(4) **Dispersion without deviation** $(\delta_{net} = 0)$

The condition for direct vision combination is :

$$[n_y - 1]\, A = [n'_y - 1]\, A' \Leftrightarrow$$

$$\left[\frac{n_v + n_r}{2} - 1\right] A = \left[\frac{n'_v + n'_r}{2} - 1\right] A' \qquad \text{(for 2 prism)}$$

(5) **Deviation without dispersion**

Condition for achromatic combination is:

$(n_v - n_r)\, A = (n'_v - n'_r)\, A'$

☞ **Refraction at Spherical Surfaces**

(1) $\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$

($n_1 \rightarrow$ r.i. of medium of incidence, $n_2 \rightarrow$ r.i. of medium of refraction)

(2) **Transverse magnification**

$$m = \frac{v - R}{u - R} = \left(\frac{v/n_2}{u/n_1}\right) = \frac{n_1}{n_2}\frac{v}{u}$$

☞ **Thin Lens**

For a spherical, thin lens having the same medium on both sides:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \text{ where } \frac{1}{f} = (n_{rel} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

where $n_{rel} = \frac{n_{lens}}{n_{medium}}$

☞ **Transverse magnification (m)**

$$m = \frac{v}{u}$$

☞ The equivalent focal length of thin lenses in contact is given by

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} \ldots$$

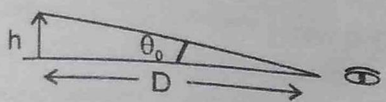
☞ The combination of lens and mirror behaves like a mirror of focal length 'f' given by

$$\frac{1}{f} = \frac{1}{F_m} - \frac{2}{F_\ell}$$

☞ Optical power of a lens P (in dioptre) = $\frac{1}{f(\text{metre})}$

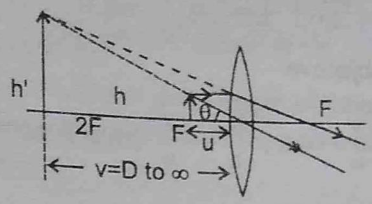
Microscope :

• Simple Mircoscope :



unadded-eye

(A)



eye with Instrument

(B)

Magnifying power is M.P

$$MP = \frac{\text{Visual angle with instrument}}{\text{Max.visual angle for unadded eye}} = \frac{\theta}{\theta_0}$$

If an object of size h is placed at a distance u (< D) from the lens and its image size h' is formed at a distance V ($\geq$D) from the eye

$$\theta = \frac{h'}{v} = \frac{h}{u} \qquad \text{with } \theta_0 = \frac{h}{D}$$

So magnifying power $MP = \frac{\theta}{\theta_0} = \frac{h}{u} \times \frac{D}{h} = \frac{D}{u}$ ...... (1)

Now there are two possibilities

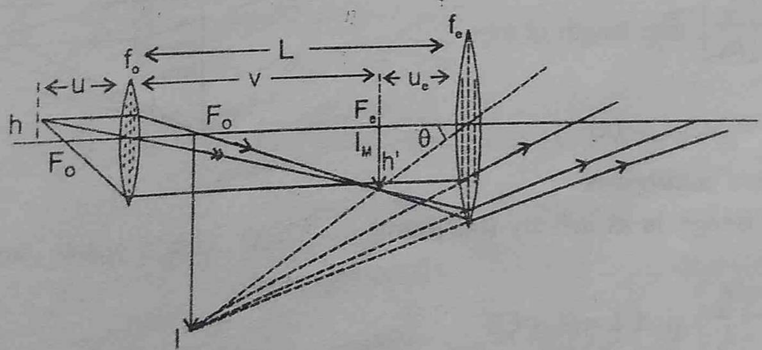
(a_1) If their image is at infinity [Far point]

So $MP = \frac{D}{u} = \frac{D}{f}$ ...... (2)

(a_2) If the image is at D [Near point]

$$MP = \frac{D}{u} = \left[1 + \frac{D}{f}\right] \quad ...... (3)$$

Compound-Microscope :



Magnifying power (MP)

Magnifying power of an optical instrument is defined as

$$MP = \frac{\text{Visual angle with instrument}}{\text{Max.Visual angle for unadded eye}} = \frac{\theta}{\theta_0}$$

If the size of object is h and least distance of distinct vision is D.

$$\theta_0 = \left[\frac{h}{u_e}\right] \times \left[\frac{D}{h}\right] = \left[\frac{h'}{h}\right]\left[\frac{D}{u_e}\right]$$

But for objective

$$m = \frac{I}{O} = \frac{v}{u} \quad \text{i.e.,} \quad \frac{h'}{h} = -\frac{v}{u} \quad \text{[as u is positive]}$$

So, $MP = -\frac{v}{u}\left[\frac{D}{u_e}\right]$

with length of tube

$L = v + u_e$ ......(1)

now there are two possibilities

(b_1) If the final image is at infinity (far point):

$$MP = -\frac{v}{u}\left[\frac{D}{f_e}\right] \text{ with } L = v + f_e \quad ..... (2)$$

(b_2) If the final image is at D (near point) :

$$MP = -\frac{v}{u}\left[1 + \frac{D}{f_e}\right] \text{ with } L = v + \frac{f_e D}{f_e + D} \quad ..... (3)$$

☞ **Telescope :**

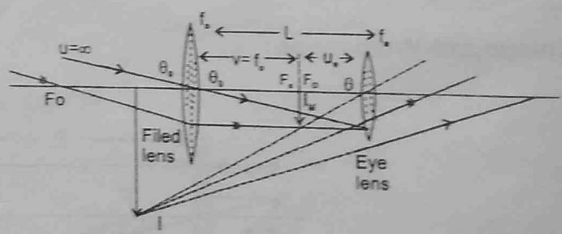
Magnifying Power (MP)

Magnifying Power of a telescope is defined as

$$MP = \frac{\text{Visual angle with instrument}}{\text{Visual angle for unadded eye}} = \frac{\theta}{\theta_0}$$

But from figure.

$$\theta_0 = \left(\frac{y}{f_0}\right) \text{ and } \theta = \left(\frac{y}{-u_e}\right)$$



So $MP = \frac{\theta}{\theta_0} = -\left[\frac{f_0}{u_e}\right]$ with length of tube

$L = (f_0 + u_e)$ .... (1)

Now there are two possibilities

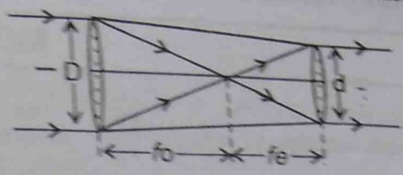
(d_1) If the final image is at infinity (far point)

$$MP = -\left(\frac{f_0}{f_e}\right) \text{ and } L = (f_0 + f_e)$$

Usually telescope operates in this mode unless stated other wise. In this mode as u_e is maximum for a given telescope MP is minimum while length of tube maximum.

(d_2) If the final image is at D (near point)

$$MP = \frac{f_0}{f_e}\left[1+\frac{f_e}{D}\right] \quad \text{with } L = f_0 + \frac{f_e D}{f_e + D} \quad \text{...... (3)}$$



In this situation u_e is minimum so for a given telescope MP is maximum while length of tube minimum and eye is most strained. In case of a telescope if object and final image are at infinity and total light entering the telescope leaves it parallel to its axis as shown in figure.

$$\frac{f_0}{f_e} = \frac{\text{Aperture of object}}{\text{Aperture of eye piece}}$$

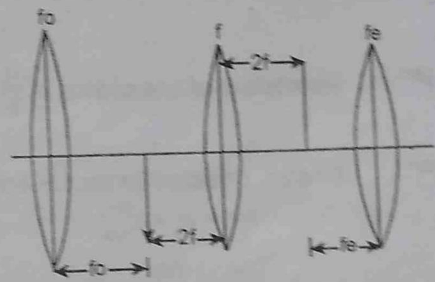
i.e., $MP = \frac{f_0}{f_e} = \frac{D}{d}$ ...... (4)

- **Terrestrial Telescope**

Uses a thrd lens in between objective and eyepieces so as to form final image erect.

This lens simply invert the image formed by objective without affecting the magnification.

Length of tube $L = f_0 + f_e + 4f$



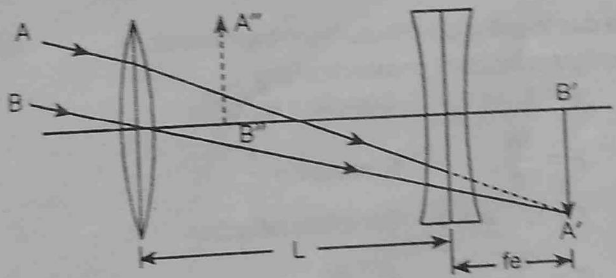
- **Galileo's Telescope**

Convex lens as objective.

Concave lens as eyepiece.

Field of view is much smaller

$\because$ eyepiece lens in concave.



(i) $M = \frac{f_0}{f_e}\left[1-\frac{f_e}{v_e}\right]$

(ii) $M = \frac{f_0}{f_e}$

Final image is at α $L = f_0 - f_e$

(iii) $M = \frac{f_0}{f_e}\left[1-\frac{f_e}{D}\right]$ Final image is at D. $L = f_0 - u_e$

MODERN PHYSICS

- Work function $W = h\nu_0 = \frac{hc}{\lambda_0}$ λ-threshold wavelength. ν_0 - threshold frequency

- Work function is minimum for cesium (1.9 eV)

- Photoelectric current is directly proportional to intensity of incident radiation. (ν – constant)
  $I = n h\nu$: where n = number of photons per unit area per unit time

- Photoelectrons ejected from metal have kinetic energies ranging from 0 to KE_{max}
  Here $KE_{max} = eV_s$ V_s - stopping potential

- Stopping potential is independent of intensity of light used (ν-constant)

- Momentum of one photon is $\frac{h}{\lambda}$.

- Einstein equation for photoelectric effect is

$$h\nu = w_0 + k_{max}$$

$$\frac{hc}{\lambda} = \frac{hc}{\lambda_0} + eV_s$$

- Energy $\Delta E = \frac{12400}{\lambda(A^0)}$ eV

- Force due to radiation (Photon) (no transmission)
  When light is incident perpendicularly
  (a) $a = 1$ $r = 0$ Complete absortion

  $F = \frac{IA}{c}$, Pressure $= \frac{I}{c}$

  (b) $r = 1$, $a = 0$ Complete reflection

  $F = \frac{2IA}{c}$, $P = \frac{2I}{c}$

  (c) when $0 < r < 1$ and $a + r = 1$ partial reflection – partial absorption

  $F = \frac{IA}{c}(1 + r)$, $P = \frac{I}{c}(1 + r)$

  When light is incident at an angle θ with vertical.
  (a) $a = 1$, $r = 0$

  $F = \frac{IA\cos\theta}{c}$, $P = \frac{F\cos\theta}{A} = \frac{I}{c}\cos^2\theta$

  (b) $r = 1$, $a = 0$

  $F = \frac{2IA\cos^2\theta}{c}$, $P = \frac{2I\cos^2\theta}{c}$

  (c) $0 < r < 1$, $a + r = 1$

  $P = \frac{I\cos^2\theta}{c}(1 + r)$

- De Broglie wavelength

$$\lambda = \frac{h}{mv} = \frac{h}{P} = \frac{h}{\sqrt{2km}}\ ;\ k = \text{kinetic energy} = \frac{h}{\sqrt{2mqV}}\ \text{where } V \to \text{potential difference}$$

H-atom

- Radius and speed of electron in hydrogen like atoms.

$$r_n = \frac{n^2}{Z} a_0 \qquad a_0 = 0.529\ \text{Å} \qquad ; Z \to \text{atomic number}$$

$$; n \to \text{orbit number}$$

$$v_n = \frac{Z}{n} v_0 \qquad v_0 = 2.19 \times 10^6\ \text{m/s}$$

- Energy in n^{th} orbit

$$E_n = E_1 \cdot \frac{Z^2}{n^2} \qquad E_1 = -13.6\ \text{eV}$$

- Wavelength corresponding to spectral lines

$$\frac{1}{\lambda} = R\left[\frac{1}{n_1^2} - \frac{1}{n_2^2}\right] \qquad R = \text{Rydberg constant} = 1.097 \times 10^7\ \text{m}^{-1}$$

for Lyman series	$n_1 = 1$	$n_2 = 2, 3, 4$..........
Balmer	$n_1 = 2$	$n_2 = 3, 4, 5$..........
Paschen	$n_1 = 3$	$n_2 = 4, 5, 6$..........

- The Lymen series is an ultraviolet, and Paschen, Brackett and Pfund series are in the infrared region. Balmer is in visible region.

- Total number of possible transitions, is $\frac{n(n-1)}{2}$, (from n^{th} state) [for gas having sufficient atom]

- If effect of nucleus motion is considered,

$$r_n = (0.529\ \text{Å})\ \frac{n^2}{Z} \cdot \frac{m}{\mu}$$

$$E_n = (-13.6\ \text{eV})\ \frac{Z^2}{n^2} \cdot \frac{\mu}{m}$$

Here μ - reduced mass

$$\mu = \frac{Mm}{(M+m)},\ M\text{ - mass of nucleus}$$

x-ray spectrum

- Minimum wavelength for x-rays

$$\lambda_{min} = \frac{hc}{eV_0} = \frac{12400}{V_0(\text{volt})}\text{Å}$$

- Moseley's Law

$$\sqrt{v} = a(z-b)$$

a and b are positive constants for one type of x-rays (independent of Z)

- Average radius of nucleus may be written as

$R = R_0 A^{1/3}$, $\quad R_0 = 1.1 \times 10^{-15}$ M

A - mass number

- Binding energy of nucleus of ${}_{z}X^{A}{}_{N}$ mass M, is given by $B = (ZM_p + NM_N - M)C^2$ and the mass defect $\Delta m = ZM_p + NM_N - M$
- For nuclear reaction $A + B \rightarrow C + Q$
  The energy of reaction Q is given by
  $Q = (m_A + m_B - m_C)\,C^2 = BE_C - BE_A - BE_B$
- α^- decay process
  $${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$
  Q-value is
  $$Q = \left[m\left({}^{A}_{Z}X\right) - m\left({}^{A-4}_{Z-2}Y\right) - m\left({}^{4}_{2}He\right)\right]C^2$$
  Kinetic energy of α-particle is given by
  $$KE_\alpha = \frac{m_Y}{m_X}Q$$
- β^- decay
  $${}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^- + \nu^-$$
  Q- value $= [m({}^{A}_{Z}X) - m({}^{A}_{Z+1}Y)]c^2$
- β^+ decay
  $${}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + \beta^+ + \nu$$
  Q- value $= [m({}^{A}_{Z}X) - m({}^{A}_{Z-1}Y) - 2m_e]c^2$
  Where $m({}^{A}_{Z}X)$, $m({}^{A}_{Z-1}Y)$ are atomic màsses.
- Electron capture : when atomic electron is captured, X-rays are emitted.
  $${}^{A}_{Z}X + {}_{-1}e^0 \longrightarrow {}^{A}_{Z-1}Y + \nu$$
  Q - value $= [m({}^{A}_{Z}X) - m({}^{A}_{Z-1}Y)]c^2$
  Where $m({}^{A}_{Z}X)$, $m({}^{A}_{Z-1}Y)$ are atomic masses.
- In radioactive decay, number of nuclei at instant t is given by $N = N_0\, e^{-\lambda t}$, λ-decay constant.
- Activity of sample : $A = A_0\, e^{-\lambda t}$
- Activity per unit mass is called specific activity.
- Half life : $T_{1/2} = \frac{0.693}{\lambda}$
- Average life : $T_{av} = \frac{T_{1/2}}{0.693}$
- Number of nuclei present after n half lives i.e. after a time $t = n\, t_{1/2}$
  $$N = \frac{N_0}{2^n}$$
- A radioactive nucleus can decay by two different processes having half lives t_1 and t_2 respectively. effective half-life of nucleus is given by $\frac{1}{t} = \frac{1}{t_1} + \frac{1}{t_2}$.
- Activity : $A = A_0\, e^{-\lambda t}$
- Activity after n half lives : $\frac{A_0}{2^n}$

WAVE OPTICS

Wavefronts :

(i) Rays are perpendicular to wavefronts.

(ii) The time taken by light to travel from one wavefront to another is the same along any ray.

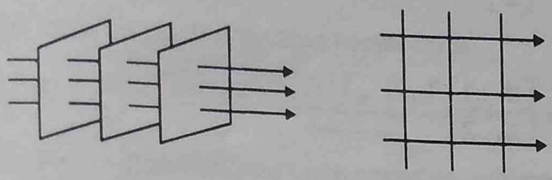
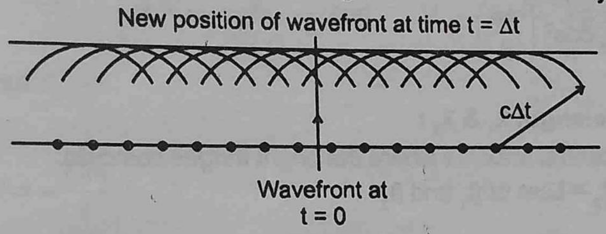


Figure : Wavefronts and the corresponding rays in case of plane wave.

Huygens' Principle :

All points on a wavefront serve as point sources of spherical secondary wavelets. After a time t, the new position of the wavefront will be that of a surface tangent to these secondary wavelets.



Interference of waves of intensity I_1 and I_2 :

resultant intensity,

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\ \cos(\Delta\phi) \text{ where, } \Delta\phi = \text{phase difference.}$$

For Constructive Interference :

$$I_{max} = \left(\sqrt{I_1} + \sqrt{I_2}\right)^2$$

For Destructive interference :

$$I_{min} = \left(\sqrt{I_1} - \sqrt{I_2}\right)^2$$

If sources are incoherent

$I = I_1 + I_2$, at each point.

YDSE :

Path difference, $\Delta p = S_2P - S_1P = d \sin\theta$

if $d << D$ $= \dfrac{dy}{D}$ if $y << D$

for maxima,

$\Delta p = n\lambda$ $\Rightarrow$ $y = n\beta$ $n = 0, \pm1, \pm2$ ....

for minima

$$\Delta p = \quad \Delta p = \begin{cases} (2n-1)\dfrac{\lambda}{2} & n = 1, 2, 3 \ldots\ldots\ldots\ldots \\ (2n+1)\dfrac{\lambda}{2} & n = -1, -2, -3 \ldots\ldots\ldots \end{cases}$$

$$\Rightarrow \quad y = \begin{cases} (2n-1)\dfrac{\beta}{2} & n = 1, 2, 3 \ldots\ldots\ldots\ldots \\ (2n+1)\dfrac{\beta}{2} & n = -1, -2, -3 \ldots\ldots\ldots \end{cases}$$

where, fringe width $\beta = \frac{\lambda D}{d}$

Here, λ = wavelength in medium.

Highest order maxima : $n_{max} = \left[\frac{d}{\lambda}\right]$

total number of maxima = $2n_{max} + 1$

Highest order minima : $n_{max} = \left[\frac{d}{\lambda} + \frac{1}{2}\right]$

total number of minima = $2n_{max}$.

Intensity on screen :

$$I = I_1 + I_2 + 2\sqrt{I_1 I_2}\ \cos(\Delta\phi) \text{ where, } \Delta\phi = \frac{2\pi}{\lambda}\Delta p$$

If $\quad I_1 = I_2,\ I = 4I_1 \cos^2\left(\frac{\Delta\phi}{2}\right)$

YDSE with two wavelength λ_1 & λ_2 :

The nearest point to central maxima where the bright fringes coincide:

$$y = n_1\beta_1 = n_2\beta_2 = \text{Lcm of } \beta_1 \text{ and } \beta_2$$

The nearest point to central maxima where the two dark fringes coincide,

$$y = (n_1 - \frac{1}{2})\,\beta_1 = n_2 - \frac{1}{2})\,\beta_2$$

Optical path difference

$$\Delta p_{opt} = \mu\Delta p$$

Phase difference $\Delta\phi = \frac{2\pi}{\lambda}\ \Delta p = \frac{2\pi}{\lambda_{vacuum}}\ \Delta p_{opt.}$

Displacement of fringe pattern on introduction of a glass-slab in the path of one of the slabs:

$$\Delta = (\mu - 1)\ t.\ \frac{D}{d} = (\mu - 1)t\ \frac{B}{\lambda}.$$

This shift is in the direction of the slit before which the glass slab is placed. If the glass slab is placed before the upper slit, the fringe pattern gets shifted upwards and if the glass slab is placed before the lower slit the fringe pattern gets shifted downwards.

YDSE with Oblique Incidence :

In YDSE, ray is incident on the slit at an inclination of θ_0 to the axis of symmetry of the experimental set-up

We obtain central maxima at a point where, $\Delta p = 0$.

or $\qquad \theta_2 = \theta_0$.

This corresponds to the point O' in the diagram.

Hence we have or path difference.

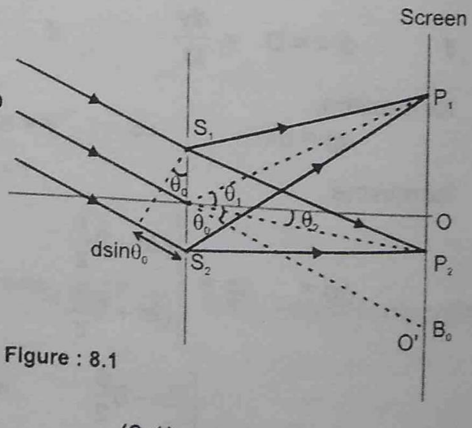


Figure : 8.1

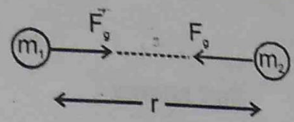
$$\Delta p = \begin{cases} d(\sin\theta_0 + \sin\theta) - \text{for points above O} \\ d(\sin\theta_0 - \sin\theta) - \text{for points between O \& O'} \\ d(\sin\theta - \sin\theta_0) - \text{for points below O'} \end{cases} \qquad \text{... (8.1)}$$

GRAVITATION

Newton's law of gravitation :

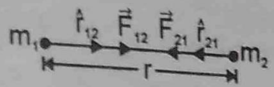
- Gravitational attraction force between two point masses

$F_g = \dfrac{Gm_1m_2}{r^2}$ and its direction will be attractive.



- Gravitational force on (1) due to (2) in vector form

$\vec{F}_{12} = \dfrac{Gm_1m_2}{r^2}\,\hat{r}_{12}$



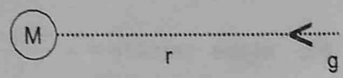
- Gravitational Field :- Gravitational force acting on unit mass.

$$g = \frac{F}{m}$$

- Gravitational Potential : - Gravitation potential energy of unit mass

$$V_g = \frac{U}{m} \quad \Rightarrow \quad g = -\frac{dV_g}{dr} \quad \text{and} \quad V_B - V_A = -\int_A^B \vec{g}\cdot d\vec{r}$$

(i) For point mass :

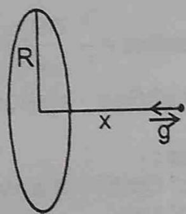


$$g = \frac{GM}{r^2}, \quad V = -\frac{GM}{r}$$

(ii) For circular ring

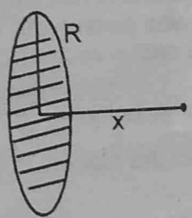
$$g = \frac{GMx}{(R^2+x^2)^{3/2}}$$

$$V = -\frac{GM}{\sqrt{R^2+x^2}}$$



(iii) For thin circular disc

$$g = \frac{2GM}{R^2}\left(1-\frac{1}{\sqrt{1+\left(\frac{R}{x}\right)^2}}\right)$$

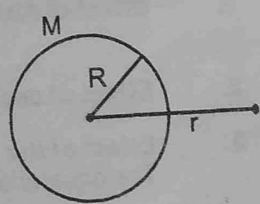


$$V = \frac{-2GM}{R^2}\left(\sqrt{R^2+x^2}-x\right)$$

(iv) Uniform thin spherical shell : -

$$g_{out} = \frac{GM}{r^2} \quad \Rightarrow \quad g_{surface} = \frac{GM}{R^2}$$

$$g_{in} = 0$$



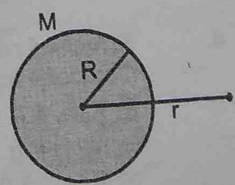
- **Potential :**

$$V_{out} = -\frac{GM}{r} \quad \Rightarrow \quad V_{surface} = -\frac{GM}{R} \quad \Rightarrow \quad V_{in} = -\frac{GM}{R}$$

(v) Uniform solid sphere :- (Most Important)

$$g_{out} = \frac{GM}{r^2} \quad \Rightarrow \quad g_{surface} = \frac{GM}{R^2}$$

$$g_{in} = \frac{GM}{R^3}r \quad \Rightarrow \quad g_{centre} = 0$$



Potential : $V_{out} = -\frac{GM}{r} \Rightarrow V_{in} = -\frac{GM}{2R^3}(3R^2 - r^2)$

$V_{surface} = -\frac{GM}{R} \Rightarrow V_{centre} = -\frac{3}{2}\frac{GM}{R}$

Self energy :

Self energy of hollow sphere = $U_{self} = -\frac{1}{2}\frac{GM^2}{R}$

Gravitational Self energy of a Uniform Sphere = $U_{self} = -\frac{3}{5}\frac{GM^2}{R}$

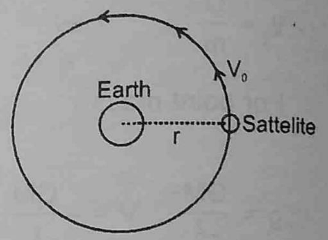
Escape speed from earth's surface

$V_e = \sqrt{\frac{2GM_e}{R}} = 11.2$ km/sec.

If a satellite is moving around the earth is circular orbit, then its orbital speed is

$V_0 = \sqrt{\frac{GM_e}{r}}$

where r is distance of satellite from the centre of earth.



PE . of the satellite = $-\frac{GM_e m}{r}$

KE of the satellite = $\frac{1}{2}mv_0^2 = \frac{GM_e m}{2r}$

TE of the satellite = $-\frac{GM_e m}{2r}$

Time period of Geo - stationary satellite = 24 hours

Kapler's laws : -

(i) Law of Orbit :- If a planet is revolving around a sun, its path is either elliptical (or circular)

(ii) Law of Area : -

View (i) If a planet is revolving around a sun, the angular momentum of the planet about the sun remains conserved

View (ii) The radius vector from the sum to the planet sweeps area at constant rate.

Areal velocity = $\frac{dA}{dt} = \frac{L}{2m}$ = constant

(iii) For all the planets of a sun

$T^2 \propto R^3 \Rightarrow T^2 = \left(\frac{4\pi^2}{GM_s}\right)R^3$

Factors Affecting Acceleration Due to Gravity :

1. **Effect of Altitude :** $g_h = \frac{GM_e}{(R_e+h)^2} = g\left(1+\frac{h}{R_e}\right)^{-2} \simeq g\left(1-\frac{2h}{R_e}\right)$ when h << R.

2. **Effect of depth :** $g_d = g\left(1-\frac{d}{R_e}\right)$

3. **Effect of the surface of Earth**
The equatorial radius is about 21 km longer than its polar radius.
We know, $g = \frac{GM_e}{R_e^2}$ Hence $g_{pole} > g_{equator}$.

4. **Effect of rotation of the Earth**
Consider a particle of mass m at latitude θ. $g' = g - \omega^2 R_e \cos^2\theta$
At pole θ = 90°
$\Rightarrow g_{pole} = g$, At equator θ = 0
$\Rightarrow g_{equator} = g - \omega^2 R_e$. Hence $g_{pole} > g_{equator}$

FLUID MECHANICS & PROPERTIES OF MATTER

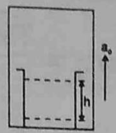
Fluids, Surface Tension, Viscosity & Elasticity :

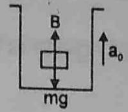
1. Hydraulic press. $p = \frac{f}{a} = \frac{F}{A}$ or $F = \frac{A}{a} \times f$.

Hydrostatic Paradox $P_A = P_B = P_C$

(i) Liquid placed in elevator : When elevator accelerates upward with acceleration a_0 then pressure in the fluid, at depth 'h' may be given by,

$$p = h_\rho\,[g + a_0]$$

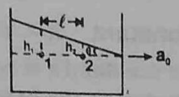




and force of buoyancy, $B = m\,(g + a_0)$

(ii) Free surface of liquid in horizontal acceleration :

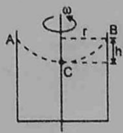
$$\tan\theta = \frac{a_0}{g}$$



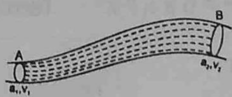
$p_1 - p_2 = \ell_\rho\, a_0$ where p_1 and p_2 are pressures at points 1 & 2. Then $h_1 - h_2 = \frac{\ell a_0}{g}$

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

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

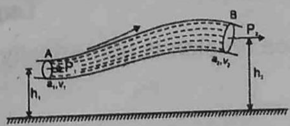


Equation of Continuity $a_1v_1 = a_2v_2$



In general av = constant .

Bernoulli's Theorem



i.e. $\frac{P}{\rho} + \frac{1}{2}$ v2 + gh = constant.

(vi) Torricelli's theorem – (speed of efflux) $v = \sqrt{\dfrac{2gh}{1 - \dfrac{A_2^2}{A_1^2}}}$,A2 = area of hole A1 = area of vessel.

Elasticity & Viscosity : stress $= \frac{\text{restoring force}}{\text{area of the body}} = \frac{F}{A}$

Strain, $\epsilon = \frac{\text{change in configuration}}{\text{original configuration}}$

(i) Longitudinal strain $= \frac{\Delta L}{L}$

(ii) ϵ_v = volume strain $= \frac{\Delta V}{V}$

(iii) **Shear Strain :** $\tan\phi$ or $\phi = \frac{x}{\ell}$

1. **Young's modulus of elasticity** $Y = \frac{F/A}{\Delta L/L} = \frac{FL}{A\Delta L}$

2. **Bulk modulus :** $K = \frac{\text{Pressure}}{\text{Volume strain}}$

The reciprocal of bulk modulus of elasticity is called compressibility. $K_{solids} > K_{liquids} > K_{gases}$
Isothermal modulus of elasticity of gas K = P (pressure of gas)

Adiabatic modulus of elasticity of gas $K = \gamma \times P$ where $\gamma = \frac{C_P}{C_V}$.

Modulus of rigidity is given by $\eta = \frac{\text{Tangential stress}}{\text{Shear strain}}$ or $\eta = \frac{F/A}{\phi} = \frac{F}{A\phi}$

Potential Energy per unit volume = $\frac{1}{2}$(stress × strain) = $\frac{1}{2}$ (Y × strain^2)

Inter-Atomic Force-Constant $k = Yr_0$.
Thus, inter-atomic force-constant k is equal to the product of Young's modulus of the material of the wire and the normal distance r_0 between the atoms of the wire.

Newton's Law of viscosity, $F \propto A\frac{dv}{dx}$ or $F = -\eta A\frac{dv}{dx}$

η is called Coefficient of viscosity. 1 decapoise = 1 N sm^{-2} = (10^5 dyne) × s × (10^2 cm)$^{-2}$ = 10 dyne s cm^{-2} = 10 poise ; $\eta \propto \frac{1}{\sqrt{T}}$

Stoke's Law $F = 6\pi\eta r v$. Terminal velocity = $\frac{2}{9}\frac{r^2(\rho-\sigma)g}{\eta}$

Surface Tension

Surface tension (T) = $\frac{\text{Total force on either of the imaginary line (F)}}{\text{Length of the line } (\ell)}$; $T = S = \frac{\Delta W}{A}$

Thus, surface tension is numerically equal to surface energy or work done per unit increase surface area.

Inside a bubble : $(p - p_a) = \frac{4T}{r} = p_{excess}$;

Inside the drop : $(p - p_a) = \frac{2T}{r} = p_{excess}$

Inside air bubble in a liquid : $(p - p_a) = \frac{2T}{r} = p_{excess}$

Capillary Rise $h = \frac{2T\cos\theta}{r\rho g}$

If two parallel plates with the spacing 'd' are placed in water reservoir, then height of rise

$\Rightarrow 2T\ell = \rho\ell hdg$ or $h = \frac{2T}{\rho dg}$

If two concentric tubes of radius 'r_1' and 'r_2' (inner one is solid) are placed in water reservoir, then height of rise $\Rightarrow$ $h = \frac{2T}{(r_2 - r_1)\rho g}$

If weight of the liquid in the meniscus is to be consider : $\left[h+\frac{r}{3}\right] = \frac{2T\cos\theta}{r\rho g}$

Capillary Rise in a Tube of Insufficient Length :

When the capillary tube is cut and its length is less then h (i.e. h'), then the liquid rises upto the top of the tube and spreads in such a way that the radius (R') of the liquid meniscus increases and it becomes more flat so that hR = h'R' = Constant. Hence the liquid does not overflow.

If h' < h then R' > R or $\frac{r}{\cos\theta'} > \frac{r}{\cos\theta} \Rightarrow \cos\theta' < \cos\theta \quad \Rightarrow \theta' > \theta$

SOUND WAVES

- Longitudinal displacement of sound wave

  $S = S_0 \sin(\omega t - kx)$

- Pressure excess during travelling sound wave

  $P_{ex} = -B\frac{\partial S}{\partial x}$ (it is true for travelling wave as well as standing waves).

  $= (B S_0 k)\cos(\omega t - kx)$

  Amplitude of pressure excess = $B S_0 k$

  where, B is bulb modules

  K is wave number

  S_0 is displacement amplitude

- Speed of sound $C = \sqrt{\frac{E}{\rho}}$

  Where E = Elastic modulus for the medium

  ρ = density of medium

  for solid $C = \sqrt{\frac{Y}{\rho}}$

  where Y = young's modulus for the solid

  for liquid $C = \sqrt{\frac{B}{\rho}}$

  where B = Bulk modulus for the liquid

  for gases $C = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{M_0}}$

  where M_0 is molecular wt. of the gas in (kg/mole)

Factors affecting speed of sound in atmosphere :

(a) **Effect of temperature :** as temperature (T) increases velocity (v) increases.

$v \propto \sqrt{T}$

(b) **Effect of pressure :**

The speed of sound in a gas is given by $v = \sqrt{\frac{\gamma P}{\rho}} = \sqrt{\frac{\gamma RT}{M}}$

(c) **Effect of humidity :** With increase in humidity density decreases. This is because the molar mass of water vapour is less than the molar mass of air.

So at constant temperature, if P changes then ρ also changes in such a way that P/ρ remains constant. Hence pressure does not have any effect on velocity of sound as long as temperature is constant.

Intensity of sound wave :

$$\langle I \rangle = 2\pi^2 f^2 A^2 \rho v = \frac{P_m^2}{2\rho v}$$

$$\langle I \rangle \propto P_m^{\ 2}$$

☛ Loudness of sound : $L = 10\log_{10}\left(\frac{I}{I_0}\right)$ dB

where $I_0 = 10^{-12}$ W/m² (This the minimum intensity human ears can listen)

Intensity at a distance r from a point source = $I = \frac{P}{4\pi r^2}$

intensity at a distance r from a line source = $\frac{P}{2\pi r}$ (P is power per unit length of the line source)

Interference of Sound Wave

if $P_1 = p_{m1} \sin(\omega t - kx_1 + \theta_1)$ $\quad P_2 = p_{m2} \sin(\omega t - kx_2 + \theta_2)$

resultant excess pressure at point O is

$$p = P_1 + P_2 \qquad p = p_0 \sin(\omega t - kx + \theta)$$

$$p_0 = \sqrt{p_{m_1}^2 + p_{m_2}^2 + 2p_{m_1}p_{m_2}\cos\phi} \quad \text{where } \phi = |k(x_1 - x_2) + (\theta_2 - \theta_1)|$$

and $I_R = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\phi$

☛ For constructive interference

$\phi = 2n\pi$ and $\Rightarrow$ $p_0 = p_{m1} + p_{m2}$ (constructive interference)

☛ For destructive interference

$\phi = (2n+1)\pi$ and $\Rightarrow$ $p_0 = |p_{m1} - p_{m2}|$ (destructive interference)

If ϕ is due to path difference only then $\phi = \frac{2\pi}{\lambda}\Delta x$. [i.e., $\Delta\theta = 0$]

Condition for constructive interference : $\Delta x = n\lambda$ [i.e., $\Delta\theta = 0$]

Condition for destructive interference : $\Delta x = (2n+1)\frac{\lambda}{2}$. [i.e., $\Delta\theta = 0$]

(a) If $p_{m1} = p_{m2}$ and $\phi = \pi, 3\pi, \ldots$
resultant p = 0 i.e. no sound

(b) If $p_{m1} = p_{m2}$ and $\phi = 0, 2\pi, 4\pi, \ldots$
$p_0 = 2p_{m2}$ & $I_0 = 4I_1$
$p_0 = 2p_{m1}$

Amplitude of resultant wave becomes two times and hence resultant intensity of sound becomes four times the intensity due to individual source.

Coherent & Incoherent Sources :

Coherent : Two sources are said to be coherent if phase difference between the waves (generated by them) at a point does not change with time.

Incoherent : $[\Delta\phi = f(t)]$ Two independent sources will generally be incoherent in nature.

Stationary Wave : -

Same conditions as discussed in the case of string.

e.g. If

$$p_A = p_0 \sin(kx - \omega t)$$
$$p_B = p_0 \sin(kx + \omega t)$$
$$p = p_A + p_B = 2\, p_0 \sin kx \cos \omega t$$

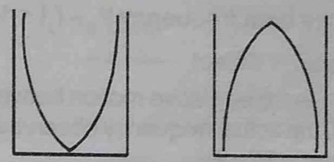
superimpose, then a standing wave forms

Vibration of air column :

Closed organ pipe :

Fundamental frequency

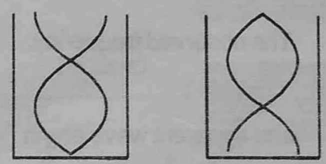
$$f_0 = \frac{v}{4\ell}$$



Displacement mode   Pressure mode

First overtone (third harmonic)

$$f_1 = \frac{3v}{4\ell}$$



Displacement mode   Pressure mode

Generally,

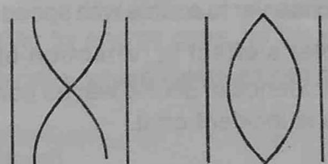
$$f = \frac{v}{4\ell}, \frac{3v}{4\ell}, \frac{5v}{4\ell}, \ldots\ldots\ldots \frac{(2n+1)v}{4\ell}$$

n = overtone

Open organ pipe :

fundamental frequency

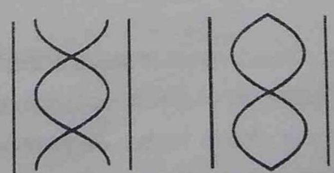
$$f_1 = \frac{v}{2\ell}$$



Displacement mode   Pressure mode

first overtone frequency (second harmonic)

$$f_2 = \frac{2v}{2\ell}$$

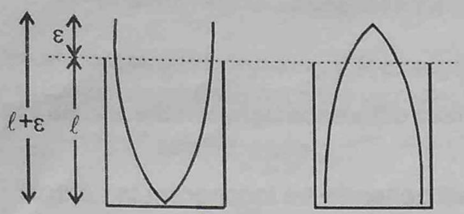


Displacement mode   Pressure mode

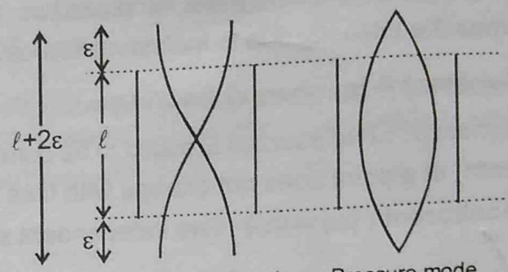
generally

$$f = \frac{v}{2\ell}, \frac{2v}{2\ell}, \frac{3v}{2\ell}, \ldots\ldots\ldots \frac{nV}{2\ell}$$

* Considering end correction ; (ε) for closed tube, ℓ is replaced by $\ell + \varepsilon$ for open tube ℓ is replaced by $\ell + 2\varepsilon$



Displacement mode   Pressure mode



Displacement mode   Pressure mode

where $\varepsilon \approx 0.3\, d = 0.6\, r$
where, d = diameter of the pipe
r is radius of the pipe

Resonance : If the forcing frequency (frequency of tuning fork) matches with any of the natural frequency (of the air column), then a large sound is produced, and air column starts vibrating violently with that particular frequency. This situation is called Resonance.

Beats : If two sound waves of slightly different frequency, meet, then Beat frequency = $|f_1 - f_2|$. Beat

time period = $\dfrac{1}{|f_1 - f_2|}$, average frequency of vibration = $\dfrac{f_1 + f_2}{2}$

Audible beat frequency $|f_1 - f_2| \le 16$ Hz

Doppler's Effect

When there is relative motion between the source of a sound/light wave & an observer along the line joining them, the actual frequency observed is different from the frequency of the source. This phenomenon is called Doppler's Effect.

(v = velocity of sound wrt. ground. , c = velocity of sound with respect to medium, v_m = velocity of medium, v_O = velocity of observer, v_s = velocity of source.)

The observed frequency, $f' = f\left(\dfrac{v - v_0}{v - v_s}\right)$

and apparent wavelength $\lambda' = \lambda\left(\dfrac{v - v_s}{v}\right)$

* In the above expression also, the positive direction is taken along the velocity of sound, i.e. from source to observer.
* In all of the above expression from equation to, v stands for velocity of sound with respect to ground.

If velocity of sound with respect to medium is c and the medium is moving in the direction of sound from source to observer with speed v_m, $v = c + v_m$, and if the medium is moving opposite to the direction of sound from observer to source with speed v_m, $v = c - v_m$

Doppler's effect in reflection of sound (echo)

For incidence of sound waves consider the reflector as an observe. It will act as a source of frequency which is incident on it.

FOR JEE (MAIN)

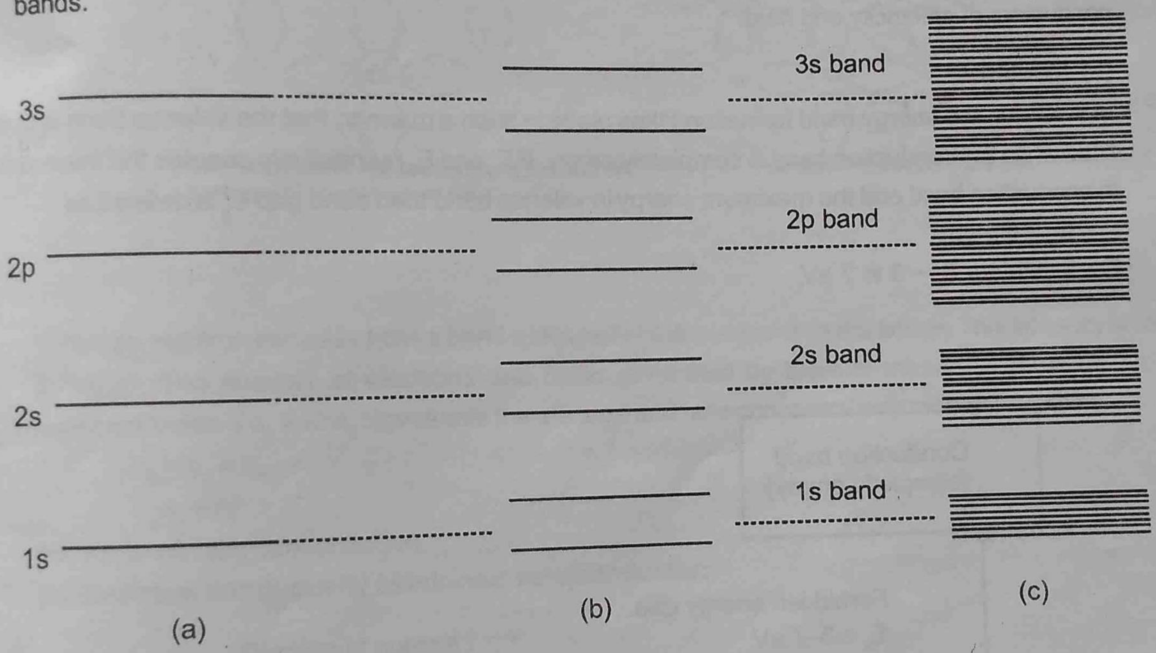
SOLIDS AND SEMICONDUCTOR DEVICES

The rapid advancement in electronics which we see today is due to the valuable contributions of semiconductor devices. They are being used in various fields such as telecommunication, entertainment, computer, nuclear physics, etc. They have following advantages

(i) Small in size
(ii) Consumes less power
(iii) Long life
(iv) More efficient than vaccum tube
(v) Low cost

Energy levels and Energy Bands in Solids :

The electrons belonging to the outermost energy level are called valence electrons. The interaction between atoms markedly affect the electron energy levels, as a result there occurs a splitting of energy levels belonging to various atoms. When these atoms are close enough, their electrons are subjected to the combined electric field of two atoms. Due to this interaction each previous single energy level splits into two levels. In the system of N interacting atoms considered here, there will be a group of N closely spaced levels corresponding to any energy of the individual atom. These closely spaced levels are referred as energy bands.



As in an isolated atom the discrete energy levels are separated by energy gaps, so the allowed energy bands in a solid are separated by forbidden bands or forbidden gaps, where electrons can not exist.

Electron in a crystal can have two type of transitions:

(i) transition between levels in a given band (intra - band transitions)

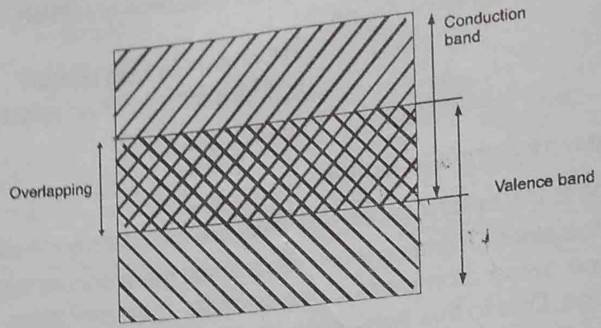
(ii) transition between one band to another (inter band transitions)

Conductor, Insulator and Semiconductor :

On the basis of electrical conductivity of materials we can devide them in three categories - conductor, insulator and semiconductor. Conductors have high value of electrical conductivity whereas insulator do not conduct electricity. Conductivity of a semiconductor is intermediate, to that of metals and insulators. The conductivity of semiconductor varies substantially with temperature. For very low temperature (around 0K) semiconductor behaves like insulator, however, its conductivity increases with increase in temperature.

(a) Conductors :

Energy form in such a way that valence band is partially filled. Electrons can make transition to upper part of this energy band, called conduction band. In case of conductors conduction band and valence band overlap each other..



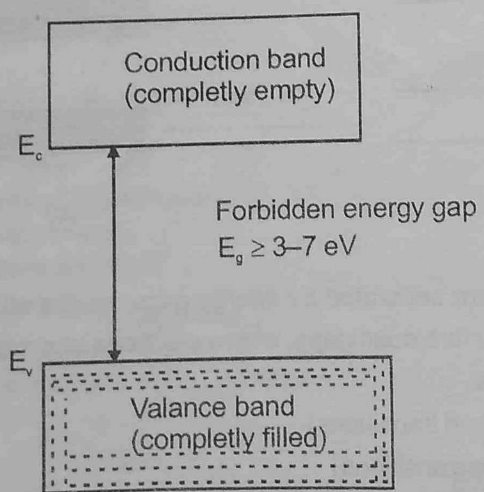
These materials have large no of free electrons and the vacant energy levels for transitions and are good conductors of electricity and heat.

(b) Insulator :

In insulator, the energy band formation takes place in such a manner, that the valence band is completely filled while the conduction band is completely empty. If E_c and E_v respectively denotes the minimum energy in conduction band and the maximum energy in valence band then band gap E_g is defined as

$E_g = E_c - E_v$

For insulators E_g ~ 3 to 7 eV.



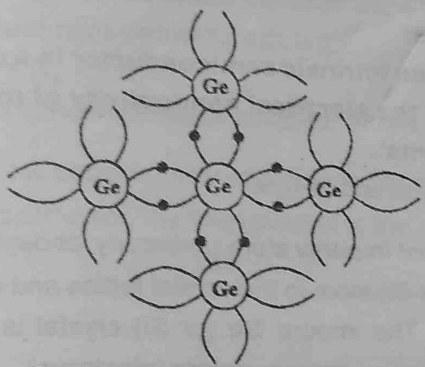
For diamond, $E_g \approx 6$ eV hence it is insulator.

(c) **Semiconductors :**

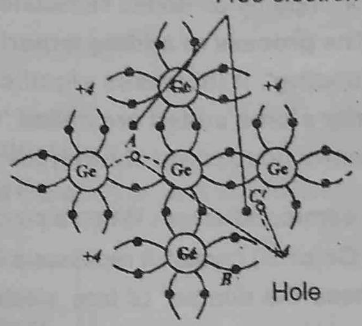
In case of semiconductors, the band gap is of the order of 1eV. At absolute zero temperature, their behaviour is same as insulators. At finite temperatures semiconductors start conducting electricity. Thus, they behave as conductors.

Intrinsic Semiconductors :

A semiconductor free from impurities is called an intrinsic semiconductor. Pure Si and Ge are examples of intrinsic semiconductor.



Two dimensional representation of the crystal structure of germanium at OK



Formation of electron hole pair

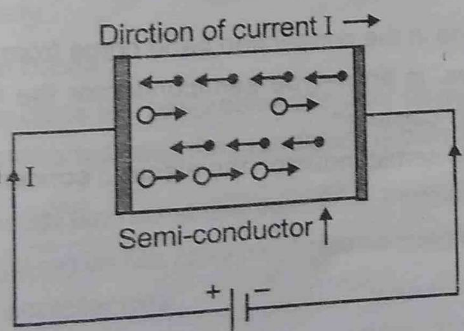
When an electron escapes from a band it leaves behind a vacancy in the lattice. This vacancy is termed as a "**hole**". The number of electrons and holes generated by thermal means is equal for an intrinsic semiconductor. If n_e and n_h represents the electron and hole concentrations respectively then

$$n_i = n_e = n_h$$

$$n_e n_h = n_i^2$$

Here n_i is intrinsic concentration.

(a) **Electrical conductivity of intrinsic semiconductor:**



Let us consider a semiconductor block of length ℓ, area of cross-section A and having electron concentration n_e and hole concentration is n_h. If i is the total current

$$i = i_e + i_h = eA\,(n_e v_e + n_h v_h)$$

Here, V_e is drift velocity of electron and V_h is the drift velocity of holes.

The mobilities of electron and hole are given by

$$\mu_e = \frac{v_e}{E} \quad \text{and} \quad \mu_h = \frac{v_h}{E}$$

Introducing μ_e and μ_h, we get electrical conductivity of the semiconductor as

$$\sigma = e(n_e \mu_e + n_h \mu_h). \qquad \because n_e = n_h = n_i \text{ for intrinsic semicondutor}$$

So $\quad \sigma = en_i(\mu_e + \mu_h)$

As temperature rises, both the concentrations n_e and n_h increase due to breakage of more covalent bonds. The mobilities μ_e and μ_h, however, slightly decrease with rise in temperature but this decrease is offset by the much greater increase in n_e and n_h.

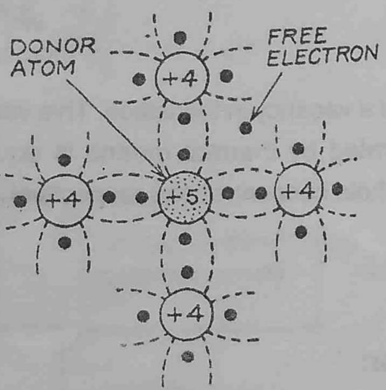
Extrinsic Semiconductors :

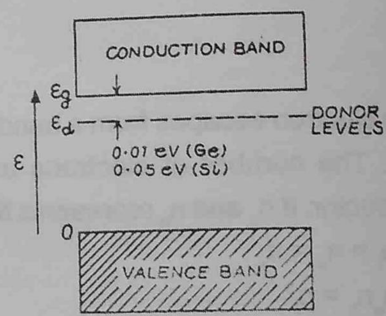
When small quantity of some pentavalent or trivalent impurity is added to a pure semiconductor, the conductivity of the semiconductor is significantly increased. Such impure semiconductors are called 'extrinsic' or 'impurity' or 'doped semiconductors.

Doping : The process of adding impurity to an intrinsic semiconductor in a controlled manner is called 'doping'. It increases significantly the electrical conductivity of the semiconductor. The impurity atoms added are called 'dopants'.

Extrinsic semiconductor are of two types : n–type and p–type.

(a) n–type semiconductor : When a pentavalent impurity atom (antimony, phosphorus or arsenic) is added to a Ge(or Si) crystal, it replaces a Ge (or Si) atom in the crystal lattice and donates a electron. This increases the number of free electrons. The impure Ge (or Si) crystal is called an 'n–type' semiconductor because it has an excess of 'negative' charge–carrier (electrons).





At ordinary temperature, almost all the electrons in the conduction band come from the donor levels, only a few come fr the valence band. Thus, in an n–type semiconductor the electrons are the 'majority carriers' a the holes are the 'minority carriers.'

Electrons and hole concentration : In a doped semiconductor, the electron concentration n_e and the hole concentration n_h are not equal but,

$$n_e n_h = n_i^2$$

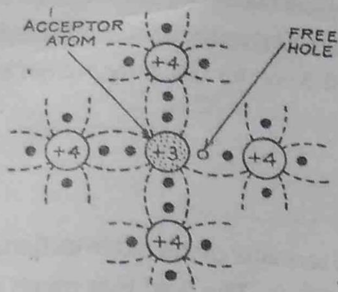
where n_i is the intrinsic concentration.

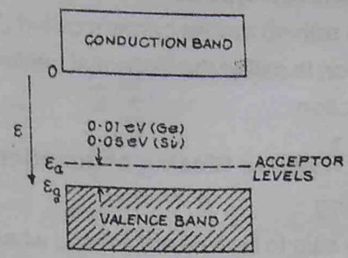
Also, $n_e \approx N_d >> n_h$

where N_d is the concentration of the donor atoms

(b) p–type semiconductor : When a trivalent impurity atom (boron, aluminium, gallium or indium) is added to a Ge (or Si) crystal, it also replaces one of the Ge (or Si) atoms in the crystal lattice. It leaves an empty space called holes. This type of semiconductors is called p-type semicondutors. impurity atoms are called acceptor

The impurity atoms inductance vacant discrete levels just above the top of the valence band. These are called 'acceptor levels'.





Thus, in a p–type semiconductor the holes are the 'majority carriers' and the few electrons, thermally excited from the valence band into the conduction band, are 'minority carriers'.

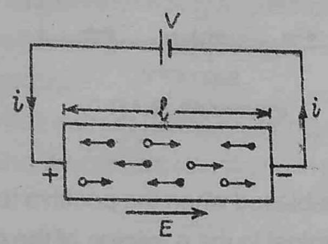
Electron and hole concentration :

$$n_h = N_a >> n_e$$

Here, N_a is concentration of acceptor atoms.

(c) Electrical conductivity of extrinsic semiconductors :

In a semiconductor, the total current is the sum of the electron and hole currents.



If we consider semiconductor block of length l, area of cross–section A and having electrons concentration n_e and hole concentration n_h The total current flowing through the semiconductor is,

$$i = i_e + i_h = eA(n_e v_e + n_h v_h)$$

introducing μ, called mobility which is defined as the drift velocity per unit field and is expressed in metre² / (volt/second). Electrical conductivity of the semiconductor is given by

$$\rho = e(n_e \mu_e + n_h \mu_h)$$

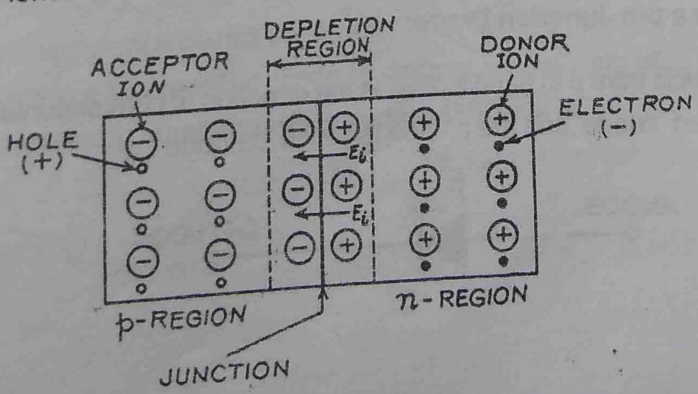
As the doping increases the coincentration of the electrons and holes increases thereby increasing the conductivity.

Junction Diode :

A junction diode is a basic semiconductor device having n-type and p-type semiconductor joined togather. The boundary between the two regions is called 'p–n junction'.

(A) Potential Barrier at the Junction: Formation of Depletion Region:

The p -type region has (positive) holes as majority charge-carriers, and an equal number of fixed negatively charged acceptor ions.

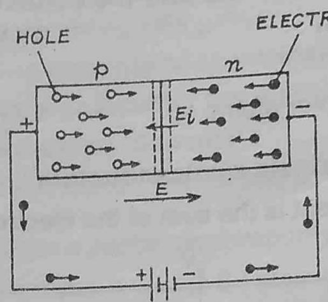


At junction electrons of n-type semiconductor and holes of p-type semiconductor combine with each other and from a region with no mobile carriers called depletion region. The potential difference developed across the depletion region is called the 'potential barrier'. It is about 0.3 volt for Ge, p-n junction and about 0·7 volt for silicon p-n junction.

(B) Forward and Reverse Biasing of Junction Diode

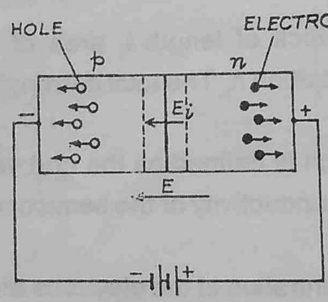
(i) Forward Biasing :

A junction diode is said to be forward-biased when the positive terminal of the external battery is conncted to the p -region and the negative terminal to the n -region of th diode. The field E is much stronger than the opposing internal field Ei. The motion of majority-carriers constitutes a current across the junction. This is called 'forward current'.



(ii) Reverse Biasing:

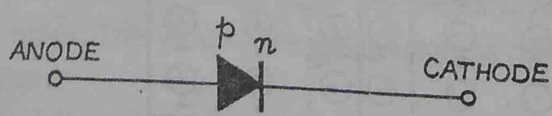
A junction diode is said to be reverse-biased when the positive terminal of the external battery is connected to the n -region and the negative terminal to the p -region of the diode.



In this condition, the external field E is directed from n toward p and thus aids the internal barrier field E_i. In reverse-biased junction, the applied field E supports tlle barrier field E_i. As a result, the majority-carriers (holes in p -region and electrons in n -region) are pushed away from the junction. Hence the width of the depletion region increases. The motion of minority-carriers(electrons in p-region and holes in n-region) constitutes a current across the junction. This is called 'reverse current'.

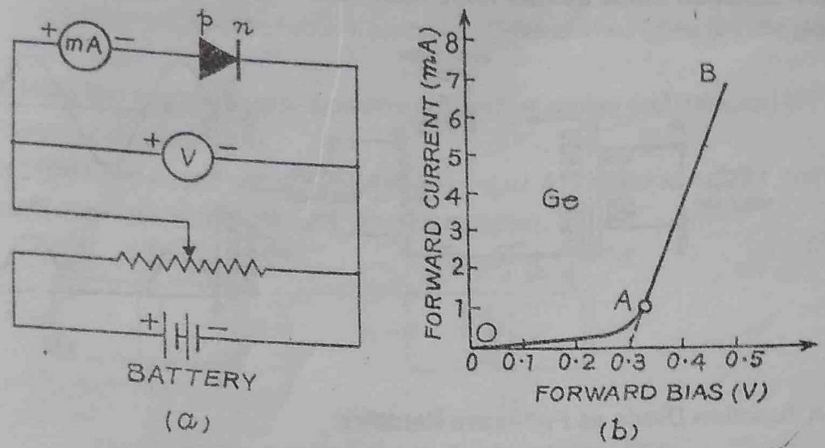
(C) Circuit Symbol for a p-n Junction Diode:

The direction of the arrow is from p to nand indicates the direction of conventional current flow under forward bias. The p -side is called 'anode' and the n -side is called 'cathode'.



(D) **Current-Voltage Characteristics of a p—n Junction Diode**

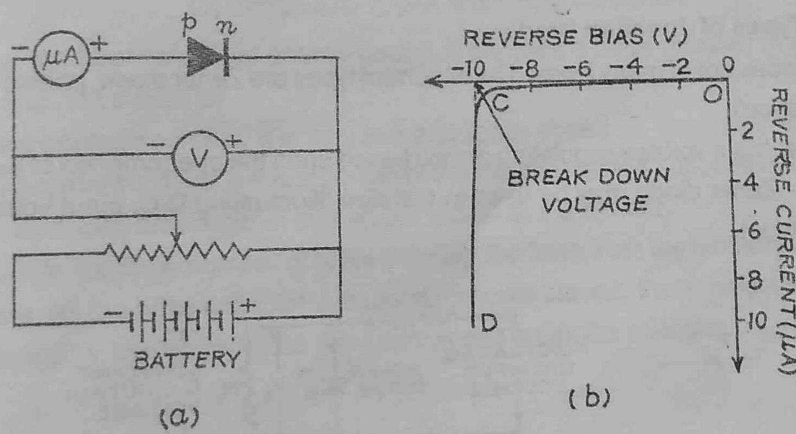
(i) **Forward-Biased Characteristics :**



The forward bias voltage is increased step by step and the corresponding forward current is noted. With increase in applied voltage, the current increases very slowly and non-linearly as in OA. With further increase in applied voltage, the current increases very rapidly and almost linearly. If this straight line is projected back, it intersects the voltage-axis at the barrier potential voltage.

(ii) **Reverse-Biased Characteristic:**

In reverse-biased diode, a very small current (of the order of μA) flows across the junction due to the motion of the few thermally-generated minority-carriers (electrons in p -region and holes in n -region) whose motion is aided by the applied voltage.



(e) **Avalanche Breakdown :**

If the reverse bias is made very high, the minority-carriers acquire kinetic energy enough to break the covalent bonds near the junction, thus liberating electron-hole pairs. These charge-carriers are accelerates and collide, to generate electron-hole pairs. The process is cumulative and an avalanche of electron-hole pairs is produced. This is known as 'avalanche breakdown'.

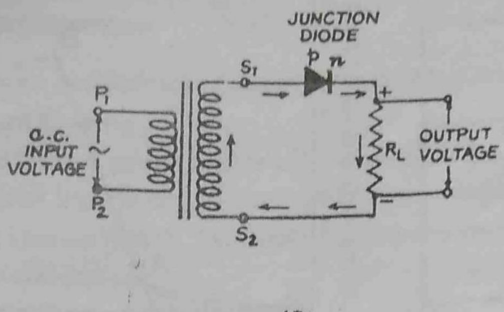
(f) **Dynamic Resistance of a Junction Diode**

The dynamic resistance of ajunction diode is defined as the ratio of a small change in applied voltage (Δ V) to the corresponding small change in current (Δi) , that is

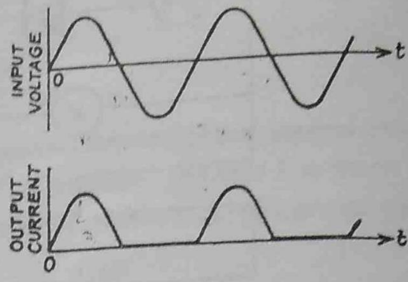
$$R_d = \frac{\Delta V}{\Delta i}$$

p-n Junction Diode as a Rectifier

(a) p-n Junction Diode as Half-wave Rectifier:

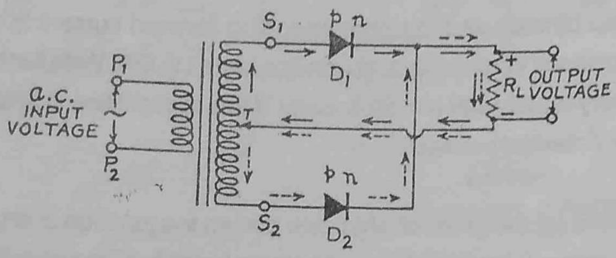


(a)

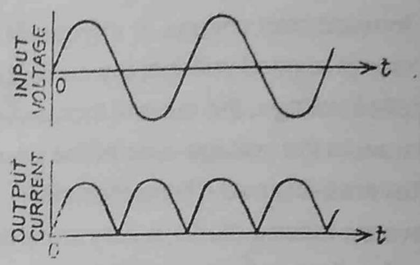


(b)

(b) p-n Junction Diode as Full-wave Rectifier:



(a)

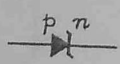


(b)

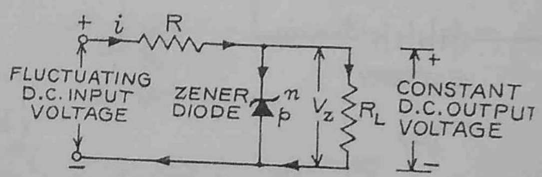
(c) Different Types of Junction Diode

The junction diodes are of many types. The important types are Zener diode, photodiode, light-emitting diode (LED) and solar cell.

(i) Zener Diode: It is a voltage-regulating device based upon the phenomenon of avalanche breakdown in a junction diode. Zener diode may be used to stabilize flliuctuating D.C. input voltage at a pre-determined value(Zener voltage).

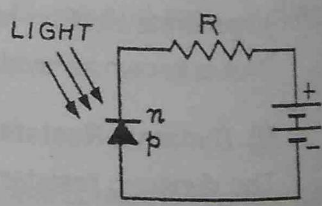


(a)

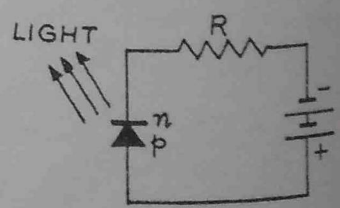


(b)

(ii) Photodiode : A photodiode is a reverse-biased p-n junction made from a photosensitive semiconductor. When no light is falling on the junction, a dark current of the order of μA flows due to the thermally-generated minority-carriers (electrons in p -region and holes in n -region). When light of appropriate frequency is made incident on the junction,'photoconductive' current of the order of mA flows.



(iii) Light-Emitting Diode (LED) : LED is a p--n junction diode in forward-biased. both the electron and the holes move towards the junction. Light is generated due to energy released in recombination of electrons and holes at the junctionc



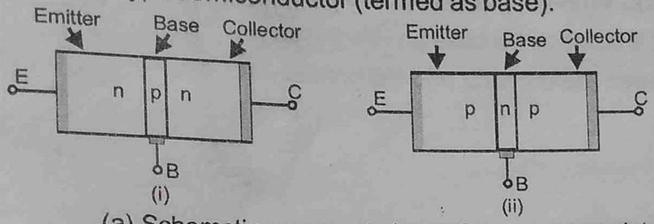
JUNCTION TRANSISTOR :

Transistor structure and action :

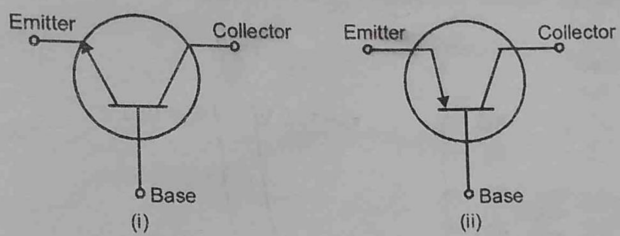
A transistor has three doped regions forming two p–n junctions There are two types of transistors, as shown in figure.

(i) n–p–n transistor : Here two segments of n–type semiconductor (emitter and collector) are separated by a segment of p–type semiconductor (base).

(ii) p–n–p transistor : Here two segments of p–type semiconductor (termed as emitter and collector) are separated by a segment of n–type semiconductor (termed as base).



(a) Schematic representations of a n–p–n transistor and p–n–p transistor



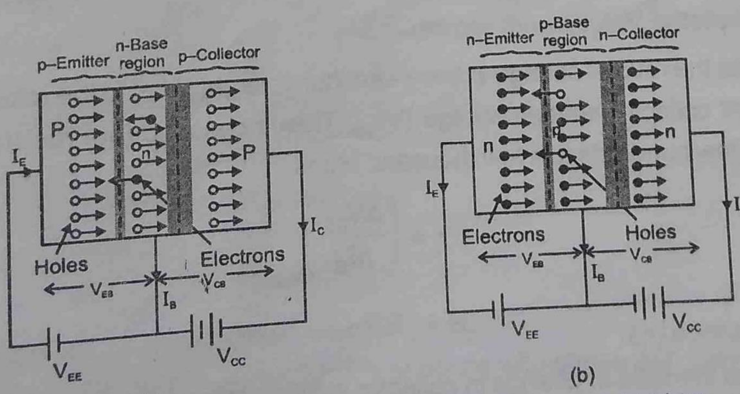
(b) Symbols for n–p–n and p–n–p transistors.

Emitter : It is of moderate size and heavily doped. It supplies a large number of majority carriers for the current flow through the transistor.

Base : This is the central segment. It is very thin and lightly doped.

Collector : This segment collects a major portion of the majority carries supplied by the emitter. The collector side is moderately doped and larger in size as compared to the emitter.

In a p–n–p transistor, the large number of holes entering the base from the emitter swamps the small number of electrons there. As the base collector–junction is reverse biased, these holes, which appear as minority carriers at the junction, can easily cross the junction and enter the collector.



Bias Voltage applied on : (a) p–n–p transistor and (b) n–p–n transistor

V_{EE}= power supply between base and emitter $\quad$ V_{EB}= voltage between emitter and base

V_{CC}= power supply between collector and emitter $\quad$ V_{CB}= voltage between collector and base

From Kirchoff's law, the emitter current is the sum of collector current and base current :

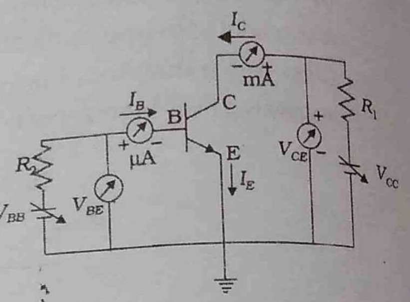
$$I_E = I_C + I_B$$

Also $I_C \approx I_E$ as base current is very small.

The transistor can be connected in either of the following three configurations :

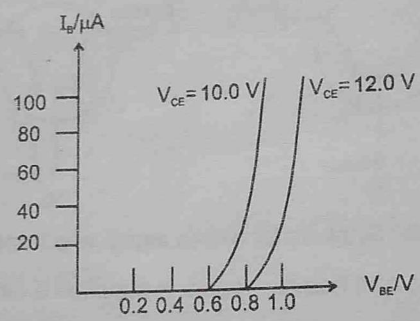
Common Emitter (CE), Common Base (CB), Common Collector (CC).

Common Emitter(CE) : When a transistor is used in CE configuration, the input is between the base and the emitter and the output is between the collector and the emitter.



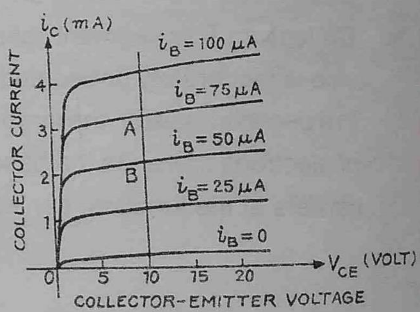
(a) Characteristics Curve

Input characteristics curve : A curve is plotted between the base current I_B against the base–emitter voltage V_{BE}. The collector–emitter voltage V_{CE} is kept fixed.



(i) Output Characteristics Curve :

The output characteristic is obtained by observing the variation of I_C as V_{CE} is varied keeping I_B constant. Both I_B and I_C will increase proportionately.



(i) Input resistance (r_i):

This is defined as the ratio of change in base - emitter voltage(ΔV_{BE}) to the resulting change in base current (ΔI_B) at. constant collector-emitter voltage (V_{CE}). This is dynamic (ac) resistance.The value of r_i can be anything from a few hundreds to a few thousand ohms.

$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)_{V_{CE}}$$

(ii) Output resistance (r_0):

This is defined as the ratio of change in collector-emitter voltage (ΔV_{CE}) to the change in collector current (ΔI_C) at a constant base current I_B.

$$r_0 = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$$

(iii) Current amplification factor (B) :

This is defined as the ratio of the change in collector current to the change in base current at a constant collector-emitter voltage (V_{CE}) when the transistor is in active state.

$$\beta_{ac} = \left(\frac{\Delta I_C}{\Delta I_B}\right)_{V_{CE}}$$

If we simply find the ratio of I_C and I_B and we get what is called dc β of the transistor. Hence $\beta = I_C/I_B$.

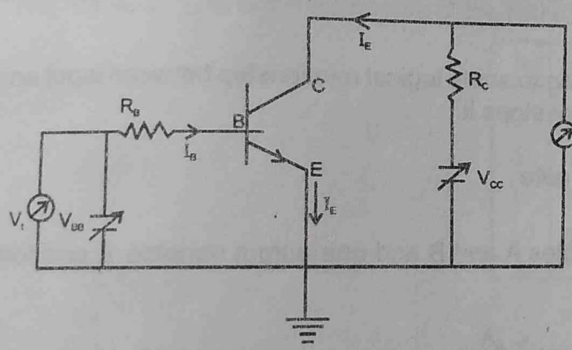
$$\beta_{dc} = \frac{I_C}{I_B}$$

(b) Transistor as a device :

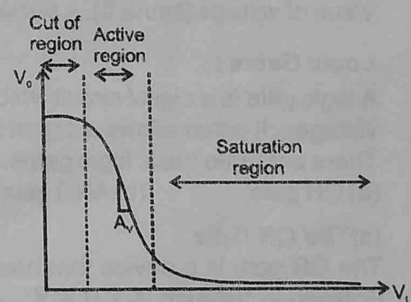
(i) Transistor as a switch:

When the transistor is not conducting it is said to be switched off and when it is driven into saturation it is said to be switched on. This shows that if we define low and high states as below and above certain voltage levels corresponding to cutoff and saturation of the transistor, then we can say that a low input switches the transistor off and a high input switches it on.

(ii) Transistor as an amplifier



(a)



(b)

For using the transistor as an amplifier we will use the active region of the V_0 Versus V_i curve. If we consider ΔV_0 and ΔV_i as small changes in the output and input voltages then $\Delta V_0/\Delta V_i$ is called the small signal voltage gain A_V of the amplifier. If we first assume that $v_i = 0$,

$A_V = -\beta_{ac}(R_C/R_B)$ Here β_{ac} is equal to $\Delta I_C/\Delta I_B$

If $v_i \neq 0$, The voltage gain of the amplifier is

$$A_v = \frac{V_0}{V_i} = \frac{\Delta V_{CE}}{r\Delta I_B} = -\frac{\beta_{ac}R_L}{r}$$

Here R_L = load resistance and input resistance $r = R_B + R_i$.

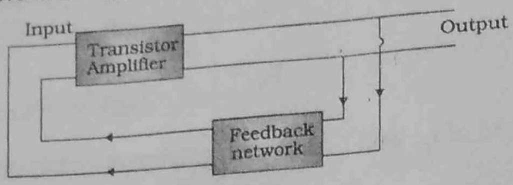
The negative sign represents that output voltage is opposite with phase with the input voltage.

Therefor the power gain A_p can be expressed as the product of the current gain and voltage gain. Mathematically

$A_p = \beta_{ac} \times A_v$

Feedback Amplifier and Transistor Oscillator :

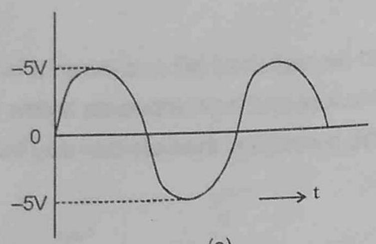
In an oscillator, we get ac output without any external input singnal. A portion of the output power is returned back to the input in phase with the starting power using positive feedback



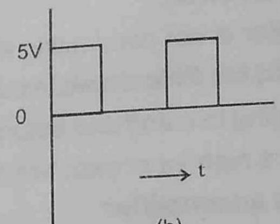
(a)

Analogue Circuits and Digital Circuits :

In analogue circuits, the voltage (or current) varies continuously with time (figure a). Such a voltage (or current) signal is called an 'analogue signal'.



(a)



(b)

On the other hand, in digital circuits, the voltage (or current) has only two levels, either zero or some constant value of voltage (figure b). A signal having only two levels of voltage (or current) is called a 'digital signal'.

Logic Gates :

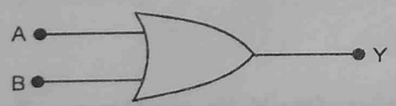
A logic gate is a digital circuit which works according to some logical relationship between input and output voltages. It either allows a signal to pass through or stops it.

There are three basic logic gates.

(a) OR gate (b) AND gate (c) NOT gate

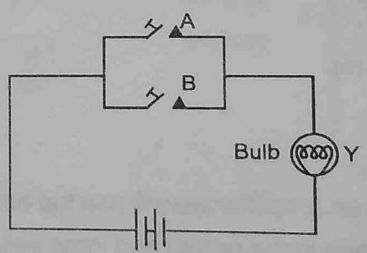
(a)The OR Gate :

The OR gate is a device that has two input variables A and B and one output variable Y, and follows the Boolean expression, A + B = Y,



(a)

Logic symbol



(b)

Equivalent electrical circuit

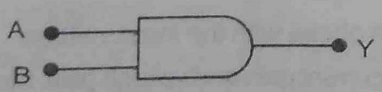
A	B	Y(= A+ B)
0	0	0
0	1	1
1	0	1
1	1	1

(c)

Truth table

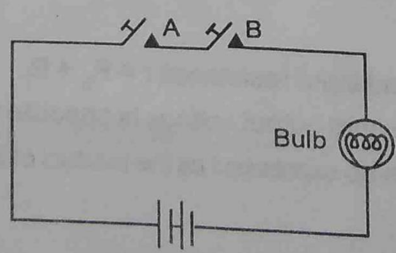
(b) The AND Gate :

The AND gate is also a two-input and one-output logic gate. It combines the inputs A and B to give the output Y, according to the Boolean expression, A.B = Y



(a)

Logic symbol



(b)

Equivalent electrical circuit

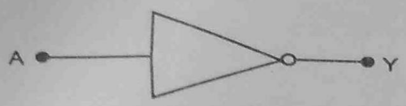
A	B	Y(= A. B)
0	0	0
0	1	0
1	0	0
1	1	1

(c)

Truth table

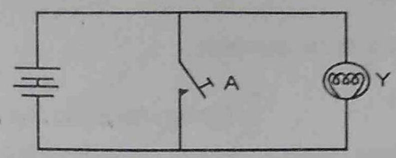
(c) The NOT Gate :

The NOT gate has only one input and one output. It combines the input A with the output Y, according to the Boolean expression, $\overline{A} = Y$.



(a)

Logic symbol



(b)

Equivalent electrical circuit

A	Y(= $\overline{A}$)
0	1
1	0

(c)

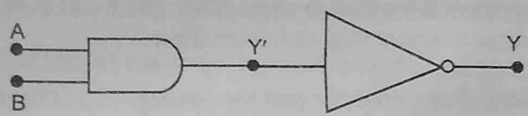
Truth table

Combinations of gates :

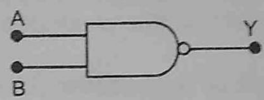
Various combinations of the three basic gates, namely, OR, AND and NOT, produce complicated digital circuits. The commonly used combinations of basic gates are NAND gate, NOR, gate. These are also called universal gates.

(i) The NAND gate :

This gate is a combination of AND and NOT gates. The Boolean expression for the NAND gate is $\overline{A \cdot B} = Y$



(a)



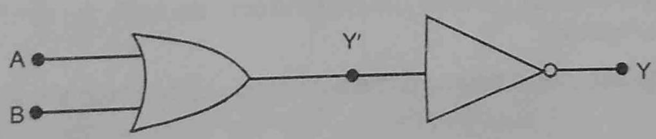
(b)

The resulting table is the truth table of the NAND gate.

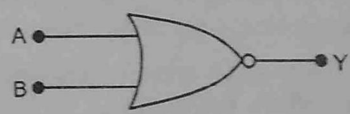
A	B	Y
0	0	1
0	1	1
1	0	1
1	1	0

(ii) The NOR Gate :

The NOR gate is a combination of OR and NOT gates. The Boolean expression for the NOR gate is $\overline{A + B} = Y$



(a)



(b)

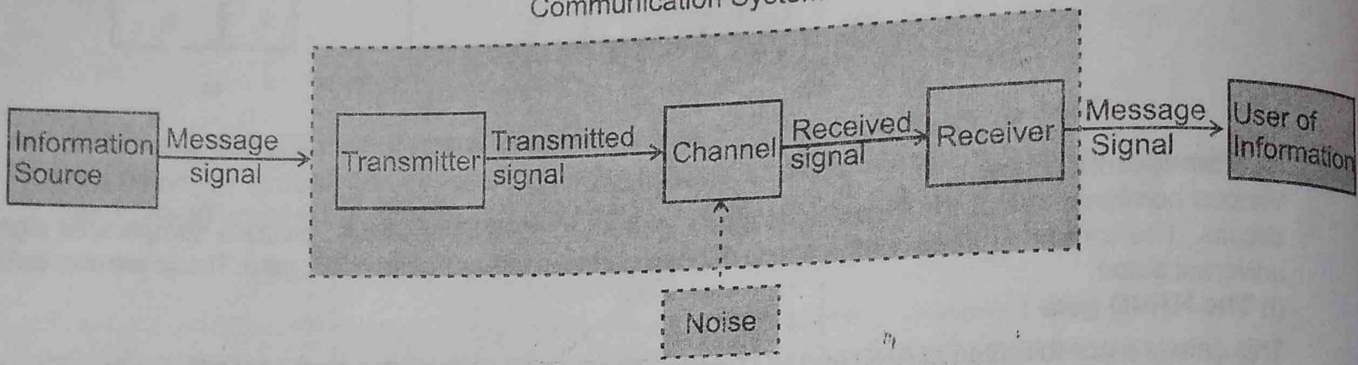
The resulting table is the truth table of the NOR gate.

A	B	Y
0	0	1
0	1	0
1	0	0
1	1	0

ELECTROMAGNETIC WAVES & COMMUNICATION SYSTEM

Communication is the act of transmission of information.

Elements of a communication system :



The transmitter is located at one place, the receiver is located at some other place (far or near) separate from the transmitter and the channel is the physical medium that connects them.

There are two basic modes of communication : Point -to-point and broadcast.

Basic Terminology Used in Electronic Communication Systems :

(i) Transducer : An electrical transducer may be defined as a device that converts some physical variable (pressure, displacement, force, temperature, etc) into corresponding variations in the electrical signal at its output.

(ii) Signal : Information converted in electrical form and suitable for transmission is called a signal. Signals can be either analog or digital. There are several coding schemes useful for digital communication. American Standard Code for Information Interchange (ASCII) is a universally popular digital code to represent numbers, letters and certain characters.

(iii) Noise : Noise refers to the unwanted signals that tend to disturb the transmission and processing of message signals in a communication system.

(iv) Transmitter : A transmitter processes the incoming message signal so as to make it suitable for transmission through a channel and subsequent reception.

(v) Receiver : A receiver extracts the desired message signals from the received signals at the channel output.

(vi) Attenuation : The loss of strength of a signal while propagating through a medium is known as attenuation.

(vii) Amplification : It is the process of increasing the amplitude (and consequently the strength) of a signal using a electronic circuit called the amplifier.

(viii) Range : It is the largest distance between a source and a destination up to which the signal is received with sufficient strength.

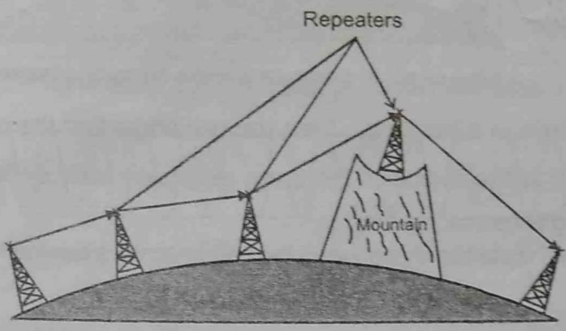
(ix) Bandwidth : Bandwidth refers to the frequency range over which an equipment operates or the portion of the spectrum occupied by the signal.

Signal type	Band width
Speech signal	2800 Hz
Audio signal	20 kHz
TV signal	4.2 MHz

(x) Modulation : At the transmitter, information contained in the low frequency message signal is superimposed on a high frequency wave, which acts as a carrier of the information. This process is known as modulation.

(xi) Demodulation : The process of retrieval of information from the carrier wave at the receiver is termed demodulation. This s the reverse process of modulation.

(xii) Repeater : A repeater is a combination of a receiver and a transmitter. They are used to extend the range of a communication system.



use of repeater station to increase the range of communication

Bandwidthof Transmission Medium :

Coaxial cables offer a bandwidth of approximately 750 MHz. Such cables are normally opertated below 18 GHz. Communication through free space using radio waves from offer a band width from a few hundreds of kHz to a few GHz. An optical fiber can offer a transmission bandwidth in excess of 100 GHz.

Propagation of electromagnetic Waves :

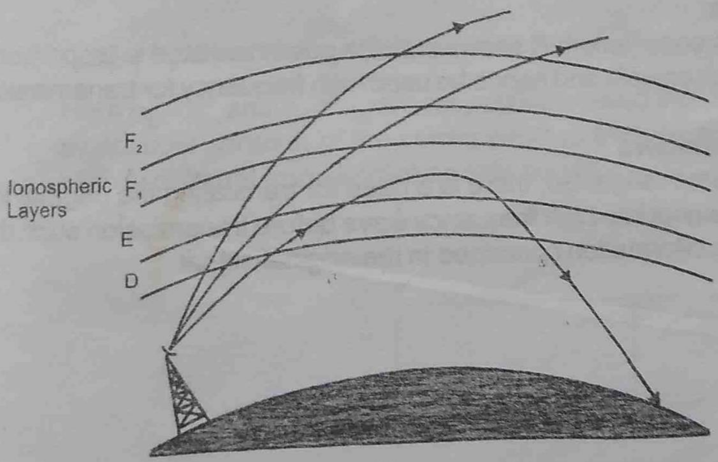
In communication using radio waves, an anetnna at the transmitter radiates the electromagnetic wave (em waves), which travel through the space and reach the receiving antenna at the other end.

Ground wave

For high frequency signal large antennas are located on ground. The mode of propagation is called surface wave propagation and the wave glides over the surface of the earth. A wave induces current in the ground over which it passes and it is attenuated as a result of absorption of energy by the earth. The attenuation of surface waves increases very rapidly with increase in frequency.

Sky waves

In the frequency range from a few MHz up to 30 to 40 MHz, long distance communication can be achieved by ionospheric reflection of radio waves back towards the earth. This mode of propagation is called sky wave propagation and is used by short wave broadcast services. The ionosphere layer acts as a reflector for a certain range of freqeuncies (3 to 30 MHz). Electromagnetic waves of frequencies higher than 30 MHz penetrate the ionosphere and escape.



D – Part of stratosphere (65 to 75 km height)

E – Part of stratosphere (100 km height)

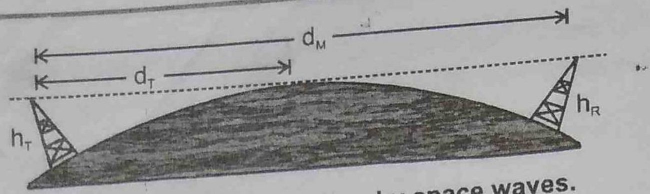
F_1 – Part of mesosphere (170 to 190 km height)

F_2 – Part of thermosphere (250 to 400 km height)

Sky wave propagation

Space wave

It is used for frequency above 40 MHz. A space wave travels in a straight line from transmitting antenna to the receiving antenna. Space waves are used for line-of-sight (LOS) communication as well as satellite communication.



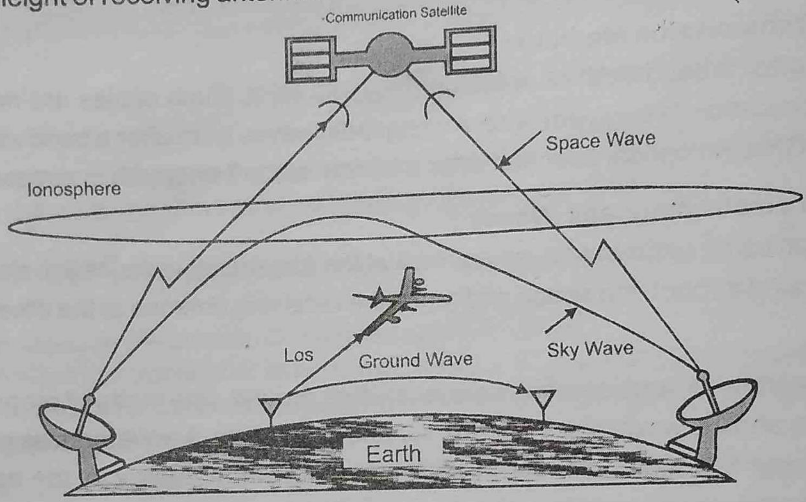
Line of sight communication by space waves.

If the transmitting antenna is at a heigth h_T, then you can show that the distance to the horizon d_T is given as $d_T = \sqrt{2Rh_T}$, where R is the radius of the earth (approximately 6400 km). d_T is also called the radio horizon of the transmitting antenna.

The maximum line-of-sight distance d_M between the two antennas having height h_T and h_R above the earth is given by

$$d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$$

where h_R is the height of receiving antenna.



Various propagation modes for em waves

Modulation And its Necessity :

1. Size of the antenna or aerial

For transmitting a signal, the antenna should have a size comparable to the wavelength of the signal (at least $\lambda/4$ in dimension) so that the antenna properly senses the time variation of the signal. For an electromagnetic wave of frequency 20 kHz. the wavelength λ is 15 km. Therefore, there is a need of translating the information contained in our original low frequency baseband signal into high or radio frequencies before transmission.

2. Effective power radiated by an antenna

A theoretical study of radiation from a linear antenna (length ℓ) shows that the power radiated is proportional to $(\ell/\lambda)^2$. For a good transmission, we need high powers and hence be used high frequency for transmission.

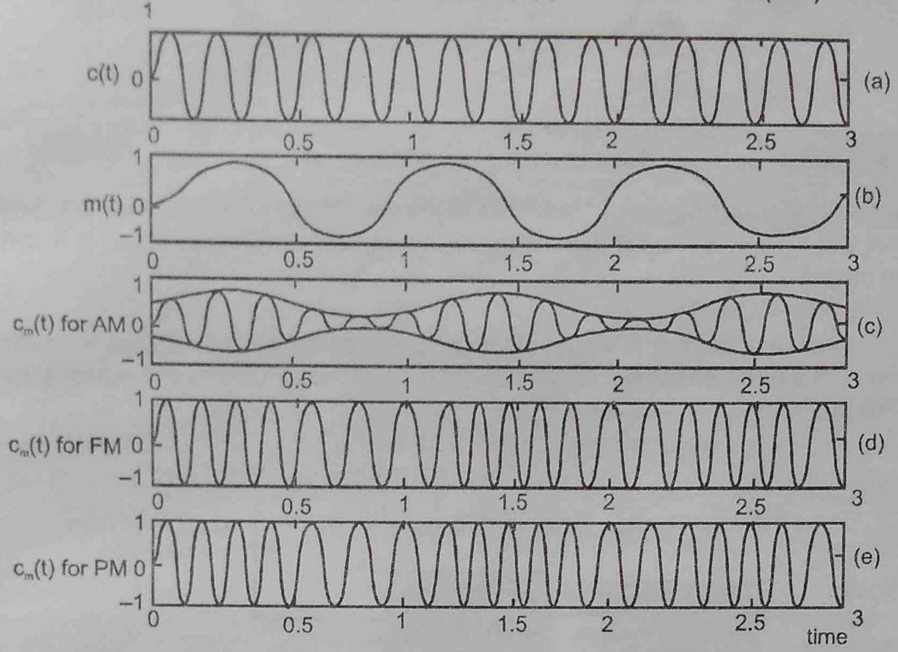
3. Mixing up of signals from different transmitters

Everyone can not transmit the signal in the same range. So, there is a need for translating the original low frequency baseband message or information signal into high frequency wave before transmission such that the translated signal continues to possess the information contained in the original signal.

Modulation

A sinusoidal carrier wave can be represented as $c(t) = A_c \sin(\omega_c t + \phi)$

During the process of modulation, any of the three parameters, i.e. A_c, ω_c and ϕ, of the carrier wave can be controlled by the message or information signal. This results in three types of modulation. (i) Amplitude modulation (AM), (ii) frequency modulation (FM) and (iii) pulse modulation (PM) as shown below.



Similarly, the significant characteristics of a pulse are : pulse amplitude, pulse duration or pulse Width, and pulse position (denotinig the time of rise or fall of the pulse amplitude) as shown in Fig. (b). Hence, different types of pulse modulation are : (a) pulse amplitude modulation (PAM), (b) pulse duration modulation (PDM) or pulse width modulation (PWM), and (c) pulse position modulation (PPM).

Amplitude Modulation

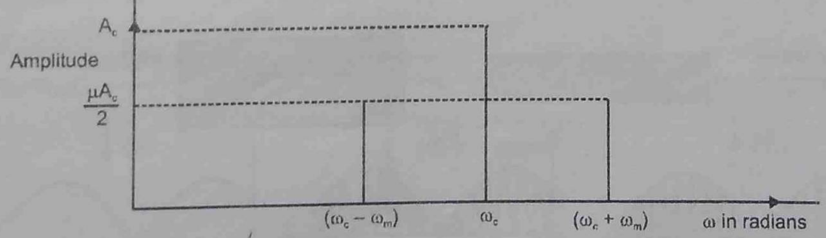
In amplitude modulation the amplitude of the carrier is varied in accordance with the information signal. The modulated signal c_m (t) can be written as

$$c_m(t) = (A_c + A_m \sin \omega_m t) \sin \omega_c t = A_c \left(1 + \frac{A_m}{A_c} \sin \omega_m t\right) \sin \omega_c t$$

This can also be written as

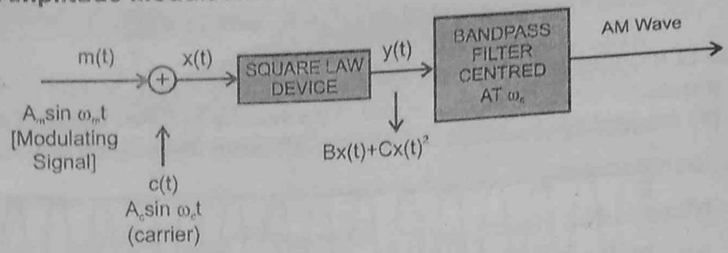
$$c_m(t) = A_c \sin \omega_c t + \frac{\mu A_c}{2} \cos(\omega_c - \omega_m) t - \frac{\mu A_c}{2} \cos(\omega_c + \omega_m) t$$

Here $\omega_c - \omega_m$ and $\omega_c + \omega_m$ are respectively called the lower side and upper side frequencies. The modulated signal now consists of the carrier wave of frequency ω_c plus two sinusoidal waves each with a frequency slightly different from, known as side bands.



A plot of amplitude versus ω for an amplitude modulated signal

Production of Amplitude Modulated Wave :

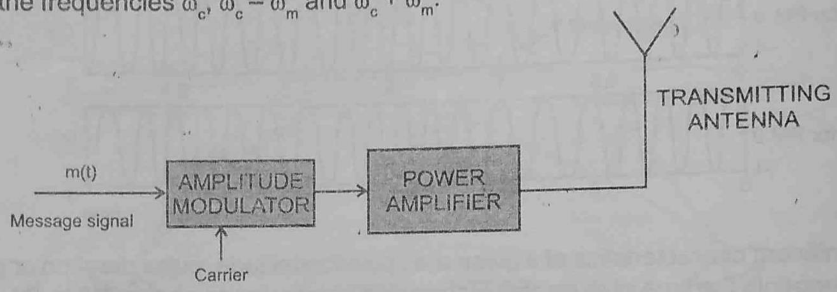


Block diagram of a simple modulator for obtaining an AM signal

Here the modulating singla $A_m \sin \omega_m t$ is added to the carrier signal $A_c \sin \omega_c t$ to produce the signal x(t). This signal $x(t) = A_m \sin \omega_m t + A_c \sin \omega_c t$ is passed through a square law device which is a non–linear device which produces an output

$$y(t) = B\,x(t) + Cx^2(t)$$

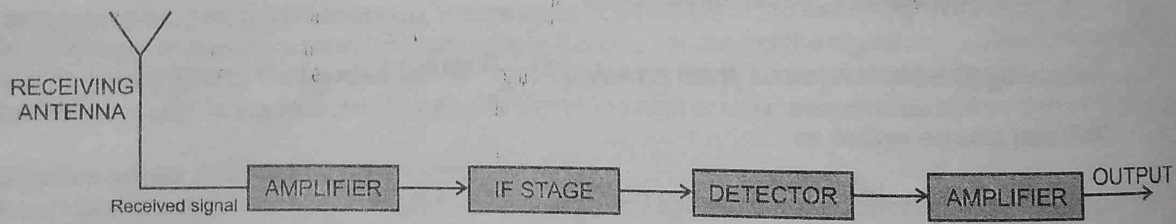
The output contains a dc term and sinusoids of frequencies $\omega_m, 2\omega_m, \omega_c, 2\omega_c, \omega_c - \omega_m$ and $\omega_c + \omega_m$. This signal is passed through a band pass filter which rejects dc and the sinusoids of frequencies ω_m, $2\omega_m$ and $2\omega_c$ and retains the frequencies ω_c, $\omega_c - \omega_m$ and $\omega_c + \omega_m$.



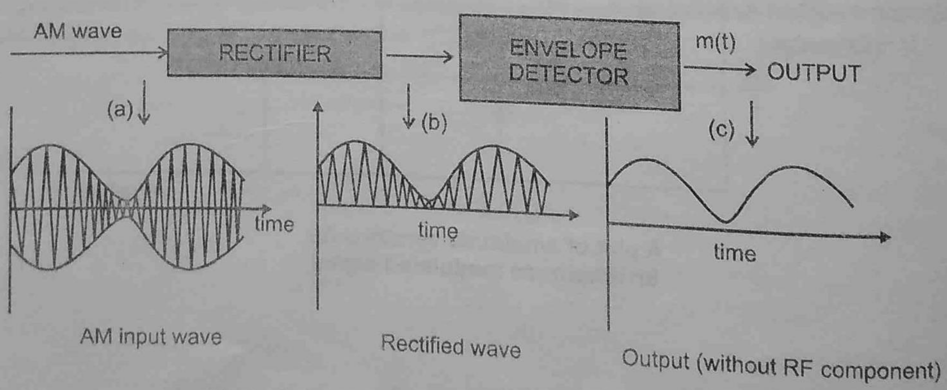
Block diagram of a transmitter

Detection of Amplitude Modulated Wave :

The transmitted message gets attenuated in propagating through the channel. The receiving antenna is therefore to be followed by an amplifier and a detector. To facilitate further processing, an intermediate frequency (IF) stage preceding the detection.

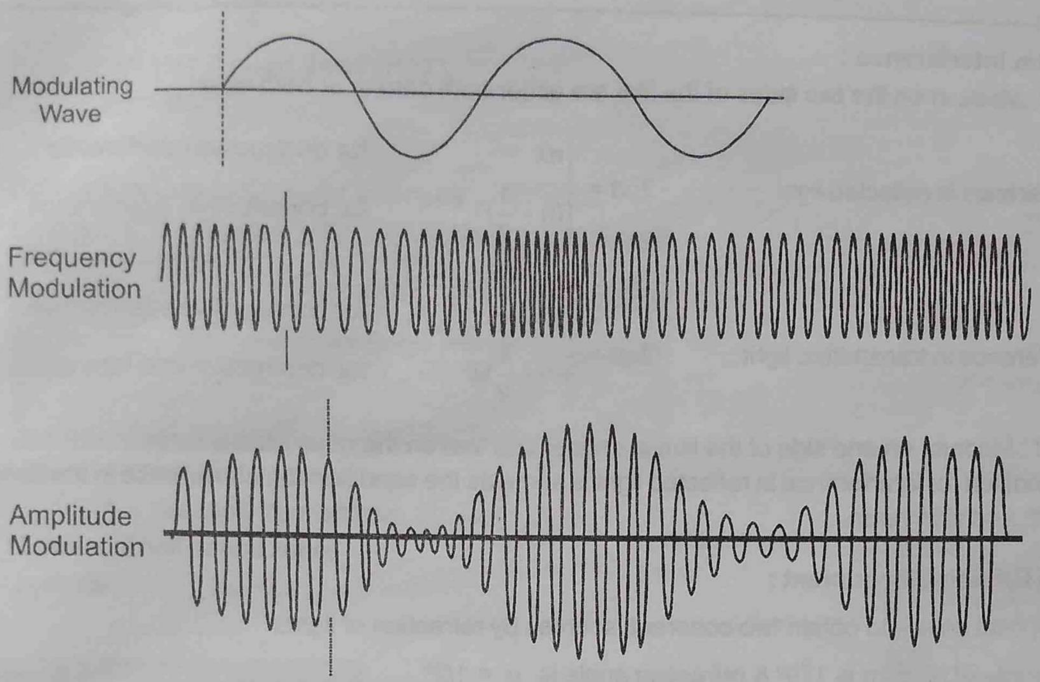


Block diagram of a receiver



Block diagram of a detector for AM signal.
The quantity on y–axis can be current or voltage

Frequency Modulation:
In this mode of modulation, the frequency of the carrier signal varies in accordance with the modulating signal.



$$\text{Frequency modulation index} = \frac{\text{frequency deviation}}{\text{modulating frequency}}$$

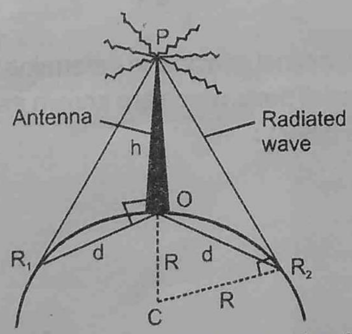
Advantage of Frequency Modulation :

1. FM is less prone to disturbances.
2. Fidelity or audio quality of the frequency modulated signal is better then amplitude modulated transmission. Therefore, FM is preferred for transmission of music

Range of Frequencies allotted for FM Radio and TV Broadcast

Nature of broadcast	Frequency band
FM radio	88 to 108 MHz
VHF TV	47 to 230 MHz
UHF TV	470 to 960 MHz

Frequency-Modulated Communication (Height of Transmitting Antenna)
The effective reception range of the broadcast is essentially the region from R_1 to R_2 which is covered by the line of sight in a conventional sense. Hence, sometimes this mode of communication is termed as **line of sight communication.**



Ray-path of transmitted waves following space-wave (or line of sight) mode of propagation. The transmitter is located at the ground on a tall tower.
The TV signal will be received in a circle of radius d.

$d = \sqrt{2Rh}$ Here R is radius of the Earth.

OPTICAL INSTRUMENT

Thin-Film Interference :

Case - 1: Medium on the two sides of the film are either both denser or both rarer

for interference in reflected light $2\mu d = \begin{cases} n\lambda & \text{for destructive interference} \\ (n+\frac{1}{2})\lambda & \text{for constructive interference} \end{cases}$

for interference in transmitted light $2\mu d = \begin{cases} n\lambda & \text{for constructive interference} \\ (n+\frac{1}{2})\lambda & \text{for destructive interference} \end{cases}$

Case - 2 : Medium on one side of the film is denser and that on the other side is rarer.
Here condition for interference in reflected light is same as the condition for interference in transmitted light of case 1, and vice versa.

Fresnel's Birpism Experiment :

(1) It is optical device to obtain two coherent sources by refraction of lights.

(2) The angle of biprism is 179° & refracting angle is α = 1/2°.

(3) Distance between source & screen D = a + b.

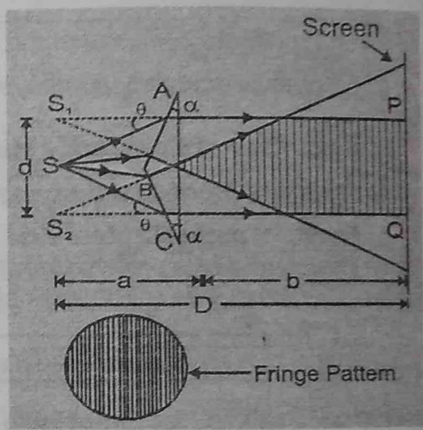
Distance between two coherent source = d = $2a(\mu-1)\alpha$

Where a = distance between source & Biprism

b = distance between screen & Biprism

μ = refractive index of the material of prism.

$$\lambda = \frac{d\beta}{D} = \frac{2a(\mu-1)\alpha\beta}{(a+b)}$$



Diffraction :

Definition : The phenomenon of bending of light waves around the sharp edges of opaque obstacles or aperture and their encroachment in the geometrical shadow of obstacle or aperture is defined as diffraction of light.

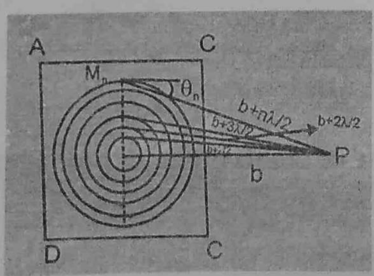
Necessary Conditions of Diffraction of Waves

The size of the obstacle (a) must be of the order of the wavelength of the waves (λ).

$$\frac{a}{\lambda} \approx 1$$

Fresnel Diffraction : According to fresnel principal to determine the intensity of light at any point, a wavefront can be divided into a number of small parts which are known as fresnel's half period zones.

* **Radius of nth Half Period Zone (HPZ) :**



$$r_n = \sqrt{nb\lambda}$$

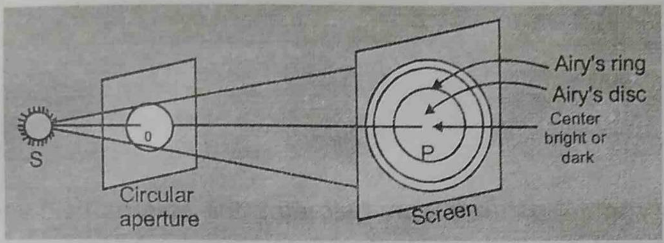
* **Average Distant of Point P From nth HPZ**

$$d_n = b + \frac{(2n-1)}{4}\lambda$$

* **Area of n^{th} Half Period Zone (HPZ)**

$$A_n = \pi b\lambda.$$

Diffraction Due to Circular Aperture

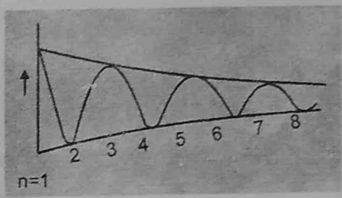


Let r = radius of aperture

b = distance from screen

Number of half period zones

$$n = \frac{\pi r^2}{\pi b\lambda}$$



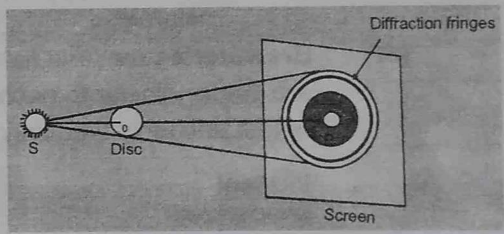
* If odd number of HPZ are allowed to pass through, the central fringe will be bright.
* The central fringe is brightest if only one HPZ is allowed to pass.
* Even number of HPZ are allowed to pass through the aperture, the central point will be nearly dark. When n = 2 central fringe is darkest.

Diffraction due to circular Disc :

* Central fringe of the shadow is always bright irrespective of number of HPZ covered by the disc.

* No. of n HPZ = Area of disc

$$n = \frac{r^2}{b\lambda}$$



fraunhofer diffraction for single slit :

In this diffraction pattern central maxima is bright on the both side of it, maxima & minima occurs symmetrically

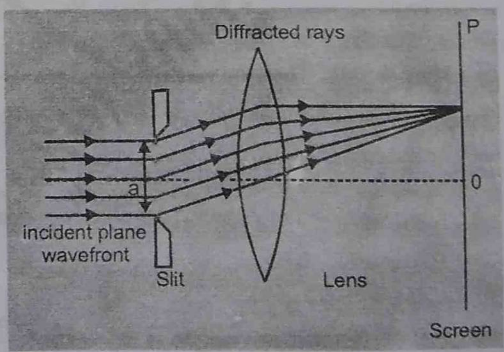
For Diffraction Maxima :

$$a \sin\theta = (2n + 1)\lambda/2$$

For Diffraction Minima :

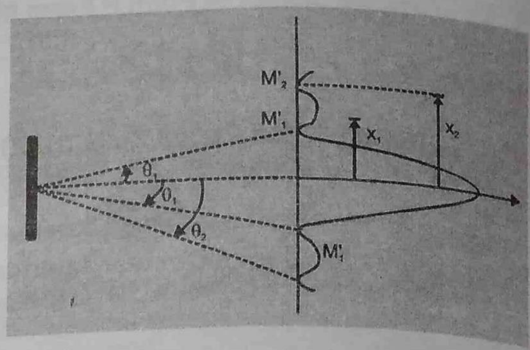
$$a \sin\theta = n\lambda$$

The maxima or minima is observed due to the superposition of waves emerging from infinite secondary sources between A & B points of slit.



Fringe width :

The distance between two secondary minima formed on two sides of central maximum is known as the width of central maximum



$$W = \frac{2f\lambda}{a}$$

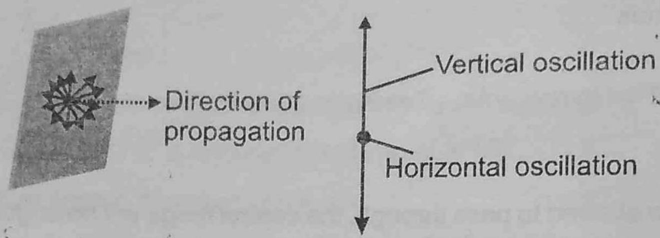
f = focal distance of convex lense

a = width of slit

Angular width = $W_\theta = \frac{2\lambda}{a}$

☛ **Polarisation of Light :**

(1) **Unpolarised light** : In ordinary light (light from sun, bulb etc.) the electric field vectors are distributed in all directions in a light is called unpolarised light.



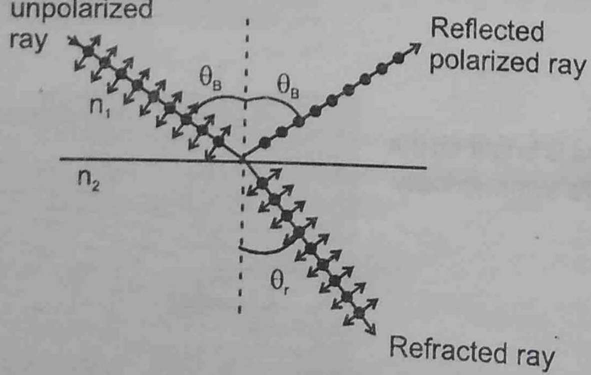
(2) **Polarised light :** The phenomenon of limiting the vibrating of electric field vector in one direction in a plane perpendicular to the direction of propagation of light wave is called polarization of light

(i) The plane in which oscillation occurs in the polarised light is called plane of oscillation.

(ii) The plane perpendicular to the plane of oscillation is called plane of polarisation.

(iii) Light can be polarised by transmitting through certain crystals such as tourmaline or polaroids.

(3) **Brewster's Low :** For light incident at the Brewster angle θ_B, The reflected and refracted rays are perpendicular to each other. The refracted light has only perpendicular components. The reflected light is then fully polarized perpendicular to the plane of incidence.



Brewster angle = $\theta_B = \tan^{-1}\frac{n_2}{n_1}$

COMPENDIUM OF FORMULAS

PHYSICAL CHEMISTRY

ATOMIC STRUCTURE

Estimation of closest distance of approach (derivation) of α-particle

$$R = \frac{4KZe^2}{m_\alpha V_\alpha^{\,2}}$$

Conserve Energy

(closest distance of approach)

Size of the nucleus :

The radius of a nucleus

Ro generally = $\frac{4}{3}$ fermi

$$R = R_0 (A)^{1/3} \text{ cm}$$

where R_0 can be 1.1×10^{-13} to 1.44×10^{-13} cm ; A = mass number ; R = Radius of the nucleus.

Planck's Quantum Theory

Energy of one photon = $h\nu = \frac{hc}{\lambda}$

h = planck's constant = 6.625×10^{-34} Js, ν = frequency of light

☞ If a charge 'q' is accelerated through a potential difference of 'V' volt then its kinetic energy will be increased by q.V.

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

Photoelectric Effect :

$$h\nu = h\nu_0 + \frac{1}{2} m_e v^2$$

where m_e is the mass of the electron and v is the velocity associated with the ejected electron.

Bohr's Model for Hydrogen like atoms :

1. $mvr = n \frac{h}{2\pi}$ (Quantization of angular momentum)

$$v = \frac{nh}{2\pi mr}$$

2. $E_n = -\frac{E_1}{n^2} z^2 = -2.178 \times 10^{-18} \frac{z^2}{n^2}$ J/atom $= -13.6 \frac{z^2}{n^2}$ eV

$$E_1 = \frac{-2\pi^2 me^4 z^2}{n^2} \quad (z = 1, \text{ for H-atom})$$

3. $r_n = \frac{n^2}{Z} \times \frac{h^2}{4\pi^2 e^2 m} = \frac{0.529 \times n^2}{Z}$ Å