the surface energy under adiabatic conditions.

- **Drops and Bubbles:-**

  (a) Drop:- Area of surface film of a spherical drop of radius R is given by, $A = 4\pi R^2$

  (b) Bubble:- The surface area of the surface films of a bubble of radius R is, $A = 2\times4\pi R^2$

- **Combination of *n* drops into one big drop:-**

  (a) $R = n^{1/3}r$

  (b) $E_i = n\,(4\pi r^2 T)$, $E_f = 4\pi R^2 T$

  (c) $E_f / E_i = n^{-1/3}$

  (d) $\Delta E/E_i = [1-(1/n^{1/3})]$

  (e) $\Delta E = 4\pi R^2 T\,(n^{1/3}-1) = 4\pi R^3 T\,(1/r - 1/R)$

- **Angle of contact:-** Angle of contact, for a pair of solid and liquid, is defined as the angle between tangent to the liquid surface drawn at the point of contact and the solid surface inside the liquid.

  (a) When $\vartheta < 90º$ (acute):-

  $F_a > F_c/\sqrt{2}$

  (i) Force of cohesion between two molecules of liquid is less than the force of adhesion between molecules of solid and liquid.

  (ii) Liquid molecules will stick with the solid, thus making solid wet.

  (iii) Such liquid is put in the solid tube; it will have meniscus concave upwards.

(b) When θ > 90º (obtuse):-$F_a<F_c/\sqrt{2}$

(i) Force of cohesion between two molecules of liquid is less than the force of adhesion between molecules of solid and liquid.

(ii) In this case, liquids do not wet the solids.

(iii) Such liquids when put in the solid tube will have a meniscus convex upwards.

(c) When ϑ = 90º:-?

$F_a=F_c/\sqrt{2}$

The surface of liquid at the point of contact is plane. In this case force of cohesion and adhesion are comparable to each other.

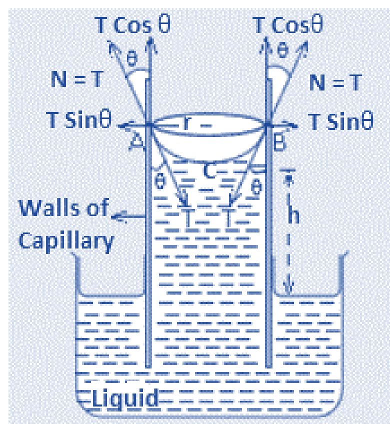
(d) $\cos\vartheta_c = T_{sa} - T_{sl}/T_{la}$

Here, T_{sa},T_{sl} and T_{la} represent solid-air, solid-liquid and liquid-air surface tension respectively). Here ϑ_c is acute if $T_{sl} < T_{sa}$ while ϑ_c is obtuse if $T_{sl} > T_{sa}$.

- **Capillarity:-**

Capillarity is the phenomenon, by virtue of which the level of liquid in a capillary tube is different from that outside it, is called capillarity.

Weight of liquid, $W = V\rho g = \pi r^2[h+(r/3)]\rho g$ (Here r is the radius meniscus)



If weight of meniscus is taken into account, the force of surface tension will be,

$T = [r(h+(r/3))\rho g]/2\cos\vartheta$

For fine capillary, force of surface tension, $T = rh\rho g/2\cos\vartheta$

So height, $h = 2T\cos\vartheta/ r\rho g$

This signifies, height of liquid risen (or depressed) in a capillary tube varies inversely as the radius of tube. Smaller the diameter of capillary tube, greater is the rise of liquid in it.

- **Tube of insufficient length:**

$Rh = 2T/\rho g$

As, T, ρ and g are all constant, Rh = Constant

Smaller the value of h, greater will be the value of R. But liquid will never flow.

- **Effect of temperature affecting surface tension of liquids:-**

  Surface tension of a liquid decreases with an increase in its temperature.

  $T_\theta = K(\vartheta_c - \vartheta)$

  Here T_θ is the surface tension at a particular temperature ϑ while ϑ_c is the critical temperature of the liquid and K is constant.

- **General formula for excess pressure:-**

  $P_{excess} = T[1/R_1 + 1/R_2]$

- **Excess pressure in liquid drop:-**

  $P_{excess} = 2T/R$, Here R is the radius of liquid drop.

- **Excess pressure for an air bubble in liquid drop:-**

  $P_{excess} = 2T/R$

- **Excess pressure in soap bubble:-**

  $P_{excess} = 4T/R$, Here R is the radius of soap bubble.

- **Pressure inside an air bubble at a depth h in a liquid:-** $P_{in} = P_{atm} + hdg + (2T/R)$

- **Forces between two plates with thin water film separating them:-**

  (a) $\Delta P = T(1/r - 1/R)$

  (b) $F = AT(1/r - 1/R)$

  (c) If separation between plate is d, then $\Delta P = 2T/d$ and $F = 2AT/d$

- **Radius of curvature of common film:-** $R_{comon} = rR/R\text{-}r$

- **Capillary depression,** $h = 2T\cos(\pi - \theta)/rdg$

- **Shape of liquid surface:-**

  (a) Plane surface (as for water – silver) if $F_{adhesive} > F_{cohesive}/\sqrt{2}$

  (b) Concave surface (as for water – glass) if $F_{adhesive} > F_{cohesive}/\sqrt{2}$

  (c) Convex surface (as for mercury-glass) if $F_{adhesive} < F_{cohesive}/\sqrt{2}$

- **Increase in temperature:-**

  $\Delta\theta = 3T/\rho s\,(1/r - 1/R)$ or $\Delta\theta = 3T/\rho sJ\,(1/r - 1/R)$

Heat Transfer

Heat Energy , Thermal Expansion , thermodynamics , Radiation

- **Conduction:-** Conduction is that mode of transmission of heat by which heat travels, through an unequally heated body, from the hot end to the cold end, from particle to particle, the particles themselves remaining at their mean positions.

- **Convection:-** It is defined as that mode of transmission of heat by which heat travels from one part of a body to another by the actual motion of the heated particles of the body.

- **Radiation:-** It is defined as that mode of transmission of heat in which heat travels from hot body to cold body in straight lines without heating the intervening medium.

  Power, $P = eA\sigma T^4$

  Here, σ is the Stefan's constant.

  $$\sigma = 5.67 \times 10^{-8} \frac{W}{m^2K^4}$$

- **Temperature Gradient:-** It is defined as the rate of change of temperature of different cross-section with distance.

- **Coefficient of thermal conductivity:-**

  Rate of flow of heat = dQ/dt

  Heat current, through a conducting rod, is defined as the amount of heat conducted across any cross-section of the rod in one second.

  H= dQ/dt

  H depends upon following factors:

  (a) Area of cross-section of rod: $H \propto A$

  (b) Temperature Gradient: $H \propto -d\vartheta/dx$

  (c) Nature of the material

  So, $H = -KA\,(d\vartheta/dx)$

  Here K is called the coefficient of thermal conductivity of the material of rod. It depends upon the nature of material of rod.

  (d) The total heat Q crossing from one cross section to the other in time t:-

  $Q = KA(\vartheta_1-\vartheta_2)t/l$

  Or $K = Ql/A(\vartheta_1-\vartheta_2)t$

Coefficient of thermal conductivity of the material of a rod is defined as the heat current (amount of heat flowing per second) flowing per unit area between two cross-section of the rod each of area 1 m^2 and separated 1 m apart.

Dimension of *K*:- $[K] = [M^1L^1T^{-3}K^{-1}]$

Unit:- C.G.S- $cal\ cm^{-1}s^{-1}\ ^{\circ}C^{-1}$

S.I – $Wm^{-1}K^{-1}$

- **Thermal Conductance (σ_h):-** It is defined as heat current per unit temperature difference.

  $\sigma_h = KA/l$

  $\sigma_h = H/d\vartheta$

  Unit- S.I- WK^{-1}

- **Thermal Resistance (R_h):-** Thermal resistance, of a conductor is defined as the temperature difference between its two cross-sections when a unit heat current flows through it.
  Reciprocal of thermal conductance is known as thermal resistance of the substance.

  $R_h = 1/\sigma_H = l/KA = d\vartheta/H$

  Units of R_h:- S.I – $W^{-1}K$

- **Analogy between electricity and heat:-**

  $H = (\vartheta_1 - \vartheta_2)/(l/KA) = (\vartheta_1 - \vartheta_2)/R_h$

- **Searle's Method for *K*:-**

  $K = m(\vartheta_4 - \vartheta_3)d/A(\vartheta_1 - \vartheta)t$

- The ratio of thermal and electrical conductivities is the same for the metals at a particular temperature and is proportional to the absolute temperature of the metal. If T is the absolute temperature, then

  $K/\sigma \propto T$ or $K/\sigma T$ = constant

- **Ingen Hausz Experiment:-** $K_1/K_2 = l_1^2/l_2^2$

- **Thermal resistance of a conductor of length *d*:-** $R_{TH} = d/KA$

- **Flow of a heat through a composite slab:-**
  - **(a) Thermal resistance in series:-** Thermal resistance of the composite slab is equal to the sum of their individual thermal resistances.

    $(l_1 + l_2)/KA = (l_1/K_1A) + (l_2/K_2A)$

    $R_{comb} = R_h + R_h'$

    If $l_1 = l_2 = l$, then, $K = 2K_1K_2/K_1+K_2$

    Temperature of the interface:-

    $\vartheta_0 = [\vartheta_1 R_h' + \vartheta_2 R_h]/ [R_h + R_h']$ **or** $\vartheta_0 = [\vartheta_1 K_1 l_2 + \vartheta_2 K_2 l_1]/ [K_1 l_2 + K_2 l_1]$

  - **(b) Thermal resistance in parallel:-** Reciprocal of the combination thermal resistance is equal to the sum of the reciprocals of individual thermal resistances.

    $1/R_{comb} = 1/R_h + 1/R_{h'}$

- **Convection:-** It is the mode of transmission of heat, through fluids, in which the particle of fluids acquire heat from one region and deliver the same to the other regions by leaving their mean positions and moving from one point to another.

- **Radiation:**- Radiation is that process of transmission of heat in which heat travels from one point to another in straight lines, with velocity of light, without heating the intervening medium.

- **Bolometer:**- If R_t and R_0 are the resistances of the conductor at 0ºC and *t*ºC, then, $R_t = R_0(1+\alpha t)$, Here α is the temperature coefficient of change of resistance with temperature.

- **Absorptive power (*a*):-** Absorptive power (*a*) of the substance is defined as the ratio between amounts of heat absorbed by it to the total amount of heat incident upon it.

  $a = Q_1/Q$

- **Reflecting Power (*r*):-** Reflecting power (*r*) of a substance is defined as the ratio between amount of heat reflected by the substance to the total amount of heat incident upon it.

  $r = Q_2/Q$

- **Transmitting power (*t*):-** Transmitting power (*t*) of a substance is defined as the ratio between amount of heat transmitted by the body to the total amount of heat incident upon it.

  $t = Q_3/Q$

- $a + r + t = Q_1/Q + Q_2/Q + Q_3/Q = [Q_1 + Q_2 + Q_3]/Q = Q/Q = 1$

- **Radiant emittance (*E*):-** Radiant emittance of a body at a temperature T is defined as the total amount of energy (for all wavelengths) radiated per unit time, per unit area by the body.

$$E = \int_0^\infty e_\lambda \cdot d\lambda$$

Unit:- S.I-$Jm^{-2}s^{-1}$

C.G.S- erg $cm^{-2}s^{-1}$

- **Energy Density:-** Total energy density (U) at any point is defined as the radiant energy per unit volume, around that point, for wave-lengths taken together.

$$U = \int_0^\infty u_\lambda \cdot d\lambda$$

- **Kirchhoff's law of heat radiation:-**
It states that at any temperature, the ratio of emissive power e_λ of a body to its absorptive power a_λ, for a particular wave-length, is always constant and is equal to the emissive power of perfect black body for that wavelength.
e_λ/a_λ = Constant = E_λ
This implies the ratio between e_λ and a_λ for any body is a constant quantity (=E_λ).

- **Wein's Displacement Law:-**
It states that wavelength of radiation which is emitted with maximum intensity varies inversely as the absolute temperature of the body.
$\lambda_m \times T$ = Constant

- **Stefan's Law:-**
Radiant emittance or the energy radiated per second per unit area by a perfect black body varies directly as the fourth power of its absolute temperature.

$E = \sigma T^4$

Here σ is the Stefan's constant and its value is 5.735×10^{-8} W$m^{-2}K^{-4}$

- **Spectral emissive power:-**

$e_\lambda = Q/At(d\lambda)$

- **Emissivity:-** $\varepsilon = e/E$, $0 \le \varepsilon \le 1$

- **Rate of loss of heat:-** $-dQ/dT = \varepsilon A\sigma(\vartheta^4 - \vartheta_0^4)$

- **For spherical objects:-** $(dQ/dT)_1/(dQ/dT)_2 = r_1^2/r_2^2$

- **The emissivity of a body is numerically equal to its absorptive power.**

  $e = a_\lambda$

  (a) Emissivity of body determines the radiant emittance of a body.

  (b) Emissivity of a perfect body is always one.

  (c) Emissivity of any body other than a perfect black body is less than one.

  (d) Emissivity of any body is numerically equal to its absorbing power.

- **Newton's Law of Cooling:-** It states that the rate of loss of heat of a body is directly proportional to the temperature difference between the body and surroundings.

  $dQ/dt = -K(T-T_0)$ or $(T-T_0) \propto e^{-KT}$

- **Wein's Radiation Law:-** $E_\lambda d\lambda = (A/\lambda^5)\, f(\lambda T)\, d\lambda = (A/\lambda^5)\, e^{-a/\lambda T}\, d\lambda$

- **Solar Constant:-** $S = (R_S/R_{ES})^2\, \sigma T^4$

- **Heat:-** Heat is the agent which produces in us the sensation of warmth and makes bodies hot. It is form of energy. The part of thermal energy which flows from one body to the other due to temperature difference is called heat.

- **Thermal Energy:-** In accordance to dynamical theory of heat the sum total of translational, vibrational and rotational energies of the molecules of a system is called the thermal energy of the system .

- **Unit of Heat:-**

  (a) Calorie (cal):- It is the amount of heat required to raise the temperature of 1 gram of water through 1ºC.

  (b) Kilocalorie (kcal):- It is the amount of heat required to raise the temperature of 1 kilo gram of water through 1ºC.

- **Temperature:-** It is defined as the degree of hotness of a body.

- **Zeroth Law of Thermodynamics:-**

  It states that the two systems (*A* and *B*) which are separately in equilibrium with a third system (C) must also be in equilibrium with each other.

- **Absoluter Zero of Temperature:-**
  (a) Charle's law:- $V_t = V_0(1+ t/273)$
  (b) Gay Lussac's law:- $P_t = P_0(1+ t/273)$
  (c) Absolute zero of temperature is defined as the temperature at which a gas has zero volume and exerts zero pressure. It is that temperature at which molecular motion ceases.
  (d) $C \propto \sqrt{T}$, $C = \sqrt{[c_1^2 + c_2^2 + \ldots\ldots + c_n^2]/n}$

- **Absolute gas scale or absolute scale of temperature:-** It is that scale of temperature whose zero (i.e. 0ºK) = -273ºC

  A centigrade degree is exactly equal to the absolute or Kelvin's degree.

- **Conversion of temperature from one scale to another:-**
  $C/100 = (K\text{-}273)/100 = (F\text{-}32)/180 = R_e/80 = (R_\alpha\text{-}492)/180$
  Here C, K, F, R_e and R_α are respectively, the temperatures of same both on centigrade, Kelvin, Fahrenheit, Reaumer and Rankin scale, respectively.

- $F = [(9/5)C\,]+32$

- $K = C+273$

- **Linear Expansion (longitudinal expansion):-**
  When the expansion due to heating takes place only along one direction, the expansion is said to be one dimensional and linear.

- **Coefficient of linear expansion (*α*):-** Coefficient of linear expansion of the material of a rod is defined as the change in length per unit length, at 0°C, per degree centigrade rise of temperature.

  $\alpha = l_t\text{-}l_0/l_0 t$

- **Expansion in two dimensions (Superficial expansion):-**
  When the thermal expansion of a body is confined to a plane, it is to be two dimensional expansion or superficial expansion.

- **Coefficient of superficial expansion (*β*):-** It is defined as the change in area of the surface per unit area at 0ºC, per degree centigrade rise of temperature.

  $\beta = S_t\text{-}S_0/S_0 t$

- **Expansion in three dimensions (Cubical expansion/volume expansion):-** When thermal expansion of the body takes place in space, it is said to be three dimensional expansion or cubical expansion.

- **Coefficient of cubical expansion (*γ*):-** Coefficient of cubical expansion is defined as the change in volume per unit volume, at 0ºC, per degree celsius rise of temperature .

  $\gamma = V_t - V_0/V_0 t$

- **Relation between expansion coefficients:-**
  (a) Relation between α and β:- $\beta = 2\alpha$
  (b) Relation between α and γ:- $\gamma = 3\alpha$
  (c) Relation between β and γ:- $\gamma = 3/2\ \beta$
  (d) $\alpha : \beta : \gamma = 1 : 2 : 3$

- **Thermal expansion of liquids:-**
  (a) Co-efficient of apparent expansion (γ_a):- The coefficient of apparent expansion of a liquid is defined as the apparent (or observed) increase in volume, per unit volume of the liquid at 0ºC per degree celcius rise of temperature.

  γ_a = apparent increase in volume/(original volume at 0ºC) × (rise of temperature)

  (b) Co-efficient of real expansion (γ_r):- The coefficient of real expansion of a liquid is defined as the real increase in volume, per unit volume of the liquid at 0ºC per degree centigrade rise of temperature.

  γ_a= real increase in volume/(original volume at 0ºC) × (rise of temperature)

- **Work and Heat:-**

  Whenever heat is conserved into work or work into heat, the quantity of energy disappearing in one form is equivalent to the quantity of energy appearing in the order.

  $W \propto H$ or $W = JH$

  Joule's mechanical equivalent of heat is defined as the amount of work required to produce a unit quantity of heat.

  $J = W/H$

  Value of J:- $J = 4.2\times10^7$ erg cal^{-1} = 4.2 J cal^{-1}

- **Specific heat capacity or specific heat (*c*):-**

  Specific heat capacity of a material is defined as the amount of heat required to raise the temperature of a unit mass of material through 1ºC.

  $c = Q/m\Delta T$

  Unit:- $kcal\ kg^{-1}K^{-1}$ or $J\ kg^{-1}K^{-1}$

  Dimension:- $M^0L^2T^{-2}K^{-1}$

- **Molar specific heat capacity(*C*):-**

  Molar specific heat capacity of a substance is defined as the amount of heat required to raise the temperature of one gram molecule of the substance through one degree centigrade.

  (a) $C = Mc$ (Here M is the molecular weight of the substance)

  (b) $C = 1/n\ (dQ/dT)$

- **Heat Capacity or Thermal Capacity:-**

  It is defined as the amount of heat required to raise the temperature of body through 1ºC.

  $Q = mc\Delta T$

  If ΔT = 1ºC, Q = heat capacity = mc

  Unit:- $kcal\ K^{-1}$ or JK^{-1}

- **Water Equivalent:-**

  Water equivalent of a body is defined as the mass of water which gets heated through certain range of temperature by the amount of heat required to raise the temperature of body through same range of temperature.

  $w = mc$

  Water equivalent of a body is equal to the product of its mass and its specific heat.

- **Latent Heat:-** When the state of matter changes, the heat absorbed or evolved is given by: $Q = mL$. Here L is called the latent heat.

  (a) Specific latent heat of fusion (L_f):-

  Specific latent heat of fusion of a substance is defined as the amount of heat required to convert 1 gram of substance from solid to liquid state, at the melting point, without any change of temperature.

(b) Specific latent heat of vaporization (L_v):-

Specific latent heat of vaporization of a substance is defined as the amount of heat required to convert 1 gram of liquid into its vapours at its boiling point without any rise of temperature.

Dimensional formula:- $M^0L^2T^{-2}$

Unit:- *kg cal* kg^{-1} or *J* kg^{-1}

- Triple point of water = 273.16 K
- Absolute zero = 0 K = -273.15ºC
- For a gas thermometer, $T = (273.15)\ P/P_{triple}$ (Kelvin)
- For a resistance thermometer, $R_e = R_0[1+\alpha\vartheta]$
- **Thermodynamics:-** It is the branch of physics which deals with process involving heat, work and internal energy. Thermodynamics is concerned with macroscopic behavior rather than microscopic behavior of the system.
- **Basic Terminology:-**
- **Kinetic Energy:-** Energy possessed by the atoms or molecules by virtue of their motion is called kinetic energy.
- **Internal Energy (ΔU):-** Sum total of kinetic and potential energies of atoms/molecules constituting a system is called the internal energy of the system.
  (a) ΔU is taken as positive if the internal energy of the system increases.
  (b) ΔU is taken as negative if the internal energy of the system decreases.
- **Heat:-** Heat is the part of internal energy which is transferred from one body to another an account of the temperature difference.
- **Work:-** Work is said to be done when a force acting on a system displaces the body in its own direction.

  $dW = Fdx = PdV$

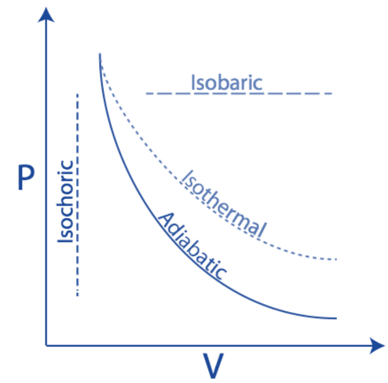
  $W = P(V_f - V_i)$

  (a) If the gas expands, work is said to be done by the system. In this case $V_f > V_i$, therefore, W will be positive.
  (b) If the gas is compressed, work is said to be done on the system. In this case $V_f < V_i$, therefore, work done is negative.
- **Thermodynamic variables or parameters:-** The thermodynamic state of system can be determined by quantities like temperature (T), volume (V), pressure (P), internal energy (U) etc. These quantities are known as thermodynamic variables, or the parameters of the system.
- **Equation of state:-** A relation between the values of any of the three thermodynamic variables for the system, is called its equation of state.

  Equation of state for an ideal gas is PV = RT
- **Equilibrium of a system:-** A system is said to be in equilibrium if its macroscopic quantities do not change with time.

- **Relation between joule and calorie:-** 1 joule = 4.186 cal
- **First law of thermodynamics:-** If the quantity of heat supplied to a system is capable of doing work, then the quantity of heat absorbed by the system is equal to the sum of the increase in the internal energy of the system, and the external work done by it.

  $dQ = dU + dW$
- **Thermodynamic Process:-** A process by which one or more parameters of thermodynamic system undergo a change is called a thermodynamic process or a thermodynamic change.



  (a) Isothermal process:- The process in which change in pressure and volume takes place at a constant temperature

  (b) Isobaric process:- The process in which change in volume and temperature of a gas take place at a constant pressure

  (c) Isochoric process:- The process in which changes in pressure and temperature take place in such a way that the volume of the system remains constant

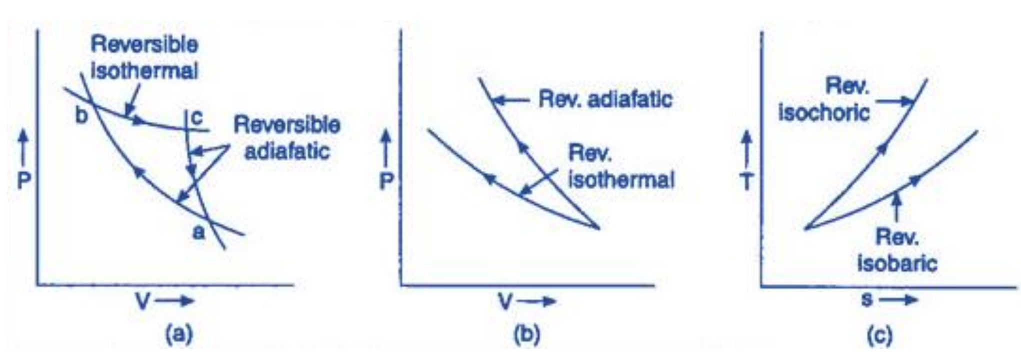
  (d) Adiabatic process:- The process in which change in pressure and volume and temperature takes place without any heat entering or leaving the system

  (e) Quasi-static process:- The process in which change in any of the parameters take place at such a slow speed that the values of P,V, and T can be taken to be, practically, constant

  (f) Cyclic process:- In a system in which the parameters acquire the original values, the process is called a cyclic process.

  (g) Free expansion:- Such an expansion in which no external work is done and the total internal energy of the system remains constant is called free expansion.

- **Reversible isothermal and adiabatic curve:-**



- **Application of first law of thermodynamics:-**
  - **(a) Cooling caused in adiabatic process:-** $dT = PdV/C_v$
  - **(b) Melting:-** $dU = mL_f$
  - **(c) Boiling:-** $dU = mL_v - P(V_f - V_i)$
  - **(d) Mayer's formula:-** $C_p - C_v = R$

- **Specific heat capacity of gases:-** Specific heat capacity of a substance is defined as the amount of heat required to raise the temperature of a unit mass of substance through 1ºC.
  - **(a) Specific heat capacity at constant volume (c_v):-** Specific heat capacity at constant volume is defined as the amount of heat required to raise the temperature of 1 *g* of the gas through 1º*C* keeping volume of the gas constant.

    Molar specific heat capacity, at constant volume (C_v), is defined as the amount of heat required to raise the temperature of 1 mole of gas through 1º*C* keeping its volume constant.

    $C_v = Mc_v$
  - **(b) Specific heat capacity at constant pressure (c_p):-** Specific heat capacity, at constant pressure, is defined as the amount of heat required to raise the temperature of 1 g of gas through 1º*C* keeping its pressure constant.

    Gram molecular specific heat capacity of a gas (C_p), at constant pressure, is defined as the amount of heat required to raise the temperature of 1 mole of the gas through 1º*C* keeping its pressure constant.

    $C_p = Mc_p$

- **Difference between two specific heat capacities – (Mayer's formula):-**
  - (a) $C_p - C_v = R/J$
  - (b) For 1 *g* of gas, $c_p - c_v = r/J$
  - (c) Adiabatic gas constant, $\gamma = C_p/C_v = c_p/c_v$

- **Relation of C_v with energy:-**

  $C_v = 1/m\ (dU/dT)$
  - **(a) Mono-atomic gas (3 degree of freedom):-**

    Total energy, $U = mN\,3\,[(1/2)\,KT]$, Here m is the number of moles of the gas and N is the Avogadro's number.

    $C_v = (3/2)\,R$

    $C_p = (5/2)\,R$

    $\gamma = C_p/C_v = 5/3 = 1.67$

  - **(b) Diatomic gas:-**

    At very low temperature, Degree of Freedom (DOF) = 3

    $U = (3/2)\,mRT$

    $C_v = (3/2)\,R$, $C_p = (5/2)\,R$

    $\gamma = C_p/C_v = 5/3 = 1.67$

    At medium temperature, DOF = 5

    $U = (5/2)\,mRT$

$C_v = (5/2)\,R$, $C_p = (7/2)\,R$

$\gamma = C_p/\,C_v = 7/5 = 1.4$

At high temperature, DOF = 7

$U = (7/2)\,mRT$

$C_v = (7/2)\,R$, $C_p = (9/2)\,R$

$\gamma = C_p/\,C_v = 9/7 = 1.29$

- **Adiabatic gas equation:-** PV^{γ} = Constant
  - (a) Equation of adiabatic change in terms of T and V:- $TV^{\gamma-1}$ = Constant
  - (b) Equation of adiabatic change in terms of P and T:- $T^{\gamma}P^{1-\gamma}$ = Constant

- **Comparison of slopes of an isothermal and adiabatic:-**
  - (a) Slope of isothermal:- $dP/dV = -P/V$
  - (b) Slope of adiabatic:- $dP/dV = -\gamma P/V$
  - (c) Adiabatic gas constant:- $\gamma = C_p/C_v$

    As, $C_p > C_v$, So, $\gamma > 1$

    This signifies that, slope of adiabatic curve is greater than that of isothermal.

- **Slope on *PV* diagram:-**
  - (a) For isobaric process: zero
  - (b) For isochoric process: infinite

- **Work done for isobaric process:-** $W = P(V_2 - V_1)$

- **Work done for isochoric process:-** $W = 0$

- **Work done in isothermal expansion and compression:-**

  ?$W = 2.3026\,RT\log_{10}V_f/V_i$ (isothermal expansion)

  $W = -\,2.3026\,RT\log_{10}V_f/V_i$ (isothermal compression)

- **Work done during an adiabatic expansion:-**

  $W = K/1-\gamma\,[V_f^{1-\gamma} - V_i^{1-\gamma}] = 1/1-\gamma\,[P_2V_2 - P_1V_1] = R/1-\gamma\,[T_2 - T_1]$
- **Adiabatic constant (γ):-** $\gamma = C_p/C_v = 1+2/f$, Here f is the degrees of freedom.

- **Work done in expansion from same initial state to same final volume:-**

  $W_{adiabatic} < W_{isothermal} < W_{isobaric}$

- **Work done in compression from same initial state to same final volume:-**

  $W_{adiabatic} < W_{isothermal} < W_{isobaric}$

- **Reversible process:-** It is a process which can be made to proceed in the reverse direction by a very slight change in its conditions so that the system passes through the same states as in direct process, and at the conclusion of which the system and its surroundings acquire the initial conditions.

- Irreversible process:- A process which cannot be made to be reversed in opposite direction by reversing the controlling factor is called an irreversible process.

- **Heat engine:-** It is a device used to convert heat into mechanical energy
  (a) **Work done**, $W = Q_1 - Q_2$
  (b) **Efficiency:-** Efficiency η of an engine is defined as the fraction of total heat, supplied to the engine which is converted into work.
  $\eta = W/Q_1 = [Q_1 - Q_2]/Q_1 = 1-[Q_2/Q_1]$

- **Carnot engine – Carnot's reverse cycle:-**
  (a) **First stroke (isothermal expansion):-** $W_1 = RT_1 \log_e[V_2/V_1]$
  (b) **Second stroke (adiabatic expansion):-** $W_2 = R/\gamma\text{-}1\ [T_1 - T_2]$
  (c) **Third stroke (isothermal compression):-** $W_3 = RT_2 \log_e V_3/V_4$
  (d) **Fourth stroke (adiabatic compression):-** $W_4 = R/\gamma\text{-}1\ [T_1 - T_2]$
  (e) **Total work done in one cycle,** $W = W_1 + W_2 + W_3 + W_4 = R\,(T_1 - T_2) \log_e (V_2/V_1)$

- **Efficiency of Carnot engine:-** Efficiency η of an engine is defined as the ratio between useful heat (heat converted into work) to the total heat supplied to the engine.
  $\eta = W / Q_1 = [Q_1 - Q_2]/Q_1 = 1-[Q_2/Q_1] = 1 - T_2/T_1$

- **Second law of thermodynamics:-**
  (a) Clausius statement:- Heat cannot flow from a cold body to a hot body without the performance of work by some external agency.
  (b) Kelvin's statement:- It is impossible to obtain a continuous supply of energy by cooling a body below the coldest of its surroundings.
  (c) Planck's statement:- It is impossible to extract heat from a single body and convert the whole of it into work.

- **Refrigerator:-** It is a device which is used to keep bodies at a temperature lower than that of surroundings.

- **Coefficient of performance (*β*):-** Coefficient of performance of a refrigerator is defined as the amount of heat removed per unit work done on the machine.
  β = Heat removed/work done $= Q_2/W = Q_2/[Q_1 - Q_2] = T_2/[T_1 - T_2]$
  Coefficient of performance of a refrigerator is not a constant quantity since it depends upon the temperature of body from which the heat is removed.
  For a perfect refrigerator, $W = 0$ or $Q_1 = Q_2$ or $\beta = \infty$

- **Mean free path:-** $\lambda = 1/\sqrt{2}\pi d^2 \rho_n$

  Here $\rho_n = (N/V)$ = number of gas molecules per unit volume

  d = diameter of molecules of the gas.

- **Heat added or removed:-**
  (a) For isobaric process:- $Q = n\, C_p \Delta T$
  (b) For isochoric process:- $Q = n\, C_v \Delta T$
  (c) For isothermal process:- $Q = nRT \log_e (V_2/V_1)$
  (d) For adiabatic process: $Q = 0$

- **Change in internal energy:-**
  (a) For isobaric process, $\Delta U = n\, C_p \Delta T$
  (b) For isobaric process, $\Delta U = n\, C_v \Delta T$
  (c) For isothermal process, $\Delta U = 0$
  (d) For adiabatic process, $\Delta U = -W = [nR\,(T_2 - T_1)]/(\gamma - 1)$

- **Mixture of gases:-** $n = n_1 + n_2$

  $M = n_1M_1 + n_2M_2/\ n_1 + n_2 = N_1m_1 + N_2m_2/N_1 + N_2$

  $$C_v = \frac{n_1C_{v_1} + n_2C_{v_2}}{n_1 + n_2} \quad \text{and} \quad C_p = \frac{n_1C_{p_1} + n_2C_{p_2}}{n_1 + n_2}$$

- **Enthalpy (H):-**
  (a) H = U+PV
  (b) **At constant pressure:-**
  $dH = dU + pdV$
  (c) **For system involving mechanical work only:-**
  $dH = Q_P$ (At constant pressure)
  (d) **For exothermic reactions:-**
  dH is negative
  (e) **For endothermic reactions:-**
  dH is positive

- **Relation between dH and dU:-**

  $dH = dU + dn_g\, RT$

Kinetic Theory of Gases & Radiation

- **Kinetic Theory of Matter:-**
  - **(a) Solids:-** It is the type of matter which has got fixed shape and volume. The force of attraction between any two molecules of a solid is very large.
  - **(b) Liquids:-** It is the type of matter which has got fixed volume but no fixed shape. Force of attraction between any two molecules is not that large as in case of solids.
  - **(c) Gases:-** It is the type of matter does not have any fixed shape or any fixed volume.
- **Ideal Gas:-** A ideal gas is one which has a zero size of molecule and zero force of interaction between its molecules.
- **Ideal Gas Equation:-** A relation between the pressure, volume and temperature of an ideal gas is called ideal gas equation.

  PV/T = Constant or $PV = nRT$

  Here, n is the number of moles and R is the universal gas constant.
- **Gas Constant:-**
  - **(a) Universal gas constant (*R*):-**

    $R = P_0 V_0/T_0$

    $= 8.311\ J\ mol^{-1}K^{-1}$
  - **(b) Specific gas constant (*r*):-**

    $PV = (R/M)\ T = rT$,

    Here, $r = R/M$
- **Real Gas:**-The gases which show deviation from the ideal gas behavior are called real gas.
- **Vander wall's equation of state for a real gas:-**

  $[P + (na/V)^2?][V - nb] = nRT$

  Here n is the number of moles of gas.
- **Avogadro's number (N):-** Avogadro's number (N), is the number of carbon atoms contained in 12 gram of carbon-12.

  $N = 6.023\times10^{23}$
  - **(a) To calculate the mass of an atom/molecule:-**

    Mass of one atom = atomic weight (in gram)/N

    Mass of one molecule = molecular weight (in gram)/N
  - **(b) To calculate the number of atoms/molecules in a certain amount of substance:-**

    Number of atoms in m *gram* = (N/atomic weight) × m

    Number of molecules in m *gram* = (N/molecular weight) × m

(c) Size of an atom:-

Volume of the atom, $V = (4/3)\pi r^3$

Mass of the atom, $m = A/N$

Here, A is the atomic weight and N is the Avogadro's number.

Radius, $r = [3A/4\pi N\rho]^{1/3\backslash}$

Here ρ is the density.

- **Gas laws:-**

(a) Boyle's law:- It states that the volume of a given amount of gas varies inversely as its pressure, provided its temperature is kept constant.

PV = Constant

(b) Charlers law or Gey Lussac's law:- It states that volume of a given mass of a gas varies directly as its absolute temperature, provided its pressure is kept constant.

V/T**=** Constant

$V–V_0/V_0 t = 1/273 = \gamma_p$

Here γ_p (=1/273) is called volume coefficient of gas at constant pressure.

Volume coefficient of a gas, at constant pressure, is defined as the change in volume per unit volume per degree centigrade rise of temperature.

(c) Gay Lussac's law of pressure:- It states that pressure of a given mass of a gas varies directly as its absolute temperature provided the volume of the gas is kept constant.

$P/T = P_0/T_0$ or $P – P_0/P_0 t = 1/273 = \gamma_p$

Here γ_p (=1/273) is called pressure coefficient of the gas at constant volume.

Pressure coefficient of a gas, at constant volume, is defined as the change in pressure per unit pressure per degree centigrade rise of temperature.

(d) Dalton's law of partial pressures:-

Partial pressure of a gas or of saturated vapors is the pressure which it would exert if contained alone in the entire confined given space.

$P= p_1+p_2+p_3+$……..

$nRT/V = p_1+p_2+p_3+$……..

(e) Grahm's law of diffusion:- Grahm's law of diffusion states that the rate of diffusion of gases varies inversely as the square root of the density of gases.

$R \propto 1/\sqrt{\rho}$ or $R_1/R_2 = \sqrt{\rho_2/ \rho_1}$

So, a lighter gas gets diffused quickly.

(f) Avogadro's law:- It states that under similar conditions of pressure and temperature, equal volume of all gases contain equal number of molecules.

For m gram of gas, $PV/T = nR = (m/M) R$

- **Pressure of a gas (P):-** $P = 1/3\ (M/V)\ C^2 = 1/3\ (\rho)\ C^2$

- **Root mean square (r.m.s) velocity of the gas:-** Root mean square velocity of a gas is the square root of the mean of the squares of the velocities of individual molecules.

$C= \sqrt{[c_1^2 + c_2^2 + c_3^2 + \ldots + c_n^2]/n} = \sqrt{3P/ \rho}$

- **Pressure in terms of kinetic energy per unit volume:-** The pressure of a gas is equal to two-third of kinetic energy per unit volume of the gas.

  $P = 2/3\ E$

- **Kinetic interpretation of temperature:-** Root mean square velocity of the molecules of a gas is proportional to the square root of its absolute temperature.

  $C = \sqrt{3RT/M}$

  Root mean square velocity of the molecules of a gas is proportional to the square root of its absolute temperature.

  At, T=0, C=0

  Thus, absolute zero is the temperature at which all molecular motion ceases.

- **Kinetic energy per mole of gas:-**

  K.E. per *gram mol* of gas = $\frac{1}{2} MC^2 = 3/2\ RT$

- **Kinetic energy per gram of gas:-**

  $\frac{1}{2} C^2 = 3/2\ rt$

  Here, $\frac{1}{2} C^2$ = kinetic energy per gram of the gas and r = gas constant for one gram of gas.

- **Kinetic energy per molecule of the gas:-**
  Kinetic energy per molecule = $\frac{1}{2} mC^2 = 3/2\ kT$
  Here, k (Boltzmann constant) = R/N
  Thus, K.E per molecule is independent of the mass of molecule. It only depends upon the absolute temperature of the gas.
- **Regnault's law:-** $P \propto T$
- **Graham's law of diffusion:-**

  $R_1/R_2 = C_1/C_2 = \sqrt{\rho_2/\rho_1}$

- **Distribution of molecular speeds:-**

  (a) Number of molecules of gas possessing velocities between *v* and *v+dv* :-

$$n_v dv = \frac{\sqrt{2}\pi n m^{3/2} v^2}{(\pi k T)^{3/2}} e^{-mv^2/2kT} dv$$

  (b) Number of molecules of gas possessing energy between u and u+dv:-

$$n_u du = \frac{2\pi n}{(\pi k T)^{3/2}} \sqrt{u} e^{\frac{-u}{kT}} du$$

  (c) Number of molecules of gas possessing momentum between *p* and *p+dp* :-

$$n_p dp = \frac{\sqrt{2}\pi n}{(\pi m k T)^{3/2}} p^2 e^{\frac{-p}{2mkT}} dp$$

(d) **Most probable speed:-** It is the speed, possessed by the maximum number of molecules of a gas contained in an enclosure.

$V_m = \sqrt{[2kT/m]}$

(e) **Average speed (V_{av}):-** Average speed of the molecules of a gas is the arithmetic mean so the speeds of all the molecules.

$V_{av} = \sqrt{[8kT/\pi m]}$

(f) **Root mean square speed (V_{rms}):-** It is the square root of the mean of the squares of the individual speeds of the molecules of a gas.

$V_{rms} = \sqrt{[3kT/m]}$

- **$V_{rms} > V_{av} > V_m$**
- **Degree of Freedom (n):-** Degree of freedom, of a mechanical system, is defined as the number of possible independent ways, in which the position and configuration of the system may change.

  In general, if *N* is the number of particles, not connected to each other, the degrees of freedom *n* of such a system will be, $n = 3N$

  If *K* is the number of constraints (restrictions), degree of freedom *n* of the system will be, $n=3N-K$
- **Degree of freedom of a gas molecule:-**

  (a) Mono-atomic gas:- Degree of freedom of monoatomic molecule, *n* = 3

  (b) Di-atomic gas:-

  At very low temperature (0-250 K):- Degree of freedom, *n* = 3

  At medium temperature (250 K – 750 K):- Degree of freedom, *n* = 5 (Translational = 3, Rotational = 2)

  At high temperature (Beyond 750 K):- Degree of freedom, *n* = 6 (Translational = 3, Rotational = 2, Vibratory =1), For calculation purposes, *n* = 7
- **Law of equipartition of energy:-** In any dynamical system, in thermal equilibrium, the total energy is divided equally among all the degrees of freedom and energy per molecule per degree of freedom is ½ kT.

  $E = \frac{1}{2} kT$
- **Mean Energy:-** K.E of one mole of gas is known as mean energy or internal energy of the gas and is denoted by U.

  $U = n/2\ RT$ (Here *n* is the degree of freedom of the gas.)

  (a) Mono-atomic gas($n = 3$):- $U = 3/2\ RT$

  (b) Diatomic gas:-

  At low temperature ($n=3$):- $U = 3/2\ RT$

  At medium temperature ($n=5$):- $U = 5/2\ RT$

  At high temperature ($n=7$):- $U = 7/2\ RT$
- **Relation between ratio of specific heat capacities (γ) and degree of freedom (n):-**

  $\gamma = C_p/C_v = [1+(2/n)]$

  (a) For mono-atomic gas ($n=3$):- $\gamma = [1+(2/n)] = 1+(2/3) = 5/3=1.67$

  (b) For diatomic gas (at medium temperatures ($n=5$)):- $\gamma = [1+(2/5)] = 1+(2/5) = 7/5=1.4$

  (c) For diatomic gas (at high temperatures ($n=7$)):- $\gamma = [1+(2/7)] = 9/7 = 1.29$

Sound & Light Waves

Sound Waves:-

It is the form of energy which produces, in us, the sensation of hearing.

- **Properties:-**
  (a) Longitudinal in nature.
  (b) It requires a material medium for its propagation.
  (c) Sound waves can be reflected.
  (d) Sound waves suffer refraction.
  (e) Sound waves show the phenomenon of interference
  (f) Sound waves shows diffraction
  (g) Sound propagates with a velocity much smaller than that of light.
  (h) Sound gets absorbed in the medium through which it passes.
- **Loudness (*L*)or Intensity (*I*):-**

  $L \propto \log I$

  So, $L = K \log_{10}(I_1/I_0)$

  Unit of intensity of sound is **bel**.
- **Intensity (*I*) and Amplitude (*A*):-** $I \propto A^2$
- **Intensity(*I*) and distance from the source (*r*):-** $I \propto 1/r^2$
- **Pitch or Shrillness:-**Pitch is a sensation which determines the shrillness of sound. It is subjective and cannot be measured quantitatively. It depends up on frequency and relative motion between the sources and the listener.
- **Quality or Timber:-** It is that characteristic of a musical sound which enables us to distinguish between two notes of the same pitch and loudness produced by two different sources.
- **Velocity *u* of longitudinal wave (sound) [Newton's Formula]:-**

  $u = \sqrt{E/\rho}$

  Here E is the coefficient of elasticity and ρ is the density of medium.
- **Velocity of sound in solids:-**

  $u = \sqrt{Y/\rho}$

  Here Y is the young's modulus of elasticity and ρ is the density.
- **Velocity of sound in liquids:-**

  $u = \sqrt{B/\rho}$

  Here B is the Bulk modulus of elasticity and ρ is the density.

- **Velocity of sound in gases:-**

  $u = \sqrt{\gamma P/\rho}$

  Here, γ ($=c_P/c_V$) is the adiabatic ratio, P is the pressure and ρ is the density.

- **Various factors affecting velocity of sound:-**
  (a) Effect of density:- The velocity of sound in a gas varies inversely as the square root of its density. $u_1/u_2 = \sqrt{[\rho_2/\rho_1]}$

  (b) Effect of moisture:- $u_m/u_d = \sqrt{[\rho_d/\rho_m]}$

  Since, $\rho_m < \rho_d$, then, $u_m > u_d$

  This signifies sound travels faster in moist air.

  (c) Effect of pressure:- $u=\sqrt{\gamma P/\rho}=\sqrt{\gamma k}$ = constant

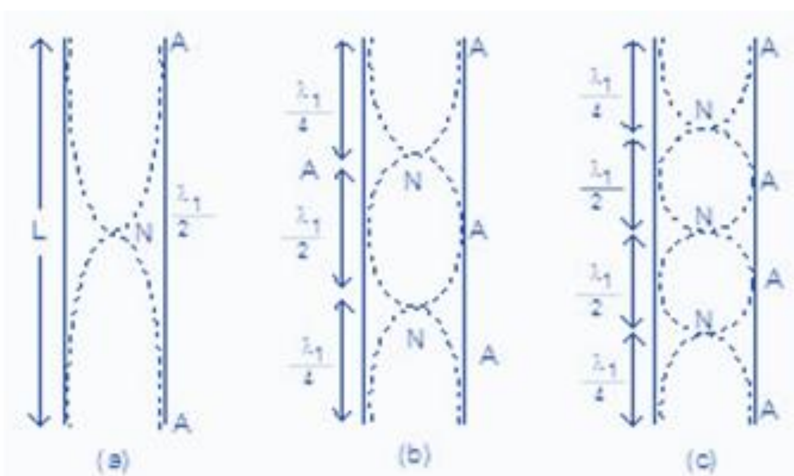
  This signifies, change of pressure has no effect on the velocity of sound.

  (d) Effect of temperature:- $u_t/u_0 = \sqrt{\rho_0/\rho_t} = \sqrt{T/T_0}$

  Thus, velocity of sound varies directly as the square root temperature on Kelvin's scale.

  (e) Temperature coefficient of velocity of sound (α):- $\alpha = u_0/546 = (u_t-u_0)/t$

- **Overtones in open pipe:-**An open pipeis open at both ends. Since air is free to vibrate at an open end, we must get an antinode at the open end.



  (a) **Fundamental frequency:-**

  Wavelength, $\lambda=2l$

  Frequency, $f=u/2l = (1/2l)\sqrt{(\gamma P/\rho)}$

  Here l is the length of the pipe and u is the velocity of sound.

  (b) **First overtone (Second Harmonic):-**

  Wavelength, $\lambda_1=l$

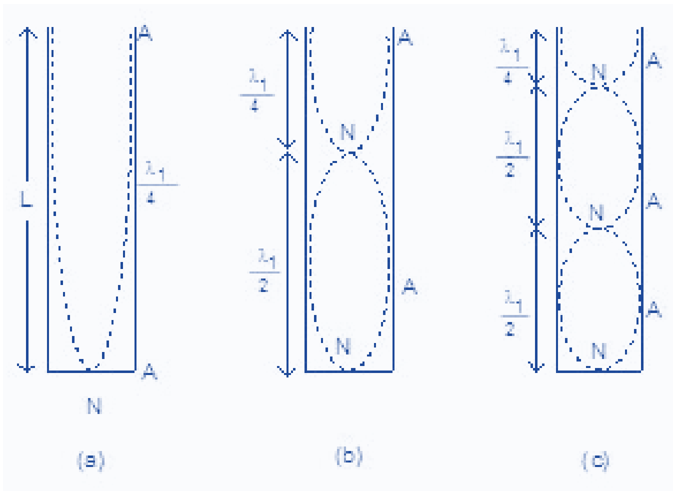
  Frequency, $f_1=2f$

(c) **Second overtone (Third Harmonic):-**

Wavelength, λ_2=2l/3

Wavelength, f_2=3f

- **Overtones in closed pipe:-**Since air, at a closed end, is not free to vibrate, there must be a node at a closed end always.



(a) Fundamental frequency:-

Wavelength, λ=4l

Frequency, F=u/4l = (1/4l)√(γP/ρ)

Here l is the length of the pipe and u is the velocity of sound.

(b) First overtone (Third Harmonic):-

Wavelength, λ_1=(4/3)l

Frequency, F_1=3F

(c) Second overtone (Fifth Harmonic):-

λ_2 = 4l/5

F_2 = 5F

- **Comparison of fundamental frequencies of a closed end of an open pipe:-** f = 2F
- **Doppler's Effect:-**Theapparent change in pitch of a note, due to the relative motion between the source and the listener is called Doppler's effect.

(a) Source in motion, listener at rest:-

(i) Source approaching the listener:-

Modifying wave length, λ' = V-a/f

Apparent frequency, f' = [V/V-a]f

Change in frequency, ?f = (a/V-a)f

Here V is the velocity of sound in air and a is the velocity of source when it moves towards the listener.

(ii) Source going away from the listener:-

Apparent frequency, f' = [V/V+a]f

Change in frequency, ?f = -(a/V+a)f

(iii) Source crossing the listener:-

Apparent frequency of the source before crossing = (V/V-a) f

Apparent frequency of the source after crossing = (V/V+a) f

Change in frequency, ?f = -(2aV/V^2-a^2)f

(b) Source at rest, listener in motion:-

(i) Listener moving away from source:-

Apparent frequency, f'= [V-b/V]f

Change in frequency, ?f = (-b/V)f

Here b is the velocity of listener.

(ii) Listener moving towards the source:-

Apparent frequency:-f'= [V+b/V]f

Change in frequency, ?f = (+b/V)f

(iii) Listener crossing the source:-

Apparent frequency of the source before crossing = (V+b/V) f

Apparent frequency of the source after crossing = (V-b/V) f

Change in frequency, ?f =-2fb/V

(c) **Source and listener both in the medium:-** Change in frequency due to relative motion of source and listener.

Source *(S)*#	**Listener (*L*) (*X*)**	**Nature of velocities**	**Expression for *f* '**
# $\xrightarrow{a}$	X $\xrightarrow{b}$	+ve, +ve	*f* ' = (*V*-*b*/*V*-*a*) *f*
# $\xrightarrow{a}$	$\xleftarrow{-b}$ X	+ve, -ve	*f* ' = (*V*+*b*/*V*-*a*) *f*
$\xleftarrow{-a}$ #	$\xleftarrow{-b}$ X	-ve, -ve	*f* ' = (*V*+*b*/*V*+*a*) *f*
$\xleftarrow{-a}$ #	X $\xrightarrow{b}$	-ve, +ve	*f* ' = (*V*-*b*/*V*+*a*) *f*

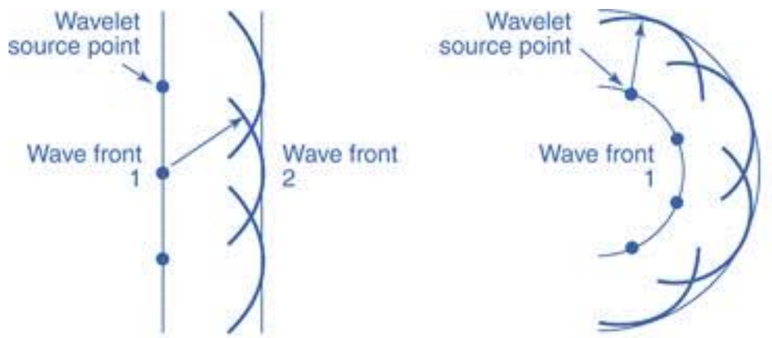
(d) Effect of motion of medium:-

Apparent frequency:-$f' = [(R-b)/(R-a)]\,f$

Here, $R = V + \omega\cos\theta$, ω is the velocity of wind, θ is the angle between direction of propagation of sound and that of wind.

Huygens Principle:- Wave-front of a wave, at any instant , is defined as the locus of all the particles in the medium which are being disturbed at the same instant of time and are in the same phase of vibration.

(a) Each point on a wave front acts as a source of new disturbance and emits its own set of spherical waves called secondary wavelets. The secondary wavelets travel in all directions with the velocity of light so long as they move in the same medium.



(d) The envelope or the locus of these wavelets in the forward direction gives the position of new wave front at any subsequent time.

- **Determination of Phase Difference:-**

  The phase difference between two waves at a point will depend upon

  (a) The difference in path lengths of the two waves from their respective sources.

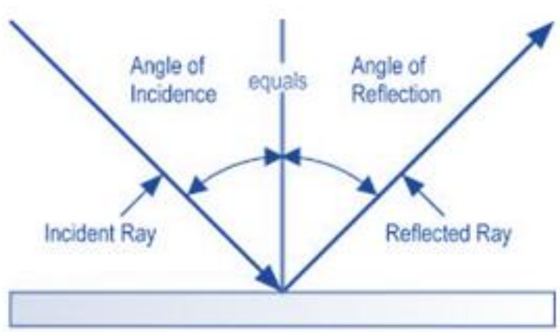
  (b) The refractive index of the medium

  (c) Initial phase difference between the source if any.

  (d) Reflections, if any, in the path followed by waves.

- **Reflection of plane wave at plane surface (Laws of reflection):-**

  (a) The incident ray, the reflected ray and normal to the reflecting surface at the point of incidence, all lie in one plane and that plane is perpendicular to the reflecting surface.



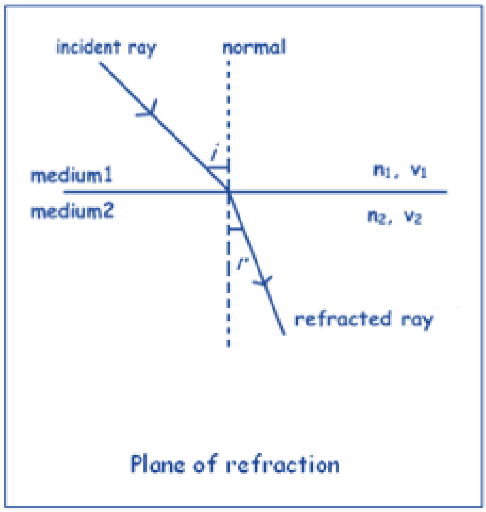
(b) The angle of incidence is equal to the angle of reflection.

So, $\angle i = \angle r$

This signifies angle of incidence is equal to the angle of reflection.

- **Refraction of light:-**

Refraction is the phenomena by virtue of which a wave going from one medium to another undergoes a change in velocity.



(a) The sine of the angle between the incident ray and the normal bears a constant ratio to the sine of the angle between refracted ray and the normal.

sin i/sin r = v_1/v_2 = ${}^1\mu_2$ = constant

Here, v_1 and v_2 are the velocities of sound in first and second medium respectively. ${}^1\mu_2$ is the refractive index of the second medium with respect to first.

(b) The incident ray, the refracted ray and the normal to the refracting surface lie in the same plane.

- **Interference:-** The modification in the distribution of light energy obtained by the superposition of two or more waves is called interference.
- **Principle of superposition:-** It states that a number of waves travelling, simultaneously, in a medium behave independent of each other and the net displacement of the particle, at any instant, is equal to the sum of the individual displacements due to all the waves.
- **Displacement equation:-** $y = R \sin 2\pi/\lambda\ (vt+x/2)$
- **Amplitude:-** $R = 2a \cos \pi x/\lambda$
- **Intensity:-** $I = K4a^2 \cos^2 (\pi x/\lambda)$ $[I = KR^2]$
- **Maxima:-** A point having maximum intensity is called maxima.

  $x = 2n\ (\lambda/2)$

  A point will be a maxima if the two waves reaching there have a path difference of even multiple of $\lambda/2$.

  $I_{max} = 4Ka^2 = 4i$ (Here, $i = Ka^2$)

- **Minima:-** A point having minimum intensity is called a minima.

  x = (2n+1) (λ/2)

  A point will be a minima if the two waves reaching there have a path difference of odd multiple of λ/2.

  $I_{min} = K.\ 4a^2 \times 0 = 0$
- **Condition for constructive interference:-**

  Path difference = (2n)λ/2

  Phase difference = (2n)π
- **Condition for destructive interference:-**

  Path difference = (2n+1)λ/2

  Phase difference = (2n+1)π
- **Coherent Sources:-** Coherent sources are the sources which either have no phase difference or have a constant difference of phase between them.
- **Conditions for interference:-**
  (a) The two sources should emit, continuously, waves of same wavelength or frequency.
  (b) The amplitudes of the two waves should be either or nearly equal
  (c) The two sources should be narrow.
  (d) The sources should be close to each other.
  (e) The two sources should be coherent one.
- **Young's double slit experiment:-**

  Path difference, $x = yd/D$

  Maxima, $y = n\lambda D/d$

  Here, n = 0,1,2,3….

  Minima, y = **(**2n+1) $\lambda D/d$

  Here, n = 0,1,2,3….
- **Fringe Width:-** It is the distance between two consecutive bright and dark fringes.

  $\beta = \lambda D/d$
- **Displacement of fringes due to the introduction of a thin transparent medium:-**

  (a) Shift for a particular order of fringes:-

  ?y = (β/λ) (μ-1)t

  (b) Shift across a particular point of observation:-

  μ = ($m\lambda/t$) +1
- **Lloyd's single mirror:-**

  ?$\lambda = \beta\ .2a/D$
- **Power of lens:-** $P = 100/f$
- **Magnifying power or magnification of a simple microscope:-** M= 1+(D/f)
- **Magnifying power or magnification of a compound microscope:-**

  $M = L/f_0\ (1+D/f_e)$

  Here, f_0 is the focal length of the objective, f_e is the focal length of the eyepiece and L is the length of the microscope tube.
- **Magnification of astronomical telescope in normal adjustment:-**

  $M = f_0/f_e$

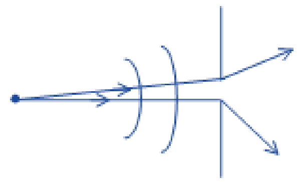
- **Magnification of astronomical telescope, when the final image is formed at the distance of distinct vision:-**

  $M = (f_0/f_e)\,[(f_e+D)/D]$

- **Magnifying power *M* of Galileo's telescope:-**

  M = focal length of objective/focal length of eye lens = F/f

- **Diffraction:-** Diffraction is the bending or spreading of waves that encounter an object (a barrier or an opening) in their path.



(a) In Fresnel class of diffraction, the source and/or screen are at a finite distance from the aperture.

(b) In Fraunhofer class of diffraction, the source and screen are at infinite distance from the diffracting aperture. Fraunhofer is a special case of Fresnel diffraction.

If I_m represents the intensity at *O*, its value at *P* is

$I_\theta = I_m (\sin\alpha/\alpha)^2$

Here, α = ?/2 = $\pi a \sin\vartheta/\lambda$

A minimum occurs when, sin α = 0 and α is not equal to zero.

so α = $n\pi$, n = 1, 2, 3...

So, $\pi a \sin\vartheta/\lambda = n\pi$

Or, $a \sin\vartheta = n\lambda$

Angular width of central maxima of diffraction pattern = $2\vartheta_1 = 2\sin^{-1}(\lambda/a)$

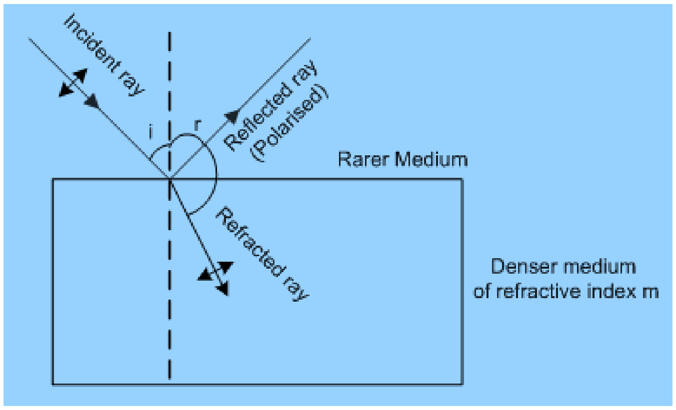
[ϑ_1 gives the angular position of first minima]

- **Polarization: -** Polarization of two interfering wave must be same state of polarization or two source of light should be un polarized.

- **Brewster Law:-**

  ?According to this law when un polarized light is incident at polarizing angle (i) on an interface separating a rarer medium from a denser medium, of refractive index m as shown in Fig., below such that, $\mu = \tan i$

  Then light reflected in the rarer medium is completely polarized. Reflected and refractive rays are perpendicular to each other.



- **Reduction in Intensity:-** Intensity of polarized light is 50% of that of the un polarized light, i.e.,

  $I_p = I_u/2$

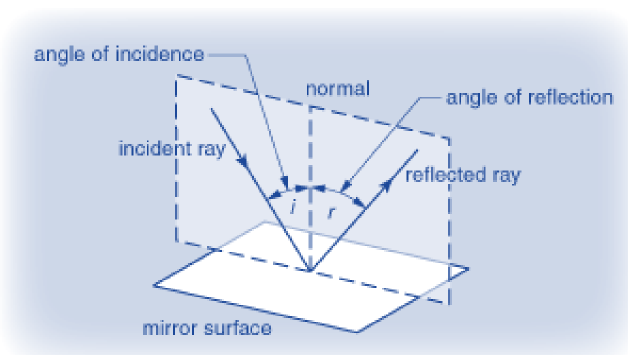
  Here, I_p = Intensity of polarized light.

  I_u = Intensity of un polarized light.

Ray Optics

Reflection:-

- **Light:-** it is an agent which produces in us the sensation of sight. It is a form of energy.
- **Transparent medium:-** It is a medium through which light can be propagated easily.(e.g., sun, candle, electric arc)
- **Translucent medium:**- It is a medium through which light is propagated partially.(e.g., paper, ground, glass)
- **Opaque:**- It is a medium through which light can be propagated. (e.g., wood, iron)
- **Reflection:**- It is the property of light by virtue of which, light is sent back into the same medium from which it is coming after being obstructed by a surface.
- **Laws of reflection:**-



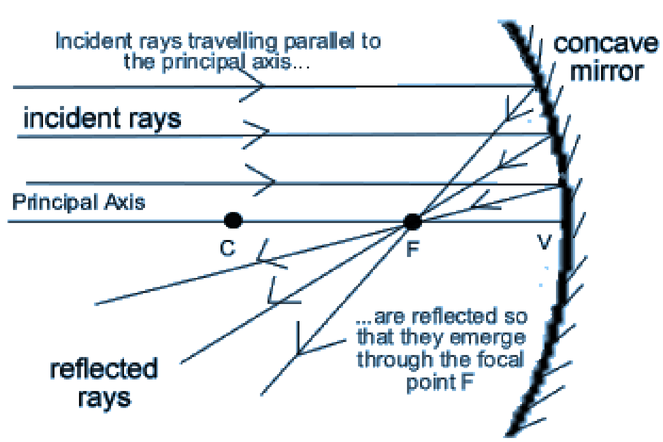
?

(a) The incident ray, the reflected ray and normal to the reflecting surface at the point of incidence, all lie in one plane and that plane is perpendicular to the reflecting surface.

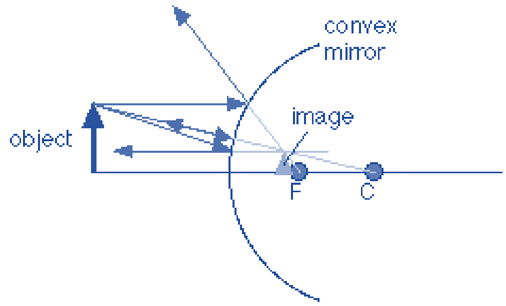
(b) The angle of incidence is equal to the angle of reflection.

So, $\angle i = \angle r$

- **Concave Mirror:-** It is a spherical mirror which when looked from the reflecting side is depressed at the center and bulging at the edges.



- **Convex mirror:-**



?It is a spherical mirror which when looked from the reflecting side bulges at the center and is depressed at the edges.

- **Radius of curvature(*R*):-**

Radius curvature of a mirror is defined as the radius of that sphere of which the mirror forms a part.

- **Principal focus:-**

Principal focus is a point, situated on the principal axis, at which a beam coming parallel to principal axis meets or appears to meet after reflection from the mirror.

- **Focal plane:-**

It is a vertical plane passing through the principal focus and perpendicular to the principal axis.

- **Focal length (*f*):-**

Focal length, of a spherical mirror is the distance of its principal focus from its pole.

- **Relation between focal length and radius of curvature:-**

$f = R/2$

This signifies, the focal length of a spherical mirror is half of its radius of curvature.

- **Mirror formula:-**

?$1/f = 1/v + 1/u = 2/r$

- **Relative positions, size and nature of image as object is brought from infinity to the pole of a concave mirror:-**

(a) If the object is at infinity, $u = \infty$

$v = -f$, $m = 0$

Thus, image is obtained at the focus of a focal plane and very small in dimensions.

(b) If object lies beyond center of curvature,

$2f > v > f$

(c) If object is at center of curvature,

$v = -2f$, m =1

Thus, a real and inverted image of same size as that of object is formed at center of curvature.

(e) Object is in between a distance f and $2f$, i.e., in between focus and center of curvature ($f < u < 2f$):-

$v < \infty$ and $m = (v/u) > 1$

Thus, a real, inverted and magnified image is formed in between center of curvature and infinity.

(e) Object is kept at focus ($u = -f$):-

$v = -\infty$

The rays after reflection are rendered into a parallel beam meeting in infinity.

(f) Object is kept within focus ($u < -f$):-

v is positive.

Thus, a virtual, erect and magnified image is formed on the other side of mirror.

- **Some important points:-**

(a) In case of spherical mirrors, focal length is half its radius of curvature image.

(b) In case of concave mirror areal object produces a real and inverted if its distance from pole is greater than the focal length while its virtual and erect if its distance from pole is less than focal length.

(c) In case of convex mirror a real object always produces a virtual and erect image.

(d) All real images are inverted and virtual images are erect.

Refraction:-

- **Refraction:-** Refraction is the phenomenon by virtue of which a ray of light going from one medium to the other undergoes a change in its velocity.
- **Incident ray:-**The ray which approaches the interface is called incident ray.
- **Refracted ray:-** Ray which goes into the second medium is called angle of incidence.
- **Laws of refraction:-**

(a) Snell's law:- The sine of the angle of incidence bears a constant ratio with the sine of the angle of refraction.

$\sin i/\sin r$ = constant

(b) The incident ray, the refracted ray and the normal to the interface at the point of incidence all lie in one plane and that plane is perpendicular to the interface separating the two media.

- **Refractive Index:-**

? (a) Refractive index of a medium with respect to another is defined as the ratio between sine of the angle of incidence to the sine of angle of refraction.

$\sin i/\sin r$ = constant = $^1\mu_2$

(b) Refractive index of medium 2 with respect to1 is also defind as the ratio between velocity of light in medium 1 to the velocity of light in medium 2.

(c) $^1\mu_2 = v_1/v_2$

(d) $\mu = c/v$

(e) Refractive index of a second medium with respect to first is defined as the ratio between absolute refractive index of second medium to the abdsolute refractive index of first medium.

(f) $^1\mu_2 = \mu_2/\mu_1$?

- **Total internal reflection:-**

(a) Critical angle:- Critical angle is the angle of incidence of a ray of light in denser medium such that its angle of refraction in the rarer medium is 90º.

(b) Total internal reflection:- It is the phenomenon by virtue of which, a ray of light travelling from a denser to a rarer medium is sent back in the same medium provided, it is incident on the interface at an angle greater than critical angle.

(c) $\mu = 1/\sin C$

- **Refraction at a single spherical surface when light travelling from medium of refractive index μ_1 (rarer) to that of refractive index μ_2 (denser):-**

(a) Refraction at a convex surface producing real image:-

$\mu_2/v - \mu_1/u = \mu_2 - \mu_1/R$

(b) Refraction at a convex surface producing virtual image:-

$\mu_2/v - \mu_1/u = \mu_2 - \mu_1/R$

(c) Refraction at a concave surface:-

$\mu_2/v - \mu_1/u = \mu_2 - \mu_1/R$

- **Refraction at a single spherical surface when light travelling from medium of refractive index μ_2 (denser) to that of refractive index μ_1(rarer) :-**

Convex surface producing a real image of a real object:-

$\mu_2/u - \mu_1/v = \mu_2 - \mu_1/R$

- **Light travelling from air to glass:-**

  $\mu/v - 1/u = \mu\text{-}1/R$

- **Light travelling from glass to air:-**

  $\mu/u - 1/v = \mu\text{-}1/R$

- **Principal focal length:-**

  (a) Second principal focal length:- Second principal focal length of a surface is the distance of that point from the pole of the surface at which a beam coming parallel to principal axis meets or appears to meet after refraction through the surface.

  $f_2 = \mu_2 R/ [\mu_2 - \mu_2]$

  (b) First principal length:- First principal focal length of a surface is defined as the distance of that point from the pole of surface from where if a beam diverges or to which a beam converges, the rays after refraction through the surface become parallel to principal axis.

  $f_1 = -\mu_1 R/ [\mu_2 - \mu_1]$

  (c) Relation between f_1 and f_2:-

  $f_2/v + f_1/u = 1$

- **Lens:-**
  A portion of refracting material bound between two spherical surfaces is called a lens.

- **Converging lens:-**
  A lens is said to be converging if the width of the beam decreases after refraction through it.

- **Diverging lens:-**
  A lens is said to be diverge if the width of the beam increases after refraction through it.

- **Center of curvature:-**
  Center of curvature of a surface of a lens is defined as the center of that sphere of which that surface forms a part.

- **Radius of curvature:-**
  Radius of curvature of a surface of a lens is defined as the radius of that sphere of which the surface forms a part.

- **Lens formula:-**
  $1/f = 1/v - 1/u$

- **Linear magnification:-**
  It is the ratio between the size of the image to the size of the object.
  $m = I/O$

- **Expression for *m* in terms of *u*, *v* and *f* :-**
  (a) In terms of *v* and *f*:- $m = [f - v] / f$
  (b) In terms of *u* and *f*:- $m = f / [f + u]$

- **Position of the image as the object is gradually moved from infinity to the pole of the lens:-**
  (a) Object being at infinity:- $v = f$, Magnification in this case is extremely small and the image is said to be real and inverted.

  (b) Object lying beyond 2*f*:- $2f > v > -f$, $m(= v/u)$ always is less than one.

  (c) Object at 2*f*:- $v = 2f$, $m = -1$

  (d) Object lying between *f* and 2*f*:- $v > 2f$, $m(= v/u)$ always is greater than one.

  (e) Object at *f*:- $v = \infty$, $m(= v/u)$ is infinite.

  (f) Object lying between *f* and optical center *C*:-

  At *f*, $u = -f$. So, $v = \infty$

  At *C*, $u = 0$, So, $v = 0$

- **Refraction through a thin double convex lens when the medium on the two sides of the lens is same (Lens maker's formula):-**

  $1/f = (\mu - 1)(1/R_1 - 1/R_2)$

- **Refraction through a thin double convex lens when the medium situated on the two sides of the lens is different:-**

  $1/f = [[\mu_3 - \mu_1]/\mu_3 R_1] + [[\mu_3 - \mu_2]/\mu_3 R_2]$

- **Double concave lens:-**
  (a) When the medium situated on the two sides of the lens is same:-

  $1/f = (\mu - 1)(1/R_1 - 1/R_2)$

  (b) When the medium situated on the two sides of the lens is different:-

  $1/f = [[\mu_3 - \mu_1]/\mu_3 R_1] + [[\mu_3 - \mu_2]/\mu_3 R_2]$

- **Combination of two convex lenses in contact:-**

  $F = f_1 f_2 / f_1 + f_2$

- **Power of a lens:-**
  The reciprocal of the focal length of a lens, expressed in meter, is called its power.
  $P = 1/f$

- **Refraction through a prism:-**

  $\mu = \sin [(A+d_m)/2] / \sin [A/2]$

  Here, d_m is the minimum angle of deviation.

- **Refraction through a prism for small angle of incidence:-**

  $d = A(\mu-1)$

  This signifies that the angle of deviation *d* is independent of the angle of incidence, provided it is small.

Dispersion:-

- **Dispersion:-** The splitting of light into its constituent colors is called dispersion.

- **Cauchy's formula:-** $\mu = A+(B/\lambda^2)+\ldots$

  Here *A* and *B* are constants and λ is the wavelength of light.

- **Refraction through a prism:-**

  (a) Deviation:- A ray of monochromatic light (light possessing one wave-length only), while passing through a prism suffers a change in its path, the phenomenon is known as deviation.

  $d = (\mu-1) A$

  Here A is the refractive angle of prism and μ is the refractive index of the material of prism for that particular wave length of light.

  (b) Dispersion:- A ray of light (containing more than one wavelengths), while passing through the prism splits up into a number of rays. The phenomenon is called dispersion.

  $d_v = (\mu_v-1) A$

  $d_r = (\mu_r-1) A$

  Here d_v is deviation for violet and d_r is the deviation for red color. μ_v and μ_r be the refractive indices of the material of prism for violet and red colors.

  Since, $\mu_v > \mu_r$, therefore d_v is greater than d_r.

- **Dispersive power (ω):-** Dispersive power of a prism is defined as the ratio between angular dispersion to mean deviation produced by the prism.

  $\omega = (d_v - d_r)/d = (\mu_v - \mu_r)/(\mu-1) = d\mu/(\mu-1)$

- **Spectrum:-** The band of colors lying side-by-side is called spectrum.
  - **(a) Impure spectrum:-** Impure spectrum is a spectrum in which the constituent colors overlap each other.
  - **(b) Pure spectrum:-** Pure spectrum is a spectrum in which all the constituent colors occupy different and distinct positions.

Optical Instruments:-

- **Power of a concave lens (P):-**
  P = (100/x) dioptre, Here 'x' is the distance of far point of the defective eye, in 'cm'.

- **Magnifying power or magnification of a simple microscope:-**
  ? M = 1+ (D/f),

  Here, 'D' is the distance of distinct vision and 'f' is the focal length.

- **Magnifying power or magnification of a compound microscope:-**
  ? $M = L/f_0[1+(D/f_e)]$

  f_0 is the focal length of object, f_e is the focal lengthy of eyepeice and L is the length of microscope tube.

- **Magnifying power or magnification of astronomical telescope (Normal Adjustment):-**

  $M = f_0/f_e$

- **Magnifying power or magnification of astronomical telescope (When the final image is formed at the distance of distinct vision):-**

  $M = (f_0/f_e)\ [(f_e+D)/D]$

- **Magnifying power or magnification of Galileo's telescope:-**

  M = F/f

Electrostatics

Electrostatic Force and Electrostatic field:-

- **Electrostatic:-** It is a branch of physics that deals with the phenomena and properties of stationary or slow-moving electric charges with no acceleration**.**

- **Coulomb's Law:-** It states that the electro-static force of attraction or repulsion between two charged bodies is directly proportional to the product of their charges and varies inversely as the square of the distance between the two bodies.

  $F = Kq_1q_2/r^2$

  Here, $K = 1/4\pi\varepsilon_0 = 9\times10^9\ Nm^2C^{-2}$ (in free space)

- **Relative Permittivity (ε_r):-** The relative permittivity (ε_r) of a medium is defined as the ratio between its permittivity of the medium (ε) and the permittivity (ε_0) of the free space.

  $\varepsilon_r = \varepsilon/\varepsilon_0$

- **Coulomb force in vector form:-** The force on charge q_1 due to q_2 is,

  $$\vec{F_{12}} = [q_1q_2/r^2]\hat{r_{21}}$$

  If $q_1q_2>0$, R.H.S is positive.

If $q_1q_2<0$, a negative sign from q_1q_2 will change $\hat{r_{21}}$ and $\hat{r_{12}}$. The relation will again be true, since, in that case have same directions.

- **Unit of Charge:-**

  C.G.S, $q = \pm1$ stat-coulomb

  S.I, $q = \pm1$ Coulomb

- **Relation between coulomb and stat-coulomb:-**

  1 coulomb = 3×10^9 stat-coulomb

  1 coulomb =(1/10) ab-coulomb (e.m.u of charge)

- **Dielectric constant:-** The dielectric constant (ε_r) of a medium can be defined as the ratio of the force between two charges separated by some distance apart in free space to the force between the same two charges separated by the same distance apart in that medium.

  So, $\varepsilon_r = \varepsilon/\varepsilon_0 = F_1/F_2$

Here, F_1 and F_2 are the magnitudes of the force between them in free space and in a medium respectively.

- **Charges:-**

  ? Line charge, $\lambda = q/L$

  Surface chage, $\sigma = q/A$

  Volume charge, $\rho = q/V$

- **Electric field ($\vec{E}$) :-** The strength of an electric field is measured by the force experienced by a unit positive charge placed at that point. The direction of field is given by the direction of motion of a unit positive charge if it were free to move.

$$\vec{E} = \vec{F}/q = Kq/r^2$$

- **Unit of Electric field:-**

  E = [Newton/Coulomb] or [Joule/(Coulomb) (meter)]

- **Electric lines of force:-** An electric line of force is defined as the path**,** straight or curved**,** along which a unit positive charge is urged to move when free to do so in an electric field. The direction of motion of unit positive charge gives the direction of line of force.

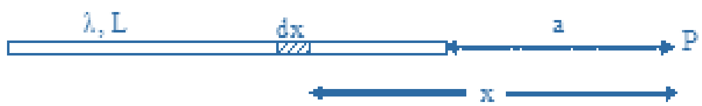
  Properties:-

  (a) The lines of force are directed away from a positively charged conductor and are directed towards a negatively charged conductor.

  (b) A line of force starts from a positive charge and ends on a negative charge. This signifies line of force starts from higher potential and ends on lower potential.

- **Electric field intensity due to a point charge:-** $E = (1/4\pi\varepsilon_0)(q/r^2)$

- **Electric field Intensity due to a linear distribution of charge:-**



? (a) At point on its axis.

$E = (\lambda/4\pi\varepsilon_0)\,[1/a - 1/a+L]$

Here, λ is the linear charge density.

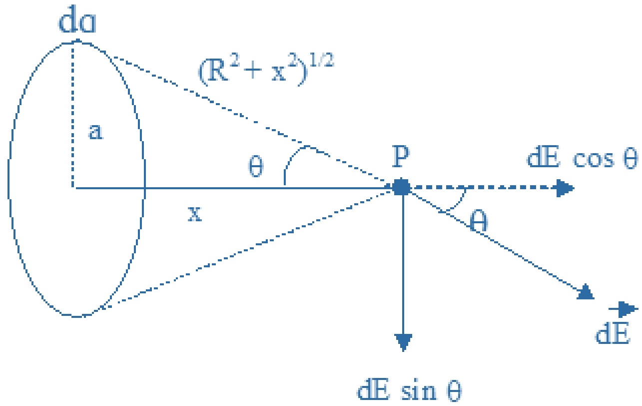
(b) At a point on the line perpendicular to one end.

$$E_X = \frac{\lambda}{4\pi\epsilon_0}\left[\frac{1}{y} - \frac{1}{\sqrt{L^2+y^2}}\right]$$

$$E_Y = \frac{\lambda}{4\pi\epsilon_0}\left[\frac{1}{y\sqrt{L^2+y^2}}\right]$$

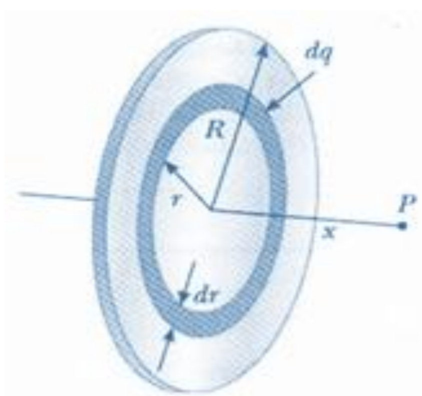
? Here λ is the line charge.

- **Electric field due to ring of uniform charge distribution:-**



At a point on its axis, $E = (1/4\pi\varepsilon_0)\ [qx/(a^2+x^2)^{3/2}]$

- **Electric field due to uniformly charged disc:-**

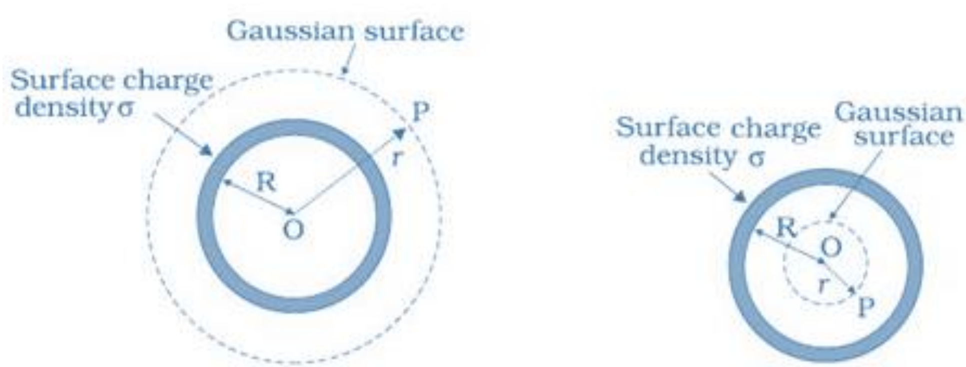


Here σ is the surface charge.

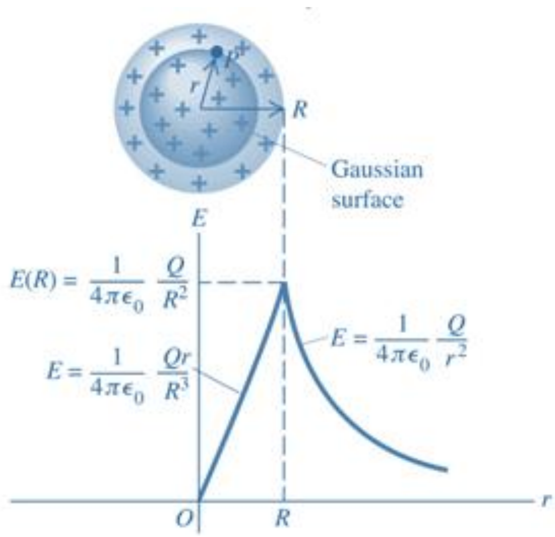
- **Electric field due to thin spherical shell:-**

(a) $E_{out} = (1/4\pi\varepsilon_0)\ (q/r^2)$

(b) $E_{in} = 0$



- **Electric field of a non-conducting solid sphere having uniform volume distribution of charge:-**



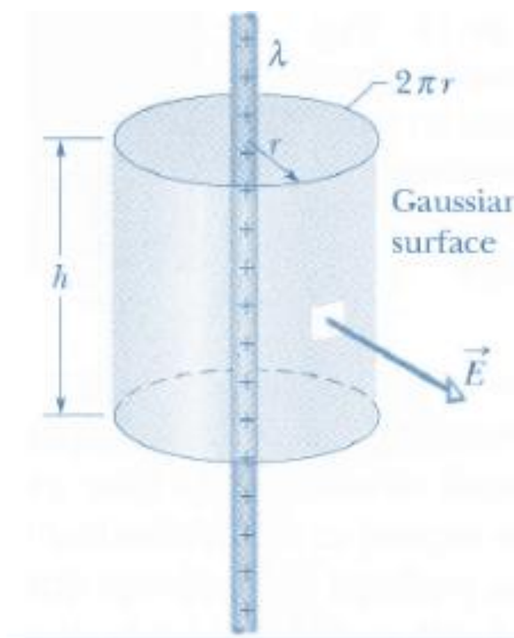
(a) Outside Point:- $E_{out} = (1/4\pi\varepsilon_0)(Q/r^2)$

(b) Inside Point:- $E_{in} = (1/4\pi\varepsilon_0)(Qr/R^3)$

(c) On the Surface:- $E_{surface} = (1/4\pi\varepsilon_0)(Q/R^2)$

Here, Q is the total charge

- **Electric field of a cylindrical conductor of infinite length having line charge *λ*:-**



(a) Outside the cylinder:- E = λ/2πε0r

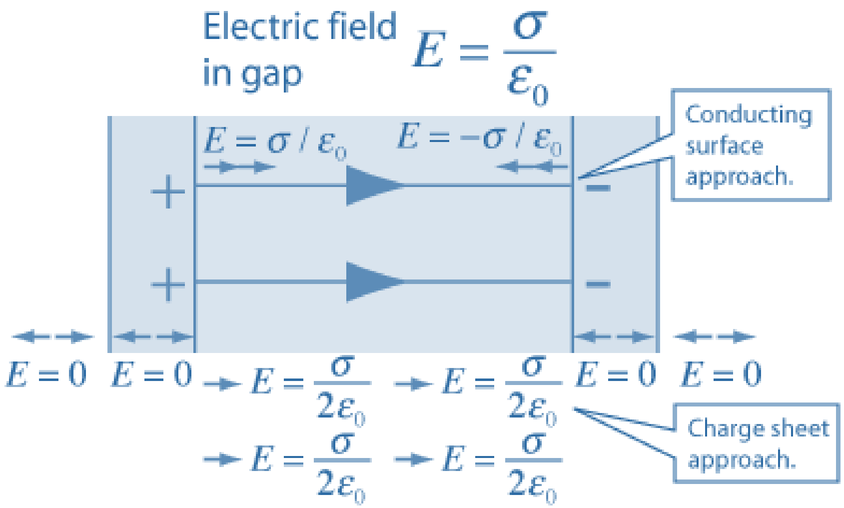
(b) Inside the cylinder:- $E = 0$

- **Electric field of a non-conducting cylinder having uniform volume density of charge:-**

  (a) Outside the cylinder:- $E = \lambda/2\pi\varepsilon_0 r$

  (b) Inside a point:- $E = \rho r/2\varepsilon_0$

- **Electric field of an infinite plane sheet of charge surface charge (σ) :-** $E = \sigma/2\varepsilon_0$



- **Electric field due to two oppositely infinite charged sheets:-**

  (a) Electric field at points outside the charged sheets:-

  $E_P = E_R = 0$

  (b) Electric field at point in between the charged sheets:-

  $E_Q = \sigma/\varepsilon_0$

- **Electric Dipole:-** An electric dipole consists of two equal and opposite charges situated very close to each other.

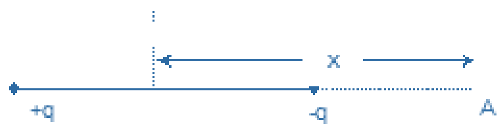
- **Dipole Moment:-** Dipole moment ($\vec{P}$) of an electric dipole is defined as the product of the magnitude of one of the charges and the vector distance from negative to positive charge.

  $$\vec{P} = q\vec{a}$$

- **Unit of Dipole Moment:-** coulomb meter (S.I), stat coulomb cm (non S.I)

- **Electric field due to an electric dipole:-**

  (a) At any point on the axial line:-

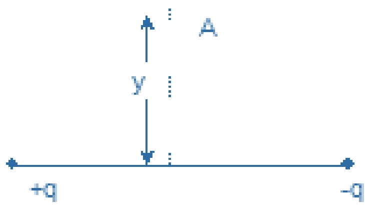


Alt Tag: Electric field due to an electric dipole on the axial line.

$$E = \frac{1}{4\pi\varepsilon_0} \frac{2px}{\left[x^2 - a^2\right]^2}$$

$$\text{For } x \gg a, \vec{E} = \frac{1}{4\pi\varepsilon_0} \frac{2\vec{p}}{x^3}$$

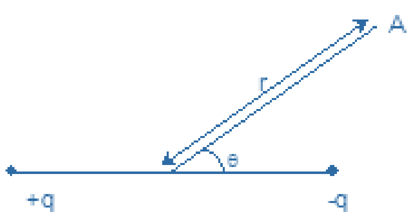
(b) At a point on the equatorial line (perpendicular bisector):-



$$E = \frac{1}{4\pi\,\varepsilon_0} \frac{p}{[a^2 + y^2]^{3/2}}$$

$$\text{For } y >> a, \vec{E} = -\frac{1}{4\pi\,\epsilon_0} \frac{\vec{p}}{y^3}$$

(c) At any point:-



$$E_r = \frac{1}{4\pi\,\varepsilon_0} \frac{2p\cos\theta}{r^3}$$

$$E_\theta = \frac{1}{4\pi\varepsilon_0} \frac{p\sin\theta}{r^3}$$

$$E = \frac{1}{4\pi\varepsilon_0} \frac{p}{r^3} \sqrt{3\cos^2\theta + 1}$$

$$\text{Angle, } \alpha = \tan^{-1}\left(\frac{1}{2}\tan\theta\right)$$

- **Torque (τ) acting on a electric dipole in a uniform electric field (*E*):-**

$\tau = pE\sin\vartheta$

Here, p is the dipole moment and ϑ is the angle between direction of dipole moment and electric field E.

- **Electric Flux:-** Electric flux ?$_E$ for a surface placed in an electric field is the sum of dot product of $\vec{E}$ and $d\vec{a}$ for all the elementary areas constituting the surface.

$$\Phi_E = \int_s \vec{E}.d\vec{a}$$

- **Gauss Theorem:-** It states that, for any distribution of charges, the total electric flux linked with a closed surface is $1/\varepsilon_0$ times the total charge within the surface.

$$\int_S \vec{E} \cdot d\vec{S} = \frac{q_{in}}{\varepsilon_0}, \text{ for free space}$$

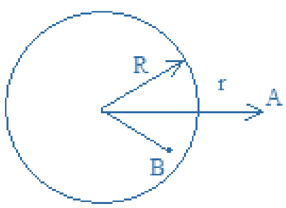
$$\int_S \vec{E} \cdot d\vec{S} = \frac{q_{in}}{\varepsilon_0 \varepsilon_r}$$

- **Electric field (*E*) of an infinite rod at a distance (*r*) from the line having linear charge density (*λ*):-**

  $E = \lambda/2\pi\varepsilon_0 r$

  The direction of electric field *E* is radically outward for a line of positive charge.

- **Electric field of a spherically symmetric distribution of charge of Radius *R*:-**

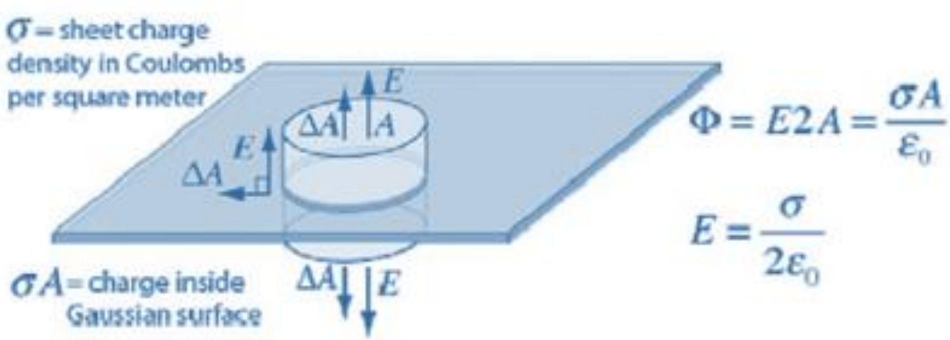


(a) Point at outside ($r > R$):- $E = (1/4\pi\varepsilon_0)\,(q/r^2)$, Here *q* is the total charge.

(b) Point at inside ($r < R$):- $E = (1/4\pi\varepsilon_0)\,(qr/R^3)$, Here *q* is the total charge.

- **Electric field due to an infinite non-conducting flat sheet having charge σ:-**

  $E = \sigma/2\varepsilon_0$



This signifies, the electric field near a charged sheet is independent of the distance of the point from the sheet and depends only upon its charge density and is directed normally to the sheet.

- **Electric field due to an infinite flat conductor carrying charge:-**

  ?E= σ/ε_0

- **Electric pressure (P_{elec}) on a charged conductor:-**

  $P_{elec} = (½\varepsilon_0)\ \sigma^2$

Electro-Static Potential and Capacitance:-

- **Electric Potential:-**

  (a) Electric potential, at any point, is defined as the negative line integral of electric field from infinity to that point along any path.

  $$V(\vec{r}) = -\int_{\infty}^{r} \vec{E}.d\vec{r}$$

  (b) $V(r) = kq/r$

  (c) Potential difference, between any two points, in an electric field is defined as the work done in taking a unit positive charge from one point to the other against the electric field.

  $W_{AB} = q\ [V_A - V_B]$

  So, $V = [V_A - V_B] = W/q$

  Units:- volt (S.I), stat-volt (C.G.S)

  Dimension:- $[V] = [ML^2T^{-3}A^{-1}]$

  Relation between volt and stat-volt:- 1 volt = (1/300) stat-volt

- **Relation between electric field (*E*) and electric potential (*V*):-**

  $E = -dV/dx = --dV/dr$

- **Potential due to a point charge:-**

  $V = (1/4\pi\ \varepsilon_0)\ (q/r)$

- **Potential at point due to several charges:-**

  $V = (1/4\pi\ \varepsilon_0)\ [q_1/r_1 + q_2/r_2 + q_3/r_3]$

  $= V_1 + V_2 + V_2 + ...$

- **Potential due to charged spherical shell:-**

  (a) Outside, $V_{out} = (1/4\pi\ \varepsilon_0)\ (q/r)$

  (b) Inside, $V_{in} = -\ (1/4\pi\ \varepsilon_0)\ (q/R)$

  (c) On the surface, $V_{surface} = (1/4\pi\ \varepsilon_0)\ (q/R)$

- **Potential due to a uniformly charged non-conducting sphere:-**
  (a) Outside, $V_{out} = (1/4\pi \varepsilon_0)(q/r)$
  (b) Inside, $V_{in} = (1/4\pi \varepsilon_0)[q(3R^2-r^2)/2R^3]$
  (c) On the surface, $V_{surface} = (1/4\pi \varepsilon_0)(q/R)$
  (d) In center, $V_{center} = (3/2)[(1/4\pi \varepsilon_0)(q/R)] = 3/2 [V_{surface}]$

- **Common potential (two spheres joined by thin wire):-**
  (a) Common potential, $V = (1/4\pi \varepsilon_0)[(Q_1+Q_2)/(r_1+r_2)]$
  (b) $q_1 = r_1(Q_1+Q_2)/(r_1+r_2) = r_1Q/ r_1+r_2$; $q_2 = r_2Q/ r_1+r_2$
  (c) $q_1/q_2 = r_1/r_2$ or $\sigma_1/ \sigma_2 = r_1/r_2$

- **Potential at any point due to an electric dipole:-**

  $$V(r,\vartheta) = qa \cos\vartheta/4\pi\varepsilon_0 r^2 = p \cos\vartheta/4\pi\varepsilon_0 r^2$$

  (a) Point lying on the axial line:- $V = p/4\pi\varepsilon_0 r^2$
  (b) Point situated on equatorial lines:- $V = 0$

- **If *n* drops coalesce to form one drop, then,**
  (a) $R = n^{1/3}r$
  (b) $Q = nq$
  (c) $V = n^{2/3}V_{small}$
  (d) $\sigma = n^{1/3} \sigma_{small}$
  (e) $E = n^{1/3} E_{small}$

- **Electric potential energy *U* or work done of the system *W* having charge q_1 and q_2:-**

  $$W = U = (1/4\pi\varepsilon_0)(q_1q_2/r_{12}) = q_1V_1$$

- **Electric potential energy *U* or work done of the system *W* of a three particle system having charge q_1, q_2 and q_3:-**

  $$W = U = (1/4\pi\varepsilon_0)(q_1q_2/r_{12} + q_1q_3/r_{13} + q_2q_3/r_{23})$$

- **Electric potential energy of an electric dipole in an electric field:-** Potential energy of an electric dipole, in an electrostatic field, is defined as the work done in rotating the dipole from zero energy position to the desired position in the electric field.

$$W = -\vec{p}.\vec{E} = -pEcos\theta$$

(a) If ϑ = 90º, then W = 0

(b) If ϑ = 0º, then $W = -pE$

(c) If ϑ = 180º, then $W = pE$

- **Kinetic energy of a charged particle moving through a potential difference:-**

K. E = $\frac{1}{2} mv^2 = eV$

- **Conductors:-** Conductors are those substance through which electric charge easily.

- **Insulators:-** Insulators (also called dielectrics) are those substances through which electric charge cannot pass easily.

- **Capacity:**- The capacity of a conductor is defined as the ratio between the charge of the conductor to its potential

C = Q/V

Units:-

S.I – farad (coulomb/volt)

C.G.S – stat farad (stat-coulomb/stat-volt)

Dimension of *C*:- $[M^{-1}L^{-2}T^4A^2]$

- **Capacity of an isolated spherical conductor:-**

$C = 4\pi\varepsilon_0 r$

- **Capacitor:-** A capacitor or a condenser is an arrangement which provides a larger capacity in a smaller space.
-
- **Capacity of a parallel plate capacitor:-**

$C_{air} = \varepsilon_0 A/d$

$C_{med} = K\varepsilon_0 A/d$

Here, A is the common area of the two plates and d is the distance between the plates.

- **Effect of dielectric on the capacitance of a capacitor:-**

$$C = \varepsilon_0 A/[d-t+(t/K)]$$

Here d is the separation between the plates, t is the thickness of the dielectric slab A is the area and K is the dielectric constant of the material of the slab.
If the space is completely filled with dielectric medium (t=d), then,

$$C = \varepsilon_0 KA/ d$$

- **Capacitance of a sphere:-**

(a) $C_{air} = 4\pi\varepsilon_0 R$

(b) $C_{med} = K\ (4\pi\varepsilon_0 R)$

- **Capacity of a spherical condenser:-**

(a) When outer sphere is earthed:-

$C_{air} = 4\pi\varepsilon_0\ [ab/(b-a)]$

$C_{med} = 4\pi\varepsilon_0\ [Kab/(b-a)]$

(b) When the inner sphere is earthed:-

$C_1 = 4\pi\varepsilon_0\ [ab/(b-a)]$

$C_2 = 4\pi\varepsilon_0 b$?

Net Capacity, $C' = 4\pi\varepsilon_0[b^2/b-a]$

Increase in capacity, $\Delta C = 4\pi\ \varepsilon_0 b$

It signifies, by connecting the inner sphere to earth and charging the outer one we get an additional capacity equal to the capacity of outer sphere.

Current Electricity

- **Current:-** Current strength, in a conductor, is defined as the rate of flow of charge across any cross section of the conductor.

  I= q/t = ne/t

  For non-uniform flow,

  I= dq/dt

  Or, q = I dt

- **Units of electric current**:-

  (a) C.G.S. electro-static unit (esu):- 1 esu of current (stat-ampere) = 1 esu of charge/1 second

  (b) C.G.S. electro-static unit (emu):- 1 emu of current (ab-ampere) = 1 emu of charge/1 second

  (c) S. I unit (ampere):- 1 ampere = 1 coulomb/1 second

  (d) 1 A = 3×10^9esu of current or stat-ampere

  (e) 1 A = 1/10 emu of current or abampere

- **Drift velocity**:-The velocity with which the free electrons are drifted towards the positive terminal, under the action of the applied field, is called the drift velocity of the free electrons.

  V = (eV/ml)τ

  Here, e is the charge of electron, V is the potential difference, m is the mass and τ is the relaxation time.

- **Electric current and Drift velocity**:- I= *q*/*t* = *nAve*

- **Ohm's Law for conductors**:- At constant temperature current flowing through a conductor of uniform area of cross-section, is proportional to the difference of potential across its terminals.

  (a) V = IR , Here, R = (ml/nAe^2) $(1/\tau)$

  (b) R=ρl/A

  (c) ρ = 1/σ

  (d) $v_d = (qE\tau/m)$

  (e) $I = neAv_d$

  (f) $\rho = m/ne^2\tau$

  (g) $\sigma = ne^2\tau/m$

- **Resistance (R)**:- Resistance of a conductor is defined as the ratio between potential differences between the two ends of the conductor to the current flowing through it.

  $R= V/I$

- **Units of R**:-

  (a) In S.I:- 1 ohm = 1 volt/1 ampere

  (b) In C.G.S system:-

  1 statohm = 1 statvolt/1 statamp

  1 abohm = 1 abvolt/1 abampere

  (c) Relation between ohm and statohm:- 1 ohm = $(1/9\times10^{11})$ statohm

  (d) Relation between ohm and abohm:- 1 ohm = 10^9abohm

- **Variation of resistance with temperature**:-

  Temperature coefficient of resistance (α) is defined as change in resistance of the conductor per unit resistance per degree centigrade rise of temperature.

  $R_t=R_0[1+\alpha(T-T_0)]$

  $\alpha = R_t - R_0/R_0(T-T_0)$

  Here, R_t,R_0 is the resistance of the conductor at tº C and 0º C respectively.

- **Resistivity of material (ρ)**:- $\rho = RA/l$,

  Here R is the resisteance of the conductor, A is cross sectional area of conductor and l is the length of the conductor

- **Relation between resistivity(ρ) and relaxation time (τ)**:-

  $\rho = m /ne^2\tau$

- **Variation of resistivity with temperature**:-

  (a) Conductors:-

  $\rho_t = \rho_0 [1+\alpha(T-T_0)]$

  Here c is called the temperature coefficient of the resistivity.

  $= (\rho_t - \rho_0) /\rho_0 (T--T_0)$

  Temperature coefficient of resistivity of a conductor is defined as the change in resistivity per unit resistivity per degree Celsius rise of temperature.

  $\alpha = \rho_t - \rho_0$

(b) Insulators:-

$$\rho_t = \rho_0 e^{\frac{-E_g}{kT}}$$

- **Conductivity (σ):- Conductivity of a material is defined as the reciprocal of the resistivity.**

  $\sigma = 1/\rho$

  Unit:- *$ohm^{-1}m^{-1}$*

- **Conductance:-**Conductanceof a conductor is defined as the reciprocal of its resistance.
  Conductance = 1/R = (1/ρ) (A/l)
  Unit:- mho or $ohm^{-1}m^{-1}$

- **Current Density:-**

  $$I = \int_S \vec{J} \cdot d\vec{A}$$

  (a) *J = I/A*

  (b) $J = nev_d$

  (c) $J = \sigma E$

  (d) $\mu = v_d/E$

  (e) $\sigma = ne\mu$

- **Relation between current density and electrified:-**

  $\vec{J} = \sigma \vec{E}$ **?**

  Thus, electrical conductivity can also be defined as electric current density per unit electric field strength.

- **Resistance in series:-** If a number of resistances are connected in series with each other, the net resistance of the combination is equal to the sum of their individual resistances.

  (a) $R = R_1 + R_2 + R_3$

  (b) $V = V_1 + V_2 + V_3$

  (c) $I = I_1 = I_2 = I_3 =$ Constant

  (d) $V_1 = IR_1$, $V_2 = IR_2$, $V_3 = IR_3$

- **Resistance in parallel:-** If a number of resistances are connected in parallel, the reciprocal of the resistance of the combination is equal to the sum of the reciprocals of their individual resistances.
  (a) $1/R = 1/R_1 + 1/R_2 + 1/R_3$
  (b) $I = I_1+I_2+I_3$
  (c) $V = V_1 = V_2 = V_3 =$ Constant
  (d) $I_1 = V/R_1$, $I_2 = V/R_2$, $I_3 = V/R_3$

- **Distribution of current in a parallel combination of resistances**:-
  (a) $I_1 = I\ (R_2/R_1+R_2)$
  (b) $I_2 = I\ (R_1/R_1+R_2)$

  In general,

  Current in one branch = total current × (resistance of second branch / sum of resistances in the two branches)

- **Grouping of cells:-**
  (a) Cells in series:-

  $I= (nE)/(R+nr)$

  If $R<<nr$, then $I = E/R$

  If $R>>nr$, then $I = nE/R$

  (b) Cells in parallel:-

  I= $E/[R+(r/m)]$

  If $R>>r/m$, then $I = E/R$

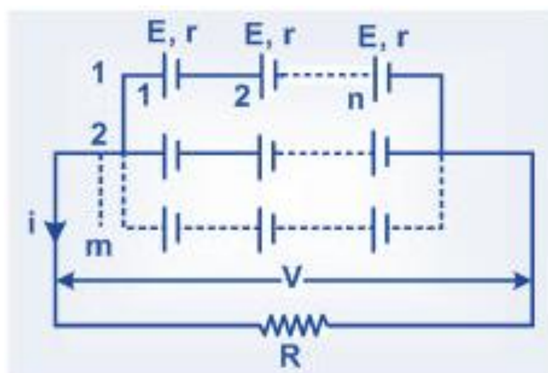
  If $R>>r/m$, then $I = m(E/R)$

  (c) Mixed grouping:-

  (a) $I = mnE/(mR+nr)$

  (b) I is maximum when $nR = mR$

  (c) $I_{max} = mnE/(2\sqrt{mnrR})$



- **Electromotive force and potential difference:-**

  The electromotive force E of a cell is defined as the difference of potential between its terminals when there is no current in the external circuit, i.e., when the cell is in open circuit.

  The potential difference of a cell is the difference of potential between two terminals when it is in closed circuit.

  $E = V + IR$

- **Internal resistance (r) of a cell:-** The resistance offered by the electrolyte of the cell when the electric current passes through it is known as the internal resistance of the cell.

  $r = R (E-V/V)$

- **Electric Power:-**

  (a) $P = VI$

  (b) $P = I^2R = V^2/R$

  Unit of power:-1 watt = 1 volt × 1 amp

- **Electric energy:-**

  $W = Vq = V(It)$

  Unit of electric energy:-

  1 joule = 1 watt sec

  1 kilowatt hour = 1000 watt hour

- **Faraday's Laws of Electrolysis:-**

  (a) The mass of ion deposited on an electrode in the process of electrolysis, is proportional to the quantity of charge that has passed through the electrolyte.

  $m = Zq = ZIt$

  (b) When same current passes through several electrolytes for the same time, the masses of various ions deposited at each of the electrodes are proportional to their chemical equivalents (equivalent weights).

  m/W = constant

  Or, $Z_1/Z_2 = W_1/W_2$

  So, W/Z = constant = F

- **Heating effect of current:-**

  $I = I^2Rt$ Joule $= I^2Rt/J$ Calorie

- **Electric Bulb:-**

  (a) Resistance of filament, $R = V^2/P$

  (b) Maximum current that can be allowed to pass through bulb, $I_{max} = P/V$

- **Total power consumed in parallel combination**:-

  $P = P_1+P_2+P_3$

- **Total power consumed in series combination:-**

  $1/P= 1/P_1+1/P_2+1/P_3$

- **Effect of stretching a resistance wire:-**

  $R_2/R_1 = (l_1/l_2)\ (A_1/A_2) = (l_2/l_1)^2 = (A_1/A_2)^2 = (r_1/r_2)^4$ [Since, $l_1 A_1 = l_2 A_2$]

- **Thermo e.m.f:-**$e = \alpha\theta + (\beta\theta^2/2)$ (Here, $\theta = \theta_H = \theta_C$)

- **Neutral temperature:** $\theta_N = -(\alpha/\beta)$

- **Temperature of inversion:-** $\theta_N = (\theta_1 + \theta_C)/2$ [Since, $\theta_1 - \theta_N = \theta_N - \theta_C$]

- **Thermoelectric power or Seebeck Coefficient:-** $S = de/d\theta = \alpha + \beta\theta$

- **Peltier effect:**-

  Heat absorbed per second at a junction when a current I flows $= \pi I$

  Here π is Peltier coefficient and is given by, $\pi = S\theta_H$

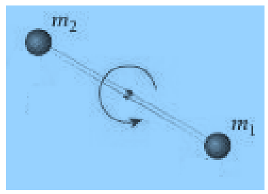
- **Thomson coefficient:-**

  $\sigma = (\Delta Q/\text{time})/I\Delta\theta$

Magnetism

- **Magneto-static:-** It is the study of magnetic fields in systems where the currents are steady (not changing with time). It is the magnetic analogue of electrostatics, where the charges are stationary.

- **Magnitude of magnetic force between two poles (Coulomb's law in magnetism):-**



$F = (\mu_0/4\pi)\,(m_1 m_2/r^2)$

Here μ_0 is called the absolute magnetic permeability of free space.

$\mu_0 = 4\pi\times10^{-7}\ Wb\ A^{-1}\ m^{-1}$

- **Magnetic fiel**d:- Magnetic field, of any magnetic pole, is the region (space) around it in which its magnetic influence can be realized.

- **Lines of Force (Flux Lines)**:- Line of force is the path along which a unit north pole would move if it were free to do so.

- **Magnetic Dipole:-** A combination of two isolated , equal and opposite magnetic poles separated by a small distance constitutes a magnetic dipole.

- **Magnetic Moment:-** Magnetic moment *M* of a magnetic dipole is defined as the product of its pole strength and the magnetic length. ***M = m×2l***

- **Torque in Magnetic field:- ?** $\vec{\tau} = \vec{M} \times \vec{B}$ **?**

- **Work done in rotating a magnetic dipole in a magnetic field:- W = *MB* ($\cos\vartheta_1 - \cos\vartheta_2$)**

- **Potential Energy of a magnetic dipole in a magnetic field:-** $\vec{W} = -\vec{M} \times \vec{B}$

- **Magnetic moment (*M*):- M = *I×A***

- **Other formulae of *M*:-**
  (a) $M = nI\pi r^2$
  (b) $M = eVr/2 = er^2\omega/2 = er^2\, 2\pi f/2 = er^2\, \pi/T$
  (c) $M = n\mu_B$

- **Resultant magnetic moment :-**
  (a) When two bar magnets are lying mutually perpendicular to each other, then,
  $M = \sqrt{[M_1^2+M_2^2]} = \sqrt{2}\ mpl$
  (b) When two coils, each of radius r and carrying current i, are lying concentrically with their planes at right angles to each other, then $M = \sqrt{[M_1^2+M_2^2]} = [\sqrt{2}I]\pi r^2$ If $M_1 = M_2$

- **Atoms as a magnetic dipole:-**
  (a) $I = e\omega/2\pi$
  (b) $M = e\omega r^2/2$
  (c) $M = n\ (eh/4\pi m)$
  The term $eh/4\pi m$ is called Bohr's magneton. It is the smallest value of magnetic moment which an electron can possess.

- **Magnetic flux density at a distance from a magnetic dipole in free space:- B= ($\mu_0/4\pi$) (m_1/r^2)**

- **Force:-** $F = (\mu_0/4\pi)\ (m_1\ m_2/r^2)$

- **Magnetic intensity at any point due to a magnetic pole in free space:- F = ($\mu_0/4\pi$) (m/r^2)**

- **Magnetic intensity due to a bar magnet in free space:-**
  (a) Point situated on the axial line (End-on position):-
  $F = (\mu_0/4\pi)\ [2Mr/(r^2-l^2)^2]$
  In case of a magnetic-dipole, $F = (\mu_0/4\pi)\ [2M/r^3]$
  (b) Point situated on equatorial line (Broad side-on position):-
  $F = (\mu_0/4\pi)\ [M/(r^2+l^2)^{3/2}]$
  In case of a magnetic-dipole, $F = (\mu_0/4\pi)\ [M/r^3]$
  (c) Point situated anywhere:-
  $F= (\mu_0/4\pi)\ [M/r^3]\ \sqrt{1+3\cos^2\vartheta}$
  Direction, $\tan \beta = ½ \tan \vartheta$

- **Combined magnetic field due to bar magnet and earth – "Neutral Points":-**
  Bar magnet placed in a magnetic meridian:-
  (a) North pole facing north of earth:-
  $B = (\mu_0/4\pi)\ [M/(r^2+l^2)^{3/2}]$
  At neutral points, $B=H$
  So, $H = (\mu_0/4\pi)\ [M/(r^2+l^2)^{3/2}]$
  (b) North pole facing south of earth:-
  $B = (\mu_0/4\pi)\ [2Mr/(r^2-l^2)^2]$
  At neutral points, $B=H$
  So, $H = (\mu_0/4\pi)\ [2Mr/(r^2-l^2)^2]$

- **Intensity of magnetization (I):-**
  Intensity of magnetization (I), is defined as the magnetic moment (M) developed per unit volume (V) of the specimen, when subjected to a uniform magnetic field.
  $I = M/V = m/a$
  Here m is the pole strength and a is the area of the specimen.

- **Relation between magnetic field (*B*) and field intensity (*H*):-** $B = H + 4\pi I$

- **Permeability (μ):-** It is defined as the ratio between magnetic induction to the strength of magnetic field. $\mu = B/H$
  (a) For paramagnetic and ferromagnetic substances, $B > H$. So, $\mu > 1$
  (b) For diamagnetic substances, $B < H$. So, $\mu < 1$

- **Susceptibility (*k*):-** Susceptibility of a magnetic substance is defined as the ratio between intensity of magnetization (I) to the strength of magnetic field (H). $k = I/H$

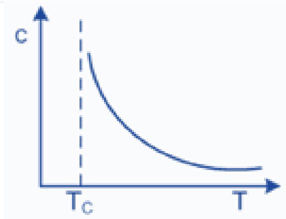
- **Relation between μ and k:-** $\mu = 1 + 4\pi k$

- **For substances which get magnetized in the direction of magnetic field,**
  (a) I is positive
  (b) k is positive
  (c) $B > H$
  (d) $\mu > 1$

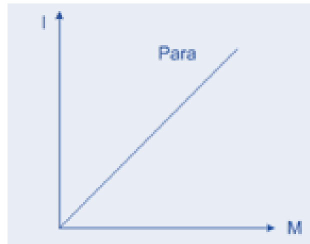
- **For substances which get magnetized in the direction opposite to that of magnetic field,**
  (a) I is negative
  (b) k is negative
  (c) $B < H$
  (d) $\mu < 1$

- **Magnetic Substance:-** A substance which is affected by a magnetic field is called a magnetic substance.
  (a) Diamagnetic substances:- Diamagnetic substances are those substances which are repelled by the magnets.
  Example- antimony, bismuth, lead, tin, zinc, mercury, gold, phosphorus
  (b) Paramagnetic substances:- Paramagnetic substances are those substances which are weakly attracted by the magnets.
  Example-aluminium, platinum, oxygen, manganese, chromium
  (c) Ferromagnetic substances:- Ferromagnetic substances are those substances which are strongly attracted by the magnets.
  Example- iron, cobalt, nickel

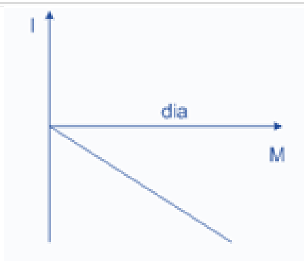
- **Curie-Weiss Law:-**



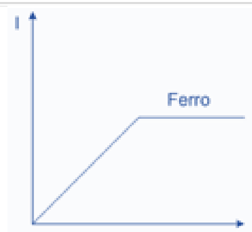
***χ – T* Curve**



***I-M* curve for paramagnetic material**



***I-M* curve for diamagnetic material**



***I-M* curve for ferromagnetic materials**

Magnetic Effect of Electric Current

- **Magnetic flux:-**

  Magnetic flux lined with the surface is defined as the product of area and component of *B* perpendicular that area.

  $$\phi_B = \vec{B} \cdot \vec{A} = BA \cos\theta$$

  and

  ?$_B$ = *μnAH*

  Here, *μ* is the permeability of the medium, *n* is the number of turns, *A* is the area and *H* is the magnetic field intensity.

  (a) When ϑ = 90º, cosϑ = 0. So, ?$_B$ = 0

  This signifies, no magnetic flux is linked with surface when the field is parallel to the surface.

  (b) When ϑ = 0º, cosϑ = 1. So,(?$_B$)$_{max}$ = 1

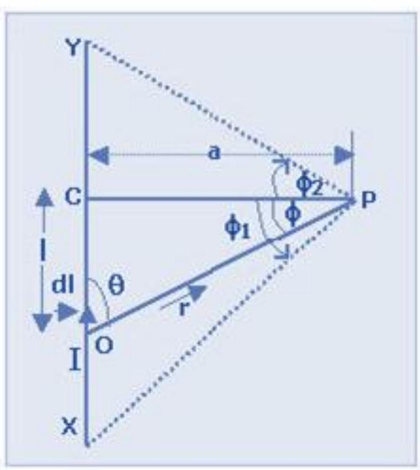
  This signifies, magnetic flux linked with a surface is maximum when area is held perpendicular to the direction of field.

- **Biot-Savart Law or Ampere's Theorem:-**

  $$d\vec{B} = \frac{\mu_0 I}{4\pi}\frac{d\vec{l} \times \vec{r}}{r^3} = \frac{\mu_0 I}{4\pi}\frac{d\vec{l} \times \hat{r}}{r^2}$$

  Or, $dB = (\mu_0/4\pi)\,(I\,dl \sin\vartheta/r^2)$

- **Field due to straight current carrying conductor of finite length at a point *P*, perpendicular distance *a* from the linear conductor *XY*:-**



B = ($\mu_0 I/4\pi a$)× (sin ?$_1$ + sin ?$_2$)

Direction:-

(a) For current in the conductor from *X* to *Y*, the direction of *B* is normal to the plane of conductor downwards.

(b) For current in the conductor from *Y* to *X*, the direction of *B* is normal to the plane of conductor downwards.

- **Field due to straight carrying conductor of infinite length at a point *P*, perpendicular distance R from the linear conductor *XY*:-**

  $B = (\mu_0 I/2\pi a)$ (Direction is same as given above)

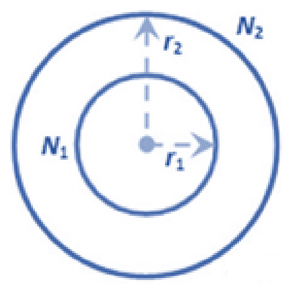
- **Field due to two concentric coils of radii r_1 and r_2 having turns N_1 and N_2 in which same current *I* is flowing in anticlockwise direction at their common center *O*:-**

  $B = \mu_0 I/2\ [N_1/r_1 + N_2/r_2]$

  If the number of turns in them is same, $B = \mu_0 NI/2\ [1/r_1 + 1/r_2]$

  Direction:- Direction of *B* will be normal to the plane of paper upwards.

- **Field due to two concentric coils of radii r_1 and r_2 having turns N_1 and N_2 in which same current *I* is flowing in mutually opposite direction at their common center *O*:-**

  $B = \mu_0 I/2\ [N_1/r_1 - N_2/r_2]$

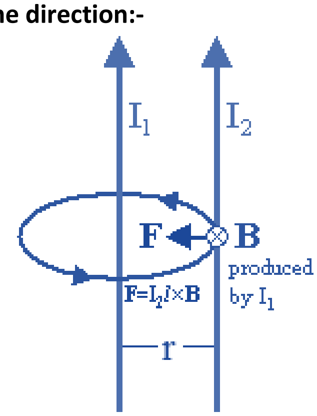
  If the number of turns in them is same, $B = \mu_0 NI/2\ [1/r_1 - 1/r_2]$

  Direction:- Direction of *B* will be normal to the plane of paper upwards.

- **Field due to circular coil at the center *O* :-**

  $B = \mu_0 I/2R$

- **Field due to two parallel very long linear conductors carrying current in same direction:-**

  (a) At point *P* i.e. at a distance *r*/2 from both conductors, ***B*=0**

  (b) At a point *Q* i.e. at a distance *x* from first and *r*+*x* from second conductor, $\mathbf{B = \mu_0 2I/4\pi\ [(1/x) + (1/r+x)]}$

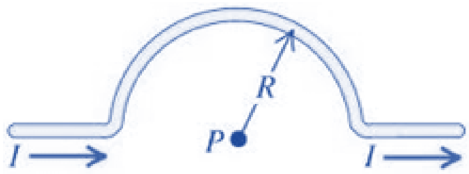
  Direction:- *B* is normal to the plane of paper downwards.

  (c) At a point *P* i.e. at a distance *x* from first and *r*-*x* from second conductor, $B = \mu_0 2I/4\pi\ [(1/x) - (1/r-x)]$

  If *B* is positive, then its direction will be normal to the plane of paper upwards.

  If *B* is negative, then its direction will be normal to the plane of paper downwards.

- **Field due to two parallel very long linear conductors carrying current in opposite direction (refer above figure):-**
  (a) At point *P* distance *x* from first conductor,
  $B = \mu_0 2I/4\pi\ [(1/x) + (1/r\text{-}x)]$
  Direction:- of *B* will be normal to the plane of paper downwards.

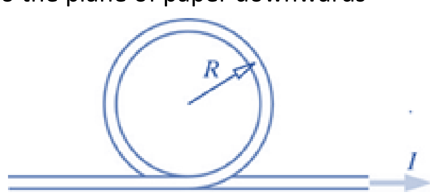


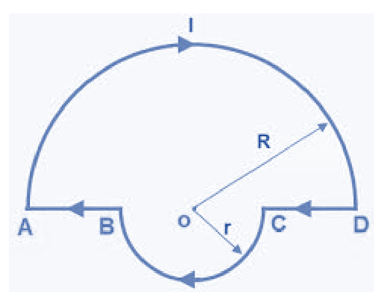
  (b) At point *Q* distance *x* from first conductor, $B = \mu_0 2I/4\pi\ [(1/x) - (1/r\text{-}x)]$
  Direction:- of *B* will be normal to the plane of paper upwards.

- **Field due to semicircular arc of wire at the center *O* of the arc:- B = (μ_0 /4π) (π*I*/*R*)**
  Direction:- Direction of *B* will be at right angle to the plane of circular arc downwards. If the direction current is in anticlockwise, then the direction of field B will be a right angle to the plane of circular arc upwards.

- **Field due to straight wire and loop at the center *O* of the loop (If the current in the looop in anticlockwise direction):-** $B = (\mu_0/4\pi)\ [2\pi I/R + 2I/R]$
  Direction:- Normal to the plane of paper upwards.

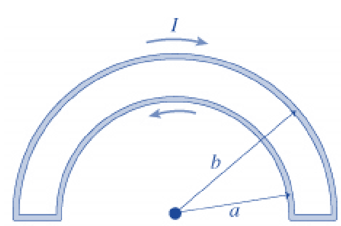
- **Field due to straight wire and loop at the center *O* of the loop(If the current in the loop in clockwise direction)**:- $B = (\mu_0/4\pi)\ [2\pi I/R - 2I/R]$
  Direction:- Normal to the plane of paper downwards



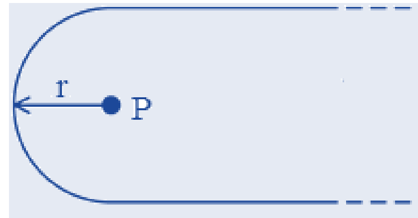


- **Field due to two semicircular arc of wire:-**
  ?B = $\mu_0 I/4\ [1/a - 1/b]$
  B = $\mu_0 I/4\ [1/R + 1/r]$
  Direction:- Normal to the plane of paper downward.

- **Field due to two concentric circular arcs at *O*:-**
  $B = (\mu_0/4\pi)\ I\vartheta\ [1/r_1 - 1/r_2]$
  Here r_1 is the radius of inner circle and r_2 is the radius of outer circle.
  Direction:- Normal to the plane of paper upwards

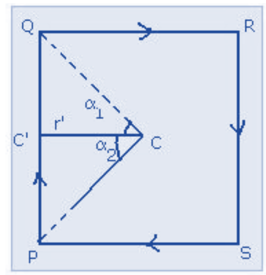


- **Field due to semicircular arc and straight conductor at point *P*:-**
  B = $(\mu_0 I/4\pi r)$ [π+2]
  Direction:- Normal to the plane upward.



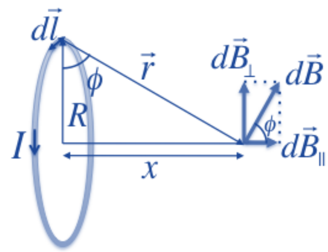
- **Field due to semicircular arc and straight conductor at point *O*:- *B* = $(\mu_0 I/4\pi r)$ [π+1]**

  Direction: Normal to the plane upward.



- **Field due to square loop having length of side *a* at center *C*:-**
  B = $2\sqrt{2}(\mu_0 I/\pi a)$
  Direction:- Normal to the plane of paper downwards.

- **Magnetic field at any point on the axis of a circular coil carrying current *I*:-**
  B = $(\mu_0/2)\ [NIa^2/(a^2 + x^2)^{3/2}]$
  (a) Magnetic field at the center of the coil:-
  $B = (\mu_0/2)\ [NI/a]$
  (b) Magnetic field at a point situated large distance away on the axis:-
  $B = (\mu_0/2\pi)\ [NIA/x^3]$
  (c) Current loop as a magnetic dipole:- $B = (\mu_0/4\pi)\ [2M/x^3]$
  Here, *M* (=*IA*) is the magnetic moment of the magnetic dipole.



- **Magnetic field at any point on the axis of a solenoid carrying current:-**
  B = $(\mu_0 NI/2l)$ [cos?$_1$-cos ?$_2$]
  For an infinitely long solenoid, ?$_1$ = 0 and ?$_2$ = π. So, $B=\mu_0 NI$
  At one end, $B = \mu_0 NI/2$

- **Field due to a current in cylindrical rod:-**
  ? (a) Outside:- $B = \mu_0 I/2\pi R$
  (b) Surface:- $B = \mu_0 I/2\pi R$
  (c) Inside:- $B = \mu_0 IR/2\pi R^2$

- **Field due to a toroid:-**
  (a) Inside:- $B = \mu_0 NI - \mu_0 NI/2\pi R$
  (b) Outside:- $B = 0$

- **Force on electric current:-** $\vec{F} = \vec{H} \times \vec{B}$

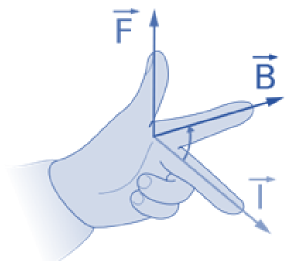
- **Force on a moving charge in a magnetic field:-**
  $$\vec{F} = q\left(\vec{v} \times \vec{B}\right)$$
  $$= qvB\sin\theta\,\hat{n}$$

- **Lorentz Force:-**
  $$\vec{F} = q\left[\vec{E} + \left(\vec{v} \times \vec{B}\right)\right]$$

- **Motion of a charged particle at right angles to a magnetic field:-**
  Radius, r = mv/Qb

- **Force on a conductor carrying current and placed in a magnetic field:-**
  $$\vec{F} = I\left(\vec{l} \times \vec{B}\right)$$
  $$= IlB \sin\theta \, \hat{n}$$

- **Fleming's left hand rule:-**



- **Force between two parallel conductors carrying currents:-**
  F = $\mu_0 I_1 I_2 / 2\pi d$

- **Torque on a current loop:-** τ **=** ***NIBA*** **cos** ϑ **=** ***NMB*** **cos** ϑ **(Since,** ***M*** **=** ***IA*****)**

- **Moving Coil Galvanometer:- I = (*C/nBA*)ϑ = *K*ϑ**
  Here *K* = *C/nBA* is known as the reduction factor of the moving coil galvanometer.

- **Sensitivity of a Galvanometer:-**
  (a) Current Sensitivity:- $S_i = C/nAH$
  Smaller the value of S_i, more sensitive is the galvanometer.
  (b) Voltage Sensitivity:- $S_v = V/G = CG/nAH$
  Smaller the value of S_v, more sensitive is the galvanometer

- **Conversion of a galvanometer into an ammeter:-**
  (a) $I_s/I_g = G/S$
  (b) $S = GI_g/I_s = GI_g/I - I_g$

- **Conversion of a galvanometer into a voltmeter:-** $R = (V/I_g) - G$

- **Ampere's current law:-**

$$\oint \vec{B}.d\vec{l} = \mu_0 I$$

Or

$$\oint \vec{H}.d\vec{l} = I$$

- **Cyclotron:-**

  (a) $T = 2\pi m/qB$

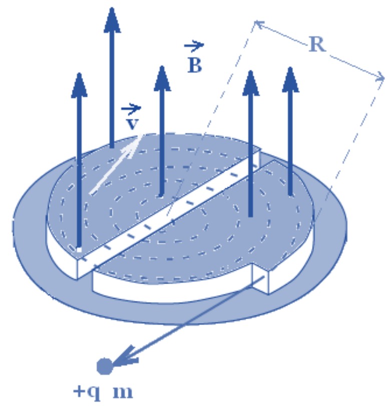
  (b) $v = qB/2\pi m$

  (c) $\omega = \vartheta B/m$

  (d) radius of particle acquiring energy E, $r = (\sqrt{2mE})/qB$

  (e) velocity of particle at radius r, $v = qBr/m$

  (f) the maximum kinetic energy (with upper limit of radius = R) $K_{max} = ½ [q^2B^2R^2/m]$



- **Magnetic field produced by a moving charge:-**

  (a) $\vec{B} = \frac{\mu_0}{4\pi}\frac{q(\vec{v}\times\vec{r})}{r^3}$

  (b) $B = \frac{\mu_0}{4\pi}\frac{qv\sin\theta}{r^2}$

Electromagnetic Induction

- **Magnetic flux:-**

  Magnetic flux lined with the surface is defined as the product of area and component of *B* perpendicular that area.

  $\phi_B = \vec{B}.\vec{A} = BAcos\theta$

  and

  $?_B = \mu nAH$

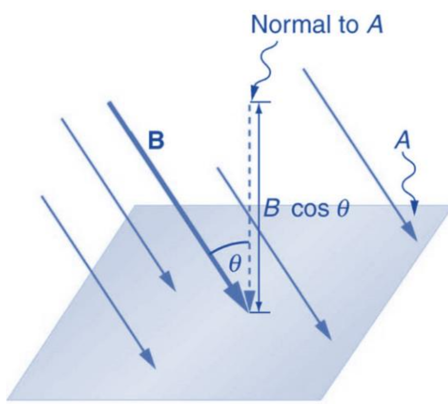
  Here, μ is the permeability of the medium, *n* is the number of turns, *A* is the area and *H* is the magnetic field intensity.

  (a) When $\vartheta = 90º$, $cos\vartheta = 0$. So, $?_B = 0$

  This signifies, no magnetic flux is linked with surface when the field is parallel to the surface.

  (b) When $\vartheta = 0º$, $cos\vartheta = 1$. So,$(?_B)_{max} = 1$

This signifies, magnetic flux linked with a surface is maximum when area is held perpendicular to the direction of field.



$\Phi = BA\cos\theta = B_{\perp}A$

- **Faraday's law of electromagnetic induction:-**

  (a) Whenever magnetic flux linked with a circuit changes, an *e.m.f* is induced in it.

  (b) The induced *e.m.f* exists in the circuit so long as the change in magntic flux linked with it continues.

  (c) The induced *e.m.f* is directly proportional to the negative rate of change of magnetic flux linked with the circuit.

  So, $E = -d?_B/dt$

  Negative sign is due to the direction of induced *e.m.f*.

- **Induced electric field:-**

$$e.m.f = \int \vec{E} d\vec{l}$$

- **Lenz's Law:-**

?It states that direction of induced *e.m.f.* is such that it tends to oppose the very csause which produces it.

The induced *e.m.f.* always tends to oppose the cause of its production.

- **Motion of a straight conductor in a uniform magnetic field:-**

(a) W = Bevl

(b) Motional *e.m.f*, $E = Bvl$

(c) Induced current, $I = E/R = Blv/R$

(d) $F = IlB = B^2l^2v/R$

(e) $P = Fv = IlBv = B^2l^2v^2/R$

(f) $H = I^2R = B^2l^2v^2/R$

- **Motion of a loop in a magnetic field when whole of the coil is in the magnetic field:**

(a) Motional *e.m.f* , $E = 0$

(b) Resultant Current, $I = 0$

(c) Force, $F = 0$

(d) Power, $P = 0$

- **Motion of a loop in a magnetic field when a part of the loop is out of the magnetic field:-**

(a) $?_B = Blx$

(b) Induced *e.m.f* , $E = Blv$

- **Power:-**

$P = I^2R = E^2/R$

$P = B^2l^2v^2/R$ (Since, $E = Blv$)

(a) Coil out of field:- $?_B = 0$, $E = 0$, $P = 0$

(b) Coil entering the magnetic field:-

$?_B$ increases gradually

E = a negative constant

P = a positive constant

(c) Coil moving in the magnetic field:-

$?_B$ = Constant

$E = 0$

P = 0

(d) Coil leaving the magnetic field:-

$?_B$ decreases gradually

E = a positive constant

P = a positive constant

(e) Coil out of magnetic field:-

$?_B$?= 0

$E = 0$

P = 0

- **Self-Induction:-** Self Induction of a circuit is defined as the property of the circuit by virtue of which it tends to oppose a change in the strength of current, through it, by inducing an e.m.f. in itself.

(a) Magnetic flux, $?_B = LI$

Here L is the coefficient of self -induction.

(b) *e.m.f.*, $E = -L\ [dI/dt]$

(c) $L = \mu_0\ \mu_r nNA$

Here, n is the number of turns per unit length

- **Series and parallel combination:-**

(a) $L = L_1 + L_2$ (If inductors are kept far apart and joined in series)

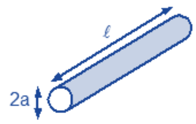
(b) $L = L_1 + L_2 \pm 2M$ (If inductors are connected in series and they have mutual inductance M)

(c) $1/L = 1/L_1 + 1/L_2$ (If two conductors are connected in parallel and are kept for apart)

(d) $M = K\sqrt{L_1 L_2}$ (If two coils of self-inductances, L_1 and L_2 are over each other)

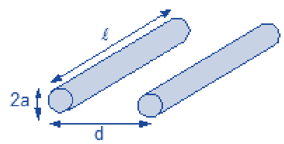
- **Inductance of wire:-**

  $L = \mu_0 l/8\pi$



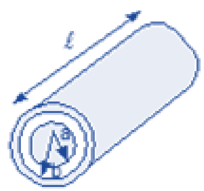
- ?**Inductance of hollow cylinder:-**

  $L = \mu_0 l/2\pi\ [\ln 2l/a - 1],\ l >> a$



- **Inductance of parallel wires:-**

  $L = \mu_0 l/\pi\ [\ln d/a - 1],\ l >> d,\ d >> a$



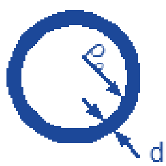
- **Inductance of Coaxial conductor:-**

  $L = \mu_0 l/\pi\ [\ \ln b/a]$

- **Inductance of Circular loop:-**

  ?$L = \mu_0 l/2\pi\ [\ln 4l/d - 2.45]$

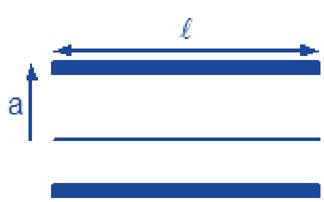
  $l = -2\pi\rho_0,\ \rho_0 >> d$



- **Inductance of Solenoid:-**

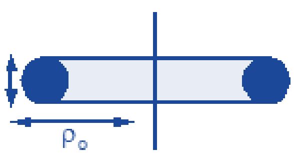
  $L = \mu_0 N^2 S/l$

  $L >> a$



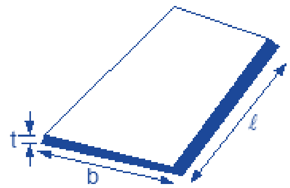
- **Inductance of Torus (of circular cross section):-**

  $L = \mu_0 N^2\ [\rho_0 - \sqrt{\rho_0^2 - a^2}]$



- **Inductance of Sheet:-**

  L = $\mu_0 2l$ [ln ($2l/b+t$) + 0.5]



- **Energy stored in an conductor:-**

  (a) W = ½ LI^2

  Here L is the coefficient of self -induction.

  (b) $U_B = B^2/2\mu_0$

- **Mutual Induction:-**

  Mutual induction of two circuits is the phenomenon where a current changing in the first coil results in the induction of an *e.m.f.* in the second.

- **Coefficient of Mutual Induction:-**

  $?_B = MI$ and $E = -M[dI/dt]$

  Here M is called the coefficient of mutual induction of two circuits.

  The value of M, $M = \mu_0 \mu_r n_1 N_2 A$

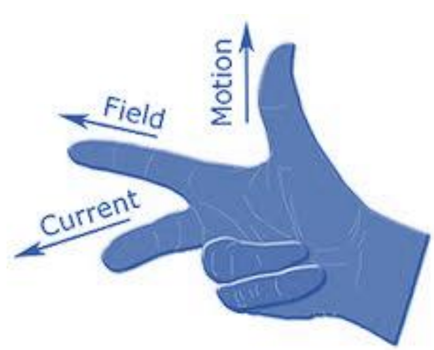
  M depends upon,

  (a) Area of cross-section of the two coils

  (b) Number of turn of each coil

  (c) Distance between the two coils

  (d) Nature of material used as core



- **Fleming's right hand rule:-**

  Stretch first finger, central finger and the thumb of your right hand in three mutually perpendicular directions. If the first finger points towards the magnetic field, thumb points towards the direction of motion of conductor, the direction of central finger gives the direction of induced current set up in the conductor.

- **Coil rotating in a uniform magnetic field:-**

  (a) Magnetic flux, $?_B = \mu naH$ [cos ωt]

  (b) Electromagnetic Induction, $E = \mu na\omega H$ [sin ωt]

  (c) Current, $I = [\mu na\omega H[\sin \omega t]]/R$

- **Growth and decay of current in LR circuit:-**

  (a) $I = I_0(1\text{-}e^{-t/\tau})$ (for growth), Here $\tau = L/R$

  (b) $I = I_0e^{-t/\tau}$ (for decay), Here $\tau = L/R$

Alternating Current

Alternating Current:

An alternating current (a.c.) is a current which continuously, changes in magnitude and periodically reverse in direction'.

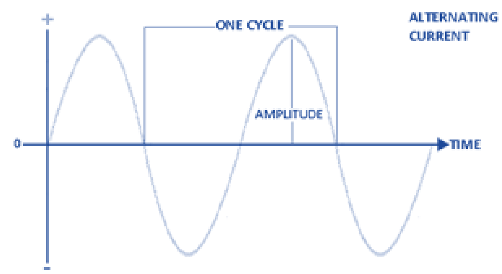
$i = I_0 \sin \omega t = I_0 \sin (2\pi/T)\, t$

Here I_0 is the peak value of *a.c*.

(a) Current, $I = I_0 \sin \omega t$

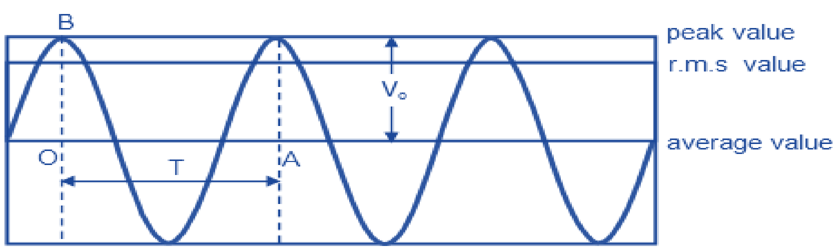
(b) Angular frequency, $\omega = 2\pi n$ (n is the frequency of a.c.)

(c) $I = I_0 \sin 2\pi n t$



- **Mean value of A.C or D.C. value of A.C.:-**

  Mean value of *a.c*. is that value of steady current which sends the same amount of charge, through a circuit, in same time as is done by *a.c*. in one half-cycle.



  $(I_{av})_{\text{half cycle}} = (2/\pi) I_0$

  Thus, mean value of alternating current is 2/π times (0.637 times) its peak value.

  $(V_{av})_{\text{half cycle}} = (2/\pi)\, V_0$

- **Average value of A.C. over a complete cycle:-**

  $I_{av} = 0$

  The average value of *a.c.* taken over the complete cycle of *a.c.*is zero.

- **Root mean square value of a.c. or virtual value of a.c.:-**

  Root mean square value of alternating current is defined as that value of steady current which produces same heating effect, in a resistance, in a certain time as is produced by the alternating current in same resistance in same time. The *r.m.s* value of *a.c.*is also called its virtual value.

  $I_{rms} = I_0/\sqrt{2}$

Root mean square value of alternating current is $I/\sqrt{2}$ times (or 0.707 times) the peak value of current.

Similarly, $V_{rms} = V_0/\sqrt{2}$

Here V_0 is the peak value of *e.m.f.*

- **Form Factor:-**

Form Factor = rms value/average value = $(V_0/\sqrt{2})/(2\ V_0/\pi) = \pi/2\sqrt{2}$

- **Current elements:-**

(a) Inductive reactance:- $X_L = \omega L$

Here, $\omega = 2\pi n$, n being frequency of *a.c.*
L is the coefficient of self-inductance of coil.

(b) Capacitative reactance:- $X_c = 1/\omega C$

Here *C* is the capacity of the condenser

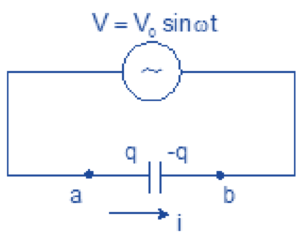
- **Capacitor in AC circuit:-**

$q = CV_0 \sin\omega t$

$I = I_0 \sin(\omega t + \pi/2)$

$V_0 = I_0/\omega C$

$X_c = 1/\omega C$



- **Inductor in AC circuit:-**

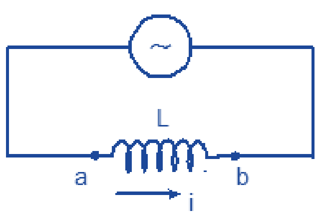
$V_L = L(dI/dt) = LI_0\omega \cos\omega t$

$I = (V_0/\ \omega L) \sin\omega t$

Here, $I_0 = V_0/\ \omega L$

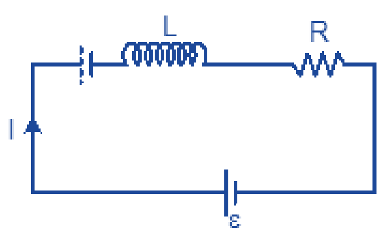
$X_L = \omega L$

And the maximum current, $I_0 = V_0/XL$

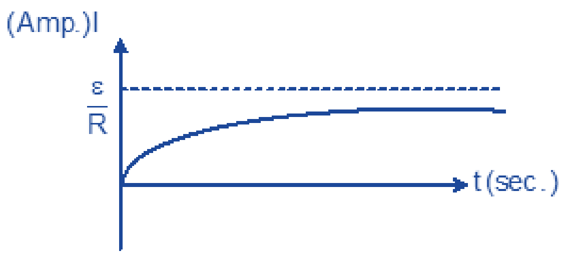


- **R-L circuit:-**

?$I = \varepsilon/R\ [1-e^{-Rt/L}]$
$V = \varepsilon\ e^{-Rt/L}$



- **Graph between I (amp) and t (sec):-**



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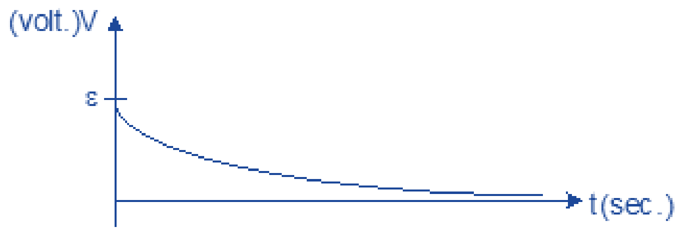
- **Graph between potential difference across inductor and time:-**



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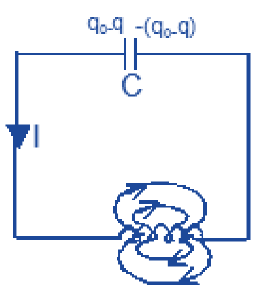
- **L-C Circuit:-**

?f = 1/2π√*LC*

q = q_0 sin (*ωt+?*)

I = q_0*ω*sin (*ωt+?*)

ω = 1/√*LC*



- **The total energy of the system remains conserved,**

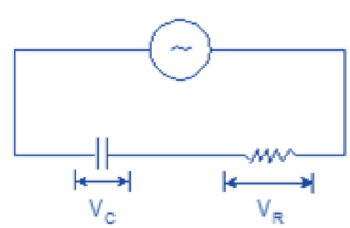
½ CV^2 + ½ Li^2 = constant = ½ CV_0^2 = ½ Li_0^2

- **Series in C-R circuit:-**

V = IZ

The modulus of impedance, |*Z* |= √R^2+(1/*ωC*)^2

The potential difference lags the current by an angle, *?* = $\tan^{-1}$(1/*ωCR*)

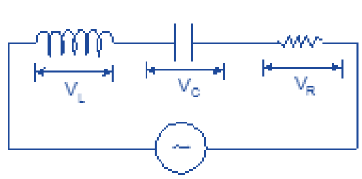


- **Series in L-C-R Circuit:**

V = IZ

The modulus of impedance, |*Z* |= √[R^2+(*ωL*-1/*ωC*)^2]

The potential difference lags the current by an angle, *?* = $\tan^{-1}$[*ωL* -1/*ωC*)/*R*]



- **Circuit elements with A.C:-**

Circuit elements	Amplitude relation	Circuit quantity	Phase of V
Resistor	$V_0 = i_0R$	R	In phase with i
Capacitor	$V_0 = i_0X_C$	C	Lags i by 90°
Inductor	$V_0 = i_0X_L$	$X_L = wL$	Leads i by 90°

- **Resonance:-**

(a) Resonance frequency:- $f_r = 1/2\pi\sqrt{LC}$

(b) At resonance, $X_L = X_C$, ? = 0, Z = R(minimum), cos? = 1, sin? = 0 and current is maximum (=E_0/R)

- **Half power frequencies:-**

(a) Lower, $f_1 = f_r - R/4\pi L$ or $\omega_1 = \omega_r - R/2L$

(b) Upper, $f_2 = f_r + R/4\pi L$ or $\omega_2 = \omega_r + R/2L$

- **Band width:-** $\Delta f = R/2\pi L$ or $\Delta f = R/L$
- **Quality Factor:-**

(a) $Q = \omega_r/\Delta\omega = \omega_r L/R$

(b) As $\omega = 1/\sqrt{LC}$, So $Q \propto \sqrt{L}$, $Q \propto 1/R$ and $Q \propto 1/\sqrt{C}$

(c) $Q = 1/\omega_r CR$

(d) $Q = X_L/R$ or $Q = X_C/R$

(e) $Q = f_r/\Delta f$

- **At resonance, peak voltages are:-**

(a) $(V_L)_{res} = e_0 Q$

(b) $(V_C)_{res} = e_0 Q$

(c) $(V_R)_{res} = e_0$

- **Conductance, susceptance and admittance:-**

(a) Conductance, $G = 1/R$

(b) Susceptance, $S = 1/X$

(c) $S_L = 1/X_L$ and $S_C = 1/X_C = \omega C$

(d) Admittance, $Y = 1/Z$

(e) Impedance add in series while add in parallel

- **Power in AC circuits:-**

  Circuit containing pure resistance:- $P_{av} = (E_0/\surd 2)\times(I_0/\surd 2) = E_v \times I_v$

  Here E_v and I_v are the virtual values of *e.m.f* and the current respectively.

  Circuit containing impedance (a combination of *R*,*L* and *C*):-

  $P_{av} = (E_0/\surd 2)\times(I_0/\surd 2)\cos ? = (E_v \times I_v)\cos ?$

  Here cos*?* is the power factor.

  (a) Circuit containing pure resistance, $P_{av} = E_v I_v$

  (b) Circuit containing pure inductance, $P_{av} = 0$

  (c) Circuit containing pure capacitance, $P_{av} = 0$

  (d) Circuit containing resistance and inductance,

  $Z = \surd R^2 + (\omega L)$

  $\cos ? == R/Z = R/[\surd\{R^2 + (\omega L)^2\}]$

  (e) Circuit containing resistance and capacitance:-

  $Z = \surd R^2 + (1/\omega C)^2$

  $\cos ? == R/Z = R/[\surd\{R^2 + (1/\omega C)^2\}]$

  (f) Power factor, cos*?* = Real power/Virtual power = $P_{av}/E_{rms}I_{rms}$

- **Transformer:-**

  (a) $C_p = N_p\ (d?/dt)$ and $e_s = N_s\ (d?/dt)$

  (b) $e_p/e_s = N_p/N_s$

  (c) As, $e_p I_p = e_s I_s$, Thus, $I_s/I_p = e_p/e_s = N_p/N_s$

  (d) Step down:- $e_s < e_p$, $N_s < N_p$ and $I_s > I_p$

  (e) Step up:- $e_s > e_p$, $N_s > N_p$ and $I_s < I_p$

  (f) Efficiency, $\eta = e_s I_s / e_p I_p$

- **AC Generator:-**

  $e = e_0 \sin(2\pi f t)$

  Here, $e_0 = NBA\omega$

Physics of Atom& Nuclei

e/m of an electron (Thomson Method):-

(a) e/m of a particle is called the specific charge of the particle.

$e/m = v/rB$

Here, r is the radius of curvature, B is the strength of magnetic field, v is the velocity, e is the charge on cathode ray particle and m is the mass.

(b) $v = E/B$

- **Electric field:-** $E = V/d$
- **Photo electric effect:-** Photo-electric effect is the phenomenon of emission of electrons from the surfaces of certain substances, mainly metals, when light of shorter wavelength is incident upon them.
- **Effect of collector's potential on photoelectric current:-**

(a) Presence of current for zero value potential indicates that the electrons are ejected from the surface of emitter with some energy.

(b) A gradual change in the number of electrons reaching the collector due to change in its potential indicates that the electrons are ejected with a variety of velocities.

(c) Current is reduced to zero for some negative potential of collector indicating that there is some upper limit to the energy of electrons emitted.

(d) Current depends upon the intensity of incident light.

(e) Stopping potential is independent of the intensity of light.

- **Effect of intensity of light:-** The photoelectric currentis directly proportional to the intensity of incident radiation.
- **Effect of frequency of light:-**

(a) Stopping potential depends upon the frequency of light. Greater the frequency of light greater is the stopping potential.

(b) Saturation current is independent of frequency.

(c) Threshold frequency is the minimum frequency, that capable of producing photoelectric effect.

- **Laws of Photo electricity:-**

(a) Photoelectric effect is an instantaneous process.

(b) Photoelectric current is directly proportional to the intensity of incident light and is independent of its frequency.

(c) The stopping potential and hence the maximum velocity of the electrons depends upon the frequency of incident light and is independent of its frequency.

(d) The emission of electrons stops below a certain minimum frequency known as threshold frequency.

- **Energy contained in bundle or packet:-**
  $E = hf = hc/\lambda$
  Here h is the Planck's constant and f is the frequency.
- **Work function:-** It is defined as the minimum energy required to pull an electron out from the surface of metal. It is denoted by W_0.
- **Einstein's equation of photoelectric effect:-**
  (a) $\frac{1}{2} mv_{max}^2 = hf - W_0$
  (b) $\frac{1}{2} mv_{max}^2 = hf - hf_0 = h(f - f_0) = h\, [c/\lambda - c/\lambda_0]$
  (c) $eV_0 = hf - W_0$
  (d) $V_0 = [(h/e)f] - [W_0/e]$
  Here f_0 is threshold frequency.
- **Threshold frequency (f_0):-** f_0 = work function/h = W/h
- **Maximum kinetic energy of emitted photo electrons:-** $?K_{max} = \frac{1}{2} mv_{max}^2 = eV_0$
- **Threshold wavelength:-** $\lambda_0 = c/f_0 = hc/hf_0 = hc/W$
- **Slope of V_0 ˜ v graph:-** Slope= h/e
- **Rest mass of photon = 0, Charge = 0**
- **Energy of photon:-** $E = hf = hc/\lambda$
- **Momentum of photon:**- $p = E/c = h/\lambda = hf/c$
- **Mass od photon:**- $m = E/c^2 = h/c\lambda = hf/c^2$
- **For electron,** $\lambda_e = [12.27/\sqrt{V}]$Å
- **For proton,** $\lambda_p = [0.286/\sqrt{V}]$Å
- **For alpha particle,** $\lambda_\alpha = [0.286/\sqrt{V}]$Å
- **For particle at temperature** T, $\lambda = h/\sqrt{3mKT}$ $(E = 3/2\ KT)$
- **The wavelength of electron accelerated by potential difference of V volts is:-** $\lambda_e = [12.27/\sqrt{V}]$Å
- **Number of photons:-**
  (a) Number of photons per sec per m^2, n_p = Intensity/hf
  (b) Number of photons incident per second, n_p = Power/hf
  (c) Number of electrons emitted per second = (efficiency per surface)× (number of photons incident per second)
- **Compton wave length:-**
  (a) $\lambda_c = h/m_0c$
  Here h is the Planck's constant, m_0 is the rest mass of electron and c is the speed of light.
  (b) Change in wavelength:- $\lambda' - \lambda = \lambda_c (1-\cos?)$
- **de Broglie wavelength (λ):-**$\lambda = h/mv = h/\sqrt{(2mE)} = h/\sqrt{(2meV)}$
- **In accordance to Bohr's postulate of atomic structure, the angular momentum of an electron is an integral multiple of h/2π.**
  So, $mvr = nh/2\pi$
- **Bragg's diffraction law:-** $2d\sin\theta = n\lambda$
  Here λ is the wavelength of electron and d is distance between the planes.

- **Rutherford's atomic model (α-particle scattering):-**

  (a) $N(\theta) \propto \text{cosec}^4(\theta/2)$

  (b) Impact parameter, $b = [(Ze^2)(\cot \theta/2)]/[(4\pi\varepsilon_0)E]$
  Here, $E = \frac{1}{2} mv^2$ = KE of theα particle.

  (c) Distance of closest approach, $r_0 = 2Ze^2/(4\pi\varepsilon_0)E$
  Here $E = \frac{1}{2} mv^2$ = KE of the α particle.

- **Bohr's atomic model:-**

  (a) The central part of the atom called nucleus, contains whole of positive charge and almost whole of the mass of atom. Electrons revolve round the nucleus in fixed circular orbits.

  (b) Electrons are capable of revolving only in certain fixed orbits, called stationary orbits or permitted orbits. In such orbits they do not radiate any energy.

  (c) While revolving permitted orbit an electron possesses angular momentum L (= mvr) which is an integral multiple of $h/2\pi$.
  $L = mvr = n(h/2\pi)$
  Here n is an integer and h is the Planck's constant.

  (d) Electrons are capable of changing the orbits. On absorbing energy they move to a higher orbit while emission of energy takes place when electrons move to a lower orbit. If f is the frequency of radiant energy,
  $hf = W_2 - W_1$
  Here W_2 is the energy of electron in lower orbit and W_1 is the energy of electron in higher orbit.

  (e) All the laws of mechanics can be applied to electron revolving in a stable orbit while they are not applicable to an electron in transition.

- **Bohr's Theory of Atom:-**

  (a) Orbital velocity of electron:- $v_n = 2\pi kZe^2/nh$

  For a particular orbit (n= constant), orbital velocity of electron varies directly as the atomic number of the substance.
  $v_n \propto Z$

  (b) For a particular element (Z= constant), orbital velocity of the electron varies inversely as the order of the orbit.
  $v_n \propto 1/n$

  (c) $v = nh/2\pi mr$

- **Relation between v_n and v_1:-**$v_n = v_1/n$
- **Radius of electron:-**

  ?$r = n^2h^2/4\pi^2kmZe^2$

  So, $r \propto n^2$
  For, C.G.S system (k = 1), $r = n^2h^2/4\pi^2mZe^2$
  S.I ($k = 1/4\pi\varepsilon_0$), $r = (\varepsilon_0/\pi)(n^2h^2/mZe^2)$

- **Kinetic energy of the electron:-** It is the energy possessed by the electron by virtue of its motion in the orbit.

  $K.E = ½ mv^2 = ½ k (Ze^2/r)$

- **Potential energy:-** It is the energypossessed by the electronby virtue of its position near the nucleus.

  $P.E = -k (Ze^2/r)$

- **Total energy:-**

  $W= K.E + P.E$

  $W=- ½ k (Ze^2/r) = -k^2 2\pi^2Z^2me^4/n^2h^2$
  For, C.G.S (k = 1), $W = - [2\pi^2Z^2me^4/n^2h^2]$
  For, S.I. ($k = 1/4\pi\varepsilon_0$), $W = - (1/8\varepsilon_0^2) [Z^2me^4/n^2h^2]$
  Since, $W \propto 1/n^2$, a higher orbit electron possesses a lesser negative energy (greater energy) than that of a lower orbit electron.

- **Frequency, wavelength and wave number of radiation:-**

  Frequency, $f = k^2[2\pi^2Z^2me^4/h^3] [1/n_1^2 – 1/n_2^2]$

  Wave number of radiation,

  $$\overline{f} = \frac{1}{\lambda} = R\left[\frac{1}{n_1^2 - n_2^2}\right]$$

  Here R is the Rydberg's constant and its value is,
  $R= k^2 [2\pi^2Z^2me^4/ch^3]$

- **Bohr's theory of hydrogen atom (Z=1):-**

  (a) Radius of orbit:-

  $r= n^2h^4/4\pi^2me^2$ (C.G.S)
  $r= (\varepsilon_0/\pi) (n^2h^2/me^2)$ (S.I)

  (b) Energy of electron:-
  $W= 2\pi^2me^4/n^2h^2$ (C.G.S)
  $W =(1/8\varepsilon_0)[me^4/n^2h^2]$

  (c) Frequency, wavelength and wave number of radiation:-

  C.G.S:- k =1 and Z=1

  Frequency= $f=2\pi^2me^4/h^3 [1/n_1^2 – 1/n_2^2]$
  Wave number = $1/\lambda = 2\pi^2me^4/ch^3 [1/n_1^2 – 1/n_2^2]$

  S.I:- $k =1/4\pi\varepsilon_0$ and Z=1

  Frequency= $f = (1/8\varepsilon_0) (me^4/h^3)[1/n_1^2 – 1/n_2^2]$
  Wave number = $1/\lambda = (1/8\varepsilon_0^2) (me^4/ch^3)[1/n_1^2 – 1/n_2^2]$

- **Rydberg's constant:-**

  $R=k^2 =2\pi^2z^2 me^4/ch^3$

- **Nuclear Physics:-** Branch of physics dealing with the study of nucleus is called nuclear Physics.
- **Constituents of nucleus (Nucleons) :-**

(a) Protons:-

Mass of proton, $m_p = 1.6726\times10^{-27}$ kg
Charge of proton = 1.602×10^{-19} C

(b) Neutron:-
Mass of neutron, $m_n = 1.6749\times10^{-27}$ kg

(c) 1 atomic mass unit (1 amu) = 1.66×10^{-27} kg

(d) 1 amu = 1 u = 931.5 MeV

- **Properties of nucleus:-**

(a) Charge on nucleus = 1.602×10^{-19} Z coulomb

(b) Size of nucleus:-
The radius r of the nucleus depends upon the atomic mass A of the element.
$r = R_0A^{1/3}$
Here $R_0 = 1.2\times10^{-13}$ cm (1 Fermi $=10^{-13}$ cm)
Volume of the nucleus:-
$V = 4/3\ \pi r^3 = 4/3\ \pi\ (R_0A^{1/3})^3$

(c) Density of nucleus:-
Density of nucleus = mass/volume = $A/(4/3\ \pi R_0^3A) = [3/(4\pi R_0^3)]$

- **Isotopes:-** Nuclei having same atomic number Z but different mass number A are called isotopes.
- **Isobars:-** Nuclei having same mass number A but different atomic number Z are called isobars.
- **Isotones:- Nuclei having the same number of neutrons (N) but different atomic number (Z) are called isotones.**
- **Nature of nuclear force:-**

(a) Nuclear forces are attractive in nature.

(b) Nuclear forces are charge independent.

(c) These are short range forces.

(d) Nuclear forces decrease very quickly with distance between two nucleons.

(e) Nuclear forces are spin dependent.

- **Mas defect:-** If the mass of the nucleus H_Z^A is M, then the mass defect,

$\Delta M = [Zm_p + (A-Z)m_n - M]$?

Here, m_p and m_n are the masses of the proton and neutron respectively.

- **Binding Energy:-**

Binding Energy = $(\Delta M)\ c^2 = [Zm_p + (A-Z)m_n - M]\ c^2$

If we use atomic mass instead of nuclear masses, then,
Binding Energy, $B = [Zm_H + (A-Z)m_n - M_{at}]\ c^2$
Here M_{at} is the mass of the atom and m_H is the mass of the hydrogen atom.

- **Binding energy per nucleon:-**

  $B/A = [Zm_p + (A-Z)m_n - M]\, c^2 / A$

  If we use atomic mass instead of nuclear masses, then,

  $B/A = [Zm_H + (A-Z)m_n - M_{at}]\, c^2/A$

- **Radioactivity:-** The phenomenon by virtue of which substance, spontaneously, disintegrate by emitting certain radiations is called radioactivity**.**
- **Radioactive radiations:-**

  ?

  (a) α – rays:- X_Z^A (mother nucleus) $\rightarrow Y_{Z-2}^{A-4}$ (daughter nucleus) $+ He_2^4$ (α – particle)

  (b) β – rays:- X_Z^A (mother nucleus) $\rightarrow Y_{Z+1}^{A}$ (daughter nucleus) $+ e_{-1}^0$ (radiation)

  (c) γ – rays :- X_Z^{*A} (mother nucleus) $\rightarrow Y_Z^A$ (daughter nucleus) $+ hf$ (γ – ray)

- **Alpha decay:-** It is the process in which a parent nucleus decays into the daughter nucleus by ejecting an alpha particle.

  ? $P_Z^A \rightarrow D_{Z-2}^{A-4} + He_2^4 + Q_\alpha$

- **Beta decay:-** It is the process in which a parent nucleus decays into the daughter nucleus by ejecting an electron.

  $P_Z^A \rightarrow D_{Z-1}^{A} + e_{-1}^0 + \bar{\nu} + Q_\beta$

  ? Here $\bar{\nu}$ is the anti-neutron and Q_β is the beta disintegration energy.

- **Gama decay:-** Sometimes the daughter nucleus is left in the excited state. It decays in to any other lower state or ground state by emitting γ-rays.

  ? $X_{Z^*}^A \rightarrow X_Z^A + hf$

- **Laws of radioactivity:-**

  (a) Radioactivity is due to the disintegration of a nucleus.

  (b) Rate of disintegration is not affected by the external conditions like temperature and pressure etc.

  (c) Law of conservation of charge holds good in radioactivity.

  (d) The disintegration is accompanied by the emission of energy in terms of α, β and γ-rays either single or all at a time.

  Emission of α- particle results in a decrease in its atomic number by 2 and a decrease in its atomic weight by 4.

Emission of β- particle results in an increase in its atomic number by 1 while its atomic weight remains unaffected.

Emission of γ- rays results neither in a change of atomic number nor in a change of atomic weight.

(e) Each of the product disintegration is a new element having physical and chemical properties different from those of the parent atom.

(f) Rate of disintegration of the radioactive substance, at any instant, is directly proportional to the number of atoms present at that instant.

$N = N_0e^{-\lambda t}$

If, $t = 1/\lambda$, then, $N = N_0/e$

Therefore, radioactive decay constant is defined as the reciprocal of time in which the number of atoms of radioactive sample is reduced to N_0/e.

- **Half-life ($T_{1/2}$):-** Half-life of a radioactive substance is defined as the time during which the number of atoms of the substance are reduced to half their original value.

  $T_{1/2} = 0.693/\lambda$

  Thus, half-life of a radioactive substance is inversely proportional to its radioactive decay constant.

- **Average life (T_{av}):-** Arithmetic mean of the lives of all the atoms is known as mean life or average life of the radioactive substance.

  T_{av} = sum of lives of all atoms / total number of atoms

  Average life of a radioactive substance is equal to the reciprocal of its radioactive decay constant.

- **Relation between $T_{1/2}$ and T_{av}:-**

  $T_{1/2} = 0.693\times T_{av}$

  Half-life = 0.693×average life

- **Units of radioactivity:-**

  (a) Curie (Ci):- Radioactivity of a substance is said to be one curie if its atoms disintegrate at the rate of 3.7×10^{10} disintegrations per second.

  (b) Rutherford (rd):- Radioactivity of a substance is said to be 1 Rutherford if its atoms disintegrate at the rate of 10^6 disintegrations per second.

- **Relation between Curie and Rutherford:-**

  $1\ C = 3.7\times10^4$ rd

- **Nuclear fission:-** Nuclear fission is the process by which a nucleus breaks up in such a way that the two products obtained are of comparable sizes.

  Fission of U_{92}^{235} by fast moving neutrons is represented as,

  $$n_0^1 + U_{92}^{235} \rightarrow Ba_{56}^{141} + Kr_{36}^{92} + N_0^1 + Q$$

  Value of Q in this reaction is 200.4443 MeV.

- **Chain reaction:-**The above quoted fission reaction proceeding in an uncontrolled manner is known as chain reaction and forms the basis of atom bomb.

Semiconductors

- **Thermoionic emission:-** Thermionic emission is the phenomenon in which electrons are emitted by a metal contains free electrons which behave like the molecules of a perfect gas.
- **Richardson Equation:-**

  $I = AT^{1/2}e^{-b/T}$

  Here I is the thermionic current density in amp per sq meter. T is the temperature on kelvin scale, A and b being constants.

  A = ne√k/2πm, b = e?/k

  Here, n is the number of electrons per unit volume, e is the charge on electron, m is the mass of electron, k is the Boltzmann's constant and ? is the potential barrier of the metal.
- **There are three types of energy bands in a solid viz.**

  (a) Valence energy band

  (b) Conduction energy band

  (c) Forbidden energy gap.
- **Energy gap or Band gap (E_g):-**

  (a) The minimum energy which is necessary for shifting electrons from valence band to conduction band is defined as band gap (E_g)

  (b) The forbidden energy gap between the valence band and the conduction band is known as band gap (E_g). i.e. $E_g = E_c - E_v$

  (c) As there are energy levels f electrons in an atom, similarly there are three specific energy bands for the electrons in the crystal formed by these atoms as shown in the figure,

  (d) Completely filled energy bands: The energy band, in which maximum possible numbers of electrons are present according to capacity is known as completely filled bank.

  (e) Partially filled energy bands: The energy band, in which number of electrons present is less than the capacity of the band, is known as partially filled energy band.

  (f) Electric conduction is possible only in those solids which have empty energy band or partially filled energy band.
- **Various types of solids:-**

  On the basis of band structure of crystals, solids are divided in three categories.

  (a) Insulators

  (b) Semi-conductors

  (c) Conductors.

- **Difference between Conductors, Semi-conductors and Insulators:-**
- **The number of electrons or cotters is given by**

$$n_i = p_i = AT^{3/2}e^{-E_g/2KT}$$

i.e. on increasing temperature, the number of current carriers increases.

- **The semiconductors are of two types.**

(a) Intrinsic or pure semiconductors

(b) Extrinsic or dopes semiconductors

- **Difference between Intrinsic and Extrinsic semiconductors:-**
- **Child's law:-**

$I_p = KV_p^{3/2}$, K is the proportionality constant.

- **Work function:-**

Work function of a metal is the amount of energy required to pull an electron from the surface of metal to a distant position.

- **Diode:**-

It is a vacuum tube containing two electrodes, an emitter and a collector.

- **Diode as a rectifier:**-

Rectification is the process of converting the alternating current into a unidirectional current.

Rectification can be done by making use of a diode. A diode affecting rectification is said to be acting

as a rectifier.

- **Diode Resistance:-**

(a) Static plate resistance:- *(i)* $R_p = V_p/I_p$ (ii) $R_p \propto (V_p)^{-1/2}$ (iii) $R_p \propto (I_p)^{-1/3}$

(b) Dynamic plate resistance:- *(i)* $r_p = (\Delta V_p/\Delta I_p)$ (ii) $r_p \propto V_p^{-1/2}$ (iii) $r_p \propto I_p^{-1/2}$

- **Half-wave rectifier:-** It is the type of rectification in which only one half of the input *a.c.* is translated into the output.
- **Full-wave rectifier:-** A rectifier in which current flows through the load for both the halves of input *a.c.* is called half-wave rectifier.
- **Triode:**- It is a vacuum tube containing three elements namely plate, filament and grid.
- **Triode constants:**-

(a) Plate resistance (r_p):- It is defined as the ratio between changes in plate potential keeping grid potential constant to the corresponding change in plate current.

$$r_p = \left(\frac{\Delta V_p}{\Delta I_p}\right)_{V_g=constant}$$

(b) Mutual Inductance (g_m):- (Trans-conductance):- It is defined as the ratio between change in plate current to the change in grid potential keeping plate potential constant required to bring about that change in current.

$$g_m = \left(\frac{\Delta I_p}{\Delta V_g}\right)_{V_p=constant}$$

(c) Amplification factor (μ):- it is defined as the ratio between change in plate potential keeping grid potential constant to the change in grid potential keeping plate potential constant, in order to bring about same change in plate current.

$$\mu = \left(\frac{\Delta V_p}{\Delta V_g}\right)_{I_p=constant}$$

(d) Relation between μ, r_p and g_m:-

$$\mu = r_p \times g_m$$

(e) $r_p \propto I_p^{-1/3}$

(f) $g_m \propto I_p^{1/3}$

- **Triode as an amplifier:-** Process of increasing the amplitude of the input signal is called amplification. A triode affecting an increase in the amplitude of a signal is said to be acting as an amplifier.
  Voltage gain:- It is the ratio between the output voltage (voltage across the load resistance R_L) to the signal voltage.
  Voltage gain = $V_0/e_g = \mu R_L/R_L+r_p = \mu/[1+(r_p/R_L)]$
  This indicates that the voltage gain depend upon the load resistance. For $R_L=\infty$, voltage gain is equal to the amplification factor.

  (a) $I_p = (\mu V_g/R_L+r_p)$

  (b) $A = \mu R_L/R_L+r_p$

  (c) $A_{max} = \mu$

  (d) $\mu = A [1+(r_p/R_L)]$

  (e) $A = \mu/2$ if $R_L = r_p$

  - **Cut off voltage:-** $V_g = -(V_p/\mu)$
  - **Plate current equation:-** $I_p = K[V_g+(V_p/\mu)]^{3/2}$

- **Triode as an oscillator:-** A triode producing high frequency oscillating waves, of constant amplitude, is said to be acting as an oscillator.
  Frequency of oscillation waves (*f*):- $f = 1/2\pi\sqrt{LC}$

  Here L is the inductance and *C* is the capacitance.

- **Majority charge carrier:-**

  (a) For *N*-type semiconductor:- electron

  (b) For *P*-type semiconductor:- hole

- **Electrical conductivity of semiconductors:-**

  Intrinsic semiconductors:-

  (a) $\sigma = e(n_e\mu_e + n_h\mu_h)$

  Here, n_e is the electron density, n_h is the hole density, μ_e is the electric mobilities and μ_h is the hole mobilities.

  (b) $\sigma = \sigma_0 e^{-E_g/2KT}$

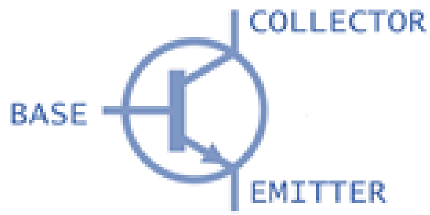
Extrinsic semiconductor:-

(a) n-type:- $\sigma = en_e\mu_e$

(b) p-type:- $\sigma = en_n\mu_n$

- **Transistor:-**

  (a) $I_E = I_C + I_B$ ($I_B << I_E$, $I_B << I_C$)

  (b) Current gains:-

  $\alpha = I_C/I_E$, $\alpha_{ac} = \Delta I_C/\Delta I_E$

  $\beta = I_C/I_B$, $\beta_{ac} = \Delta I_C/\Delta I_B$

  (c) Relation between α and β:-

  $\alpha = \beta/[1+\beta]$

  or

  $\beta = \alpha/[1-\alpha]$

Communication Technology

- **Transmitter**

  (a) It process and encode the information and make it suitable for transmission.

  (b) The message signal for communication can be analog signals or digital signals.

  (c) An analog signal can be converted suitably into a digital signal and vice-versa.

  (d) An analog signal is that in which current or voltage value varies continuously with time.

- **Communication channel**

  The medium through which information propagate from transmitter to receiver is called communication channel.

- **Receiver**

  It receives and decode the signal.

- **Analog signal**

  A signal in which current or voltage changes its magnitude continuously with time, is called an analog signal.

- **Digital signal**

  A signal in which current or voltage have only two values, is called a digital signal. An analog signal can be converted suitable into a digital signal and vice-versa.

- **Modulation**

  The process of superimposing the audio signal over a high frequency carrier wave is called modulation.

- **Need of modulation**

  ?(a) Energy carried by low frequency audio waves (20 Hz to 20000 Hz) is very small.

  (b) For efficient radiation and reception of signal, the transmitting and receiving antennas should be very high approximately 5000 m.

  (c) The frequency range of audio signal is so small that overlapping of signals create a confusion.

- **Amplitude Modulation**

  In this type of modulation in which the amplitude of a high frequency carrier wave is varied in accordance with some characteristic of the modulating signal.

  Band width required for amplitude modulation = twice the frequency of the modulating signal.

- **Frequency modulation**

  In this type of modulation, the frequency of high frequency carrier wave is varied in accordance to instantaneous frequency of modulating signal.

- **Pulse modulation**

  In this type of modulation, the continuous waveforms are sampled at regular intervals. Information is transmitted only at the sampling times.

- **Demodulation**

  The process of separating of audio signal from modulated signal is called demodulation.

- **Antenna**

  An antenna converts electrical energy into electromagnetic waves at transmitting end and pick up transmitted signal at receiving end and converts electromagnetic waves into electrical signal.

- **Modem**

  The term modem is contraction of the term modulator and demodulator. Modem is a device which can modulate as well as demodulate the signal. It connect one computer to another through ordinary telephone lines.

- **Fax (Facsimile telegraph)**

  The electronic reproduction of a document at a distant place is called FAX.

- **Radio waves**

  ??The radio waves are the electromagnetic waves of frequency ranging from 500 kHz to about 1000 MHz. These waves are used in the field of radio communication.

- **Ground wave or surface wave propagation**

  It is suitable for low and medium frequency upto 2 MHz. It is used for local broad casting.

- **Sky wave propagation**

  It is suitable for radiowaves of frequency between 2 MHz to 30 MHz. It is used for long distance radio communication.

  (a) Critical frequency

  The highest frequency of radio wave that can be reflected back by the ionosphere is called critical frequency.

  Critical frequency, $f_c = 9 (N_{max})^{1/2}$

  Here, N_{max} = number density of electrons/meter^3

  (b) Skip distance

  The minimum distance from the transmitter at which a sky wave of a frequency but not more than critical frequency, is sent back to the earth.

  Skip distance $(D_{skip}) = 2h\,(f_{max}/f_c)^2 - 1$

  Here h is height of reflecting layer of atmosphere.

  f_{max} is maximum frequency of electromagnetic waves and f_c is critical frequency.

  (c) Fading

  The variation in the strength of a signal at receiver due to interference of waves, is called fading.

- **Space wave propagation**

  It is suitable for 30 MHz to 300 Mhz. It is used in television communication and radar communication. It is also called line of sight communication.

Range is limited due to curvature of earth. If h be the height of the transmitting antenna, then signal can be received up to a maximum distance

$d = \sqrt{2Rh}$

If the height of transmitting and receiving antennas be h_T and h_R respectively. The effective range will

$d = \sqrt{2Rh_T} + \sqrt{2Rh_R}$

Microwaves are electromagnetic wave of frequency 1 to 300 GHz, greater than those of TV signals. The wavelength of microwaves is of the order of a few mm.

Microwave communication is used in radar to locate the flying objects in space.

These waves can be transmitted as beam signals in a particular direction, much better than radio wave.

There is no diffraction of microwave around corners of an obstacle which happens to lie along its passage.

- **Satellite communication**

  It is carried out between a transmitter and a receiver through a satellite. A geostationary satellite is utilized for this purpose, whose time period is 24 hours.

- **Geo-synchronous orbit**

  The orbit in which the geo-satellite above revolves around the earth is known as geo-synchronous orbit.

- **Remote sensing**

  It is a technique of observing or measuring the characteristics of the object at a distance. A polar satellite is utilized for this purpose.

  Distance upto which a signal can be obtained from an antenna is given by

  $d = \sqrt{2hR}$

  Here, h is height of antenna and R is radius of earth.

- **LED and Diode laser**

  (a) Light emitting diode (LED) and diode laser are preferred sources for optical communication.

  (b) Each produces light of suitable power required in optical communication. Diode laser provides light which is monochromatic and coherent

  (c) LED provides almost monochromatic light. This suitable for small distance transmission.

- **Line communication**

  Transmission lines are used to interconnect points separated from each other. Line communication may be in the form of electrical signal or optical signal.

- **Optical fibers**

  An optical fiber is a long thread consisting of a central core of glass or plastic of uniform refractive index.

- **Types of optical fiber**

  Single mode step index fiber

  Multi mode step index fiber

  Multi mode graded index fiber

Electromagnetic Waves

- **Electromagnetic wave**

  Electric and magnetic fields fluctuating together can form a propagating wave, appropriately called an electromagnetic wave.

- **Equation of plane progressive electromagnetic wave**

  $E = E_0 \sin \omega (t - x/c)$

  $B = B_0 \sin \omega (t - x/c)$

  Here, $\omega = 2\pi f$

- **Properties of electromagnetic wave**

  (a) These waves are transverse in nature and it does not require a medium for propagation.

  (b) These waves propagate through space with speed of light, i.e., 3×10^8 m/s.

  (c) It carries energy as it propagates. The higher the frequency, the higher the energy associated with the wave.

  (d) It can transfer its energy to the matter on which it impinges.

  (e) Its propagation obeys the inverse square law.

  (f) It can be used to carry information.

  (g) It can be reflected or refracted.

  (h) It can be split and recombined to form diffraction patterns.

  (i) It can travel great distances. The radiation resulting from a simple100 volt, 1 MHz sine wave fed into a suitable antenna can be detected as far away as the next planet.

  (j) It travels in straight lines.

  (k) It can be bent around the Earth's circumference by reflection from the ionosphere.

  (l) It can pass through walls.

  (m) It can be captured by placing a metal rod, a loop, parabolic metal dish or horn in its path and it can be launched into the atmosphere with the same tools.

  (n) The E and B fields are perpendicular to each other.

  (o) The E and B fields are in phase (both reach a maximum and minimum at the same time).

  (p) The E and B fields are perpendicular to the direction of travel (transverse waves).

- **Speed of electromagnetic wave**

  $c = 1/\sqrt{\mu_0 \varepsilon_0}$

  Here, μ_0 is permeability of free space and ε_0 is the permittivity `of free space.

  $c = E_0/B_0$

  Here E_0 and B_0 are maximum values of electric and magnetic field vector.

- **Total radiant flux (Power)**

  $P = q^2a^2/6\pi\varepsilon_0 c^2$

- **Poynting vector**

  The rate of flow of energy in an electromagnetic wave is described by the vector S called the poynting vector.

  $S = (1/\mu_0) [E \times B]$

  SI unit of S is watt/m^2

  The energy in electromagnetic waves is divided equally between electric field and magnetic field vectors.

- **Average electric energy density**

  $U_E = ½ \varepsilon_0 E^2 = ¼ \varepsilon_0 E_0^2$ S

- **Average magnetic energy density**

  $U_B = ½ (B^2/\mu_0) = ¼ (B_0^2/\mu_0)$

- **Intensity of electromagnetic Wave**

  ?It is defined as energy crossing per unit area per unit time perpendicular to the directions of propagation of electromagnetic wave.

  $I = \langle\mu\rangle c = ½ (\varepsilon_0 E_0^2 c)$

- **Displacement current**

  ?It is a current which produces in the region in which the electric field and hence the electric flux changes with time.

  Displacement current, $I_D = \varepsilon_0 (d\phi_E/dt)$

  Here, ϕ_E is the electric flux.

- **Ampere- Maxwell law**

  ?B.dl = $\mu_0 (I + I_D)$

  Where, μ_0 = Permeability = $4\pi \times 10^{-7}$ V/Am

- **Maxwell's Equations**

  (a) ?E.dS = q/ε_0

  This equation is Gauss's law in electrostatics.

  (b) ?E.dS = 0

  This equation is Gauss's law in magnetostatics.

  (c) ?E.dl = (– d/dt) ?B.dS

  This equation is Faraday's law of electromagnetic Induction.

  (d) ?B.dl = $\mu_0 [I + \varepsilon_0 (d\phi_E/dt)]$

  This equation is Ampere – Maxwell law.

- **Electromagnetic spectrum (consists of EM waves of all frequencies)**
  (a) radio waves (biggest wavelength, smallest frequency)
  (b) microwaves
  (c) infrared waves
  (d) visible light (ROY G BIV)
  (e) ultraviolet light
  (f) x-rays
  (g) gamma rays (smallest wavelength, highest frequency)

- **Speed of waves:**
  (a) $v = f\lambda$
  (b) Speed of EM waves through a material is less than in a vacuum
  (c) Index of refraction: $n = c/v$, where *v* is the speed of light in the material
  (d) When a waves passes from one material to another, the frequency remains constant but the wavelength changes:
  (e) $\lambda = \lambda_0/n$, where λ_0 is the wavelength in vacuum

- **Polarization**
  (a) for an EM wave, the direction of polarization is taken to be the direction of the electric field
  (b) when an EM wave passes through a polarizing filter, the intensity of the transmitted light decreases:

  $I = \frac{1}{2} I_0$ initially unpolarized light
  $I = I_0 \cos^2\theta$ initially polarized light
  After light passes through a filter, it is polarized in the direction of the filter.

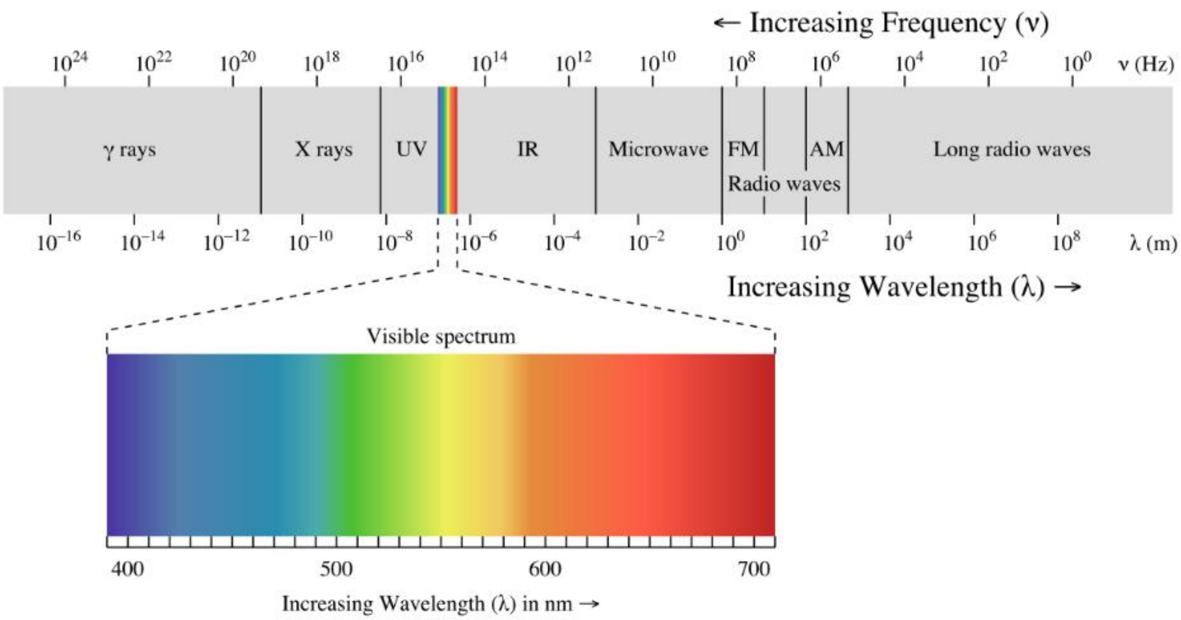
- **Right Hand Rule:**

  An electromagnetic wave propagating in the positive x direction: E and B are perpendicular to each other and in phase. The direction of propagation is given by the thumb of the right hand, after pointing the fingers in the direction of E and curling them toward B (palm towards B).

- **Propagation of Electromagnetic Spectrum**

  In radio wave communication between two places, the electromagnetic waves are radiated out by the transmitter antenna at one place which travel through the space and reach the receiving antenna at the other place.

- **Electromagnetic Spectrum**



The arranged array of electromagnetic radiations in the sequence of their wavelength or frequency is called electromagnetic spectrum.

- **Radio and microwaves** are used in radio and TV communication.
- **Infrared rays are used to**
  (a) Treat muscular strain
  (b) For taking photographs in fog or smoke
  (c) In green house to keep plants warm
  (d) In weather forecasting through infrared photography
- **Ultraviolet rays are used**
  (a) In the study of molecular structure.
  (b) In sterilizing the surgical instruments.
  (c) In the detection of forged documents, finger prints.
- **X-rays are used**
  (a) In detecting faults, cracks, flaws and holes in metal products.
  (b) In the study of crystal structure.
  (c) For the detection of pearls in oysters.
- **γ-rays** are used for the study of nuclear structure.

- **Thermosphere**
  The thermosphere is a thermal classification of the atmosphere. In the thermosphere, temperature increases with altitude. The thermosphere includes the exosphere and part of the ionosphere.

- **Exosphere**

  The exosphere is the outermost layer of the Earth's atmosphere. The exosphere goes from about 400 miles (640 km) high to about 800 miles (1,280 km). The lower boundary of the exosphere is called the critical level of escape, where atmospheric pressure is very low (the gas atoms are very widely spaced) and the temperature is very low.

- **Mesosphere**

  The mesosphere is characterized by temperatures that quickly decrease as height increases. The mesosphere extends from between 31 and 50 miles (17 to 80 kilometers) above the earth's surface.

- **Stratosphere**

  The stratosphere is characterized by a slight temperature increase with altitude and the absence of clouds. The stratosphere extends between 11 and 31 miles (17 to 50 kilometers) above the earth's surface. The earth's ozone layer is located in the stratosphere. Ozone, a form of oxygen, is crucial to our survival; this layer absorbs a lot of ultraviolet solar energy. Only the highest clouds (cirrus, cirrostratus, and cirrocumulus) are in the lower stratosphere.

- **Troposphere**

  The troposphere is the lowest region in the Earth's (or any planet's) atmosphere. On the Earth, it goes from ground (or water) level up to about 11 miles (17 kilometers) high. The weather and clouds occur in the troposphere. In the troposphere, the temperature generally decreases as altitude increases.

- **Ionosphere**

  The ionosphere starts at about 43-50 miles (70-80 km) high and continues for hundreds of miles (about 400 miles = 640 km). It contains many ions and free electrons (plasma). The ions are created when sunlight hits atoms and tears off some electrons. Auroras occur in the ionosphere.

  (a) D-layer is at a virtual height of 65 km from surface of earth and having electron density $\approx 10^9\ m^{-3}$.

  (b) E-layer is at a virtual height of 100 km, from the surface of earth, having electron density $\approx 2\times10^{11} m^{-3}$.

  (c) F_1-layer is at a virtual height of 180 km from the surface of earth, having electron density $\approx 3\times10^{11} m^{-3}$.

  (d) F_2-layer is at a vertical height of about 300 km in night time and about 250 to 400 km in day time. The electron density of this layer is $\approx 8\times10^{11} m^{-3}$.