APPLIED PHYSICS MATERIAL – R20

(JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY: KAKINADA)

FRESHMEN ENGINEERING DEPARTMENT

Course: B.Tech.   **Regulation: R20**

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REGISTER   NUMBER: _____

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PHYSICS IS NATURE

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY: KAKINADA

KAKINADA – 533 003, Andhra Pradesh, India

I Year	APPLIED PHYSICS (R20)	L	T	P	C
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UNIT-I: WAVE OPTICS

Interference: Principle of superposition –Interference of light - Interference in thin films (Reflection Geometry) & applications - Colors in thin films- Newton's Rings - Determination of wavelength and refractive index.

Diffraction: Introduction - Fresnel and Fraunhofer diffraction - Fraunhofer diffraction due to single slit, double slit – N-slits (Qualitative) – Diffraction Grating - Dispersive power and resolving power of Grating(Qualitative).

Polarization: Introduction-Types of polarization - Polarization by reflection, refraction and Double refraction - Nicol's Prism -Half wave and Quarter wave plates.

UNIT-II: LASERS AND FIBER OPTICS

Lasers: Introduction – Characteristics of laser – Spontaneous and Stimulated emissions of radiation – Einstein's coefficients – Population inversion – Lasing action - Pumping mechanisms– Ruby laser – He-Ne laser - Applications of lasers.

Fiber optics: Introduction –Principle of optical fiber- Acceptance Angle - Numerical Aperture - Classification of optical fibers based on refractive index profile and modes – Propagation of electromagnetic wave through optical fibers - Applications.

UNIT III:QUANTUM MECHANICS, FREE ELECTRON THEORY & BAND THEORY

Quantum Mechanics: Dual nature of matter – Heisenberg's Uncertainty Principle – Significance and properties of wave function – Schrodinger's time independent and dependent wave equations– Particle in a one-dimensional infinite potential well.

Free Electron Theory: Classical free electron theory (Qualitative with discussion of merits and demerits) – Quantum free electron theory– Equation for electrical conductivity based on quantum free electron theory- Fermi-Dirac distribution- Density of states (3D) - Fermi energy.

Band theory of Solids: Bloch's Theorem (Qualitative) - Kronig - Penney model (Qualitative)- E vs K diagram - v vs K diagram - effective mass of electron – Classification of crystalline solids–concept of hole.

UNIT-IV: DIELECTRIC AND MAGNETIC MATERIALS

Dielectric Materials: Introduction - Dielectric polarization - Dielectric polarizability, Susceptibility and Dielectric constant - Types of polarizations - Electronic (Quantitative), Ionic (Quantitative) and Orientation polarizations (Qualitative) - Lorentz internal field- Clausius- Mossotti equation- Piezoelectricity.

Magnetic Materials: Introduction - Magnetic dipole moment - Magnetization-Magnetic susceptibility and permeability - Origin of permanent magnetic moment - Classification of magnetic materials: Dia, para, Ferro, antiferro & Ferri magnetic materials - Domain concept for Ferromagnetism & Domain walls (Qualitative) - Hysteresis - soft and hard magnetic materials- Eddy currents- Engineering applications.

UNIT-V:SEMICONDUCTORS AND SUPERCONDUCTORS

Semiconductors: Introduction- Intrinsic semiconductors – Density of charge carriers – Electrical conductivity – Fermi level – extrinsic semiconductors – density of charge carriers – dependence of Fermi energy on carrier concentration and temperature - Drift and diffusion currents – Einstein's equation- Hall effect – Hall coefficient –Applications of Hall effect.

Superconductors: Introduction – Properties of superconductors – Meissner effect – Type I and Type II superconductors – BCS theory (Qualitative) – Josephson effects (AC&DC) – SQUIDs- High T_c superconductors – Applications of superconductors.

Text books:

1. M. N. Avadhanulu, P.G.Kshirsagar & TVS Arun Murthy" A Text book of Engineering Physics"- S.Chand Publications, 11th Edition 2019.
2. Engineering Physics by D.K.Bhattacharya & Poonam Tandon, Oxford press (2015)
3. Applied Physics by P.K.Palanisamy SciTech publications.

Reference Books:

1. Fundamentals of Physics – Halliday, Resnick and Walker, John Wiley &Sons
2. Engineering Physics by M.R.Srinivasan, New Age international publishers (2009).
3. Shatendra Sharma, Jyotsna Sharma, " Engineering Physics", Pearson Edu-2018.
4. Engineering Physics - Sanjay D. Jain, D. Sahasrabudhe and Girish, University Press
5. Semiconductor physics and devices- Basic principle – Donald A, Neamen, Mc Graw Hill
6. B.K. Pandey and S. Chaturvedi, Engineering Physics, Cengage Learning.

UNIT- I : WAVE OPTICS

1) **INTERFERENCE:** Principle of superposition - Interference of light - Interference in thin films (Reflection Geometry) & applications - Colours in thin films - Newton's Rings - Determination of wavelength and refractive index.

2) **DIFFRACTION:** Introduction - Fresnel and Fraunhofer diffraction - Fraunhofer diffraction due to single slit, double slit, N-slits (Qualitative) - Diffraction Grating - Dispersive power and resolving power of Grating (Qualitative).

3) **POLARIZATION:** Introduction -Types of polarization - Polarization by reflection, refraction and Double refraction - Nicol's Prism - Half wave and Quarter wave plates.

1)   INTERFERENCE

➢ **PRINCIPLE OF SUPERPOSITION**   .

"When two or more light waves arrive at a point, the resultant displacement is equal to sum of the displacements of individual light waves."

$$Y = Y_1 \pm Y_2$$

Constructive superposition: If the displacements of two light waves are in same phase, it is called constructive superposition.

$$Y = Y_1 + Y_2$$

Destructive superposition: If the displacements of two waves are in opposite phase, it is called destructive superposition.

$$Y = Y_1 - Y_2$$

➢ **INTERFERENCE OF LIGHT**   .

"The variation of light intensity due to superposition of two or more light waves of same wavelength, amplitude, frequency and constant phase difference, is called interference."

Constructive interference: If two light waves are in same phase, it is called constructive interference.

It gives maximum light intensity, $I_{max} = (a + b)^2$

Path difference   = $n \lambda$ .... $(n = 0, 1, 2, . . . \alpha)$

Phase difference = $2 \pi n$ .... $(n = 0, 1, 2, . . . \alpha)$

Destructive interference: If two light waves are in opposite phase, it is called destructive interference.

It gives minimum intensity, $I_{min} = (a - b)^2$

Path difference = $(2n \pm 1) \lambda/2$ $(n=0, 1, 2, . . . \alpha)$

Phase difference = $(2n \pm 1) \pi$ $(n=0, 1, 2, ... \alpha)$

➢ **CONDITIONS FOR SUSTAINED INTERFERENCE**   .

To produce sustained interference, the following points required.

1. Two light sources must be required.
2. Light sources should be monochromatic.
3. Light sources should be coherent.
4. Light sources must be same amplitude.
5. Light sources must be as nearer as possible.
6. Screen must be as far from the source.
7. Light sources must be narrow and extremely small.

> **INTERFERENCE IN THIN FILMS BY REFLECTION GEOMETRY** .
> **- COSIN LAW-**

Thin Film: **The smallest thickness of a medium is called thin film.**

When a white light is reflected from thin films like soap bubbles they produce variety of colors due to interference. When the light is reflected from the upper and lower boundaries of a thin film, the reflected light rays produce interference pattern.
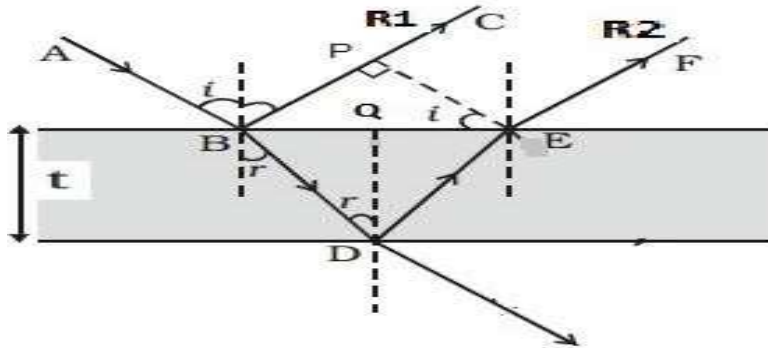
1. Consider a thin film of thickness 't' is shown in the figure.
2. Let the light AB is incident on the thin film at B.
3. BC is reflected light called as R_1
4. BD is refracted light and reflected at D and passes as DF called as R_2.
5. R_1 and R_2 produce interference.

Path difference between R_1 and R_2 is Δ

$$\Delta = \mu (BD + DE) - BP \quad \text{------ (1)}$$

from Δle BDQ,   BD = QD/cos r = t/cos r   ------ (2)

from Δle QDE,   DE = QD/cos r = t/cos r   ------ (3)

from the Δle BEP,   sin i = BP/BE

           BP = BE sin i

           BP = (BQ + QE) sin i---- (4)

from the Δle BDQ, sin r = BQ/BD

           BQ = BD sin r = (t/cos r) sin r = t Tan r   ---------- (5)

from the Δle EDQ,   sin r = QE/DE

           QE = DE sin r = (t/cos r) sin r = t Tan r   ---------- (6)

from equations (4),   BP = (t Tan r + t Tan r) sin i

           BP = 2t Tan r . sin i

from equations (1), (2), (3), (4), (5) & (6),

Path difference $(\Delta) = \mu (BD+DE) - BP$

$$= \mu\left(\frac{t}{\cos r} + \frac{t}{\cos r}\right) - 2t \tan r \sin i$$

$$= \frac{2\mu t}{\cos r} - 2t\frac{\sin r}{\cos r}\sin i\left(\mu\frac{\sin r}{\sin i}\right)$$

$$= \frac{2\mu t}{\cos r} - 2\mu t\frac{\sin^2 r}{\cos r}$$

$$= \frac{2\mu t}{\cos r}\left(1 - \sin^2 r\right)$$

$$(\Delta) = \frac{2\mu t}{\cos r}\left(\cos^2 r\right)$$

Path difference $(\Delta) = 2\mu t \cos r$

Path difference between R_1 and R_2 $(\Delta) = 2\mu t \cos r$

When the light is reflected at air- denser medium, it can lose path difference of '$\lambda/2$'.

The resultant path difference $= 2\mu t \cos r - \dfrac{\lambda}{2}$ --------- (7)

Case (i): Condition for Constructive interference (Bright fringes):

for bright fringe, Path difference $= n\lambda$---------(8)

from equations (7) & (8),

$$2\mu t \cos r - \dfrac{\lambda}{2} = n\lambda$$

$$2\mu t \cos r = n\lambda + \dfrac{\lambda}{2}$$

$$2\mu t \cos r = (2n+1)\dfrac{\lambda}{2}$$

Case (ii): Condition for destructive interference (Dark fringes):

For dark fringe, Path difference $= (2n-1)\,\lambda/2$------------(9)

from equations (7) & (9),

$$2\mu t \cos r - \dfrac{\lambda}{2} = (2n-1)\dfrac{\lambda}{2}$$

$$2\mu t \cos r = n\lambda$$

Case(iii): If the thickness of the thin film is extremely small, it gives destructive interference and film will appear as dark.

If **t = 0**, from equation (7), Path difference $= \pm \dfrac{\lambda}{2}$

➢ APPLICATIONS OF INTERFERENCE .

1. Used for determination of wavelength of light.
2. Used for determination of the radius of curvature of Plano-convex lens.
3. Used for determination of thickness of material (small objects) & optical flatness ofsurfaces.
4. Used for determination of refractive index of transparent solids, liquids & gasses.
5. Used to find the difference between spectral lines of nearly same wavelength.
6. Used to find the velocity of light using Michelson interferometer.

➢ COHERENCE .

Ordering of light field is called Coherence.

Types of coherence:

2. **Temporal (Longitudinal) Coherence:** The correlation of phase between any two pointson the wave is same, that coherence is called as temporal coherence.

3. **Spatial (Transverse) Coherence:** The correlation of phase between any two points onany two waves is same, that coherence is called as special coherence.

➢ COLOURS IN THIN FILMS .

Colors in thin films are due to the interference between the light waves reflected from the tops and the bottom surfaces of thin films.

"The variation of light intensity due to superposition of two or more light waves of same wavelength, amplitude, frequency and constant phase difference is called interference."

When the white light is incident on a thin film, it appeared colors like soap bubbles, oil layers and metal surfaces.

A variety of colors could be seen in our daily life due to the interference phenomenon.

The color depends upon the thickness of the film and also the angle of incidence of the light. This thin-film interference is a natural phenomenon.

Thin Film: *The smallest thickness of a medium is called thin film.*

When a white light is reflected from thin films like soap bubbles they produce variety of colors due to interference. When the light is reflected from the upper and lower boundaries of a thin film, the reflected light rays produce interference pattern.
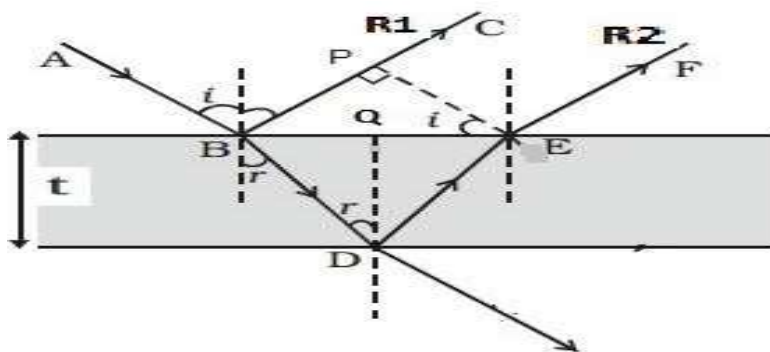
The resultant path difference between two reflected light rays R1 and R2 is

$$P.D = 2\mu t \cos r - \frac{\lambda}{2} \text{ --------- (1)}$$

Case (i): Condition for Constructive interference (Bright fringes):

for bright fringe, Path difference = $n\lambda$---------(2)

from equations (1) & (2),

$$2\mu t \cos r - \frac{\lambda}{2} = n\lambda$$

$$2\mu t \cos r = n\lambda + \frac{\lambda}{2}$$

$$2\mu t \cos r = (2n+1)\frac{\lambda}{2}$$

Case (ii): Condition for destructive interference (Dark fringes):

For dark fringe, Path difference = $(2n-1)\lambda/2$------------(3)

from equations (1) & (3),

$$2\mu t \cos r - \frac{\lambda}{2} = (2n-1)\frac{\lambda}{2}$$

$$2\mu t \cos r = n\lambda$$

Case(iii): If the thickness of the thin film is extremely small, it gives destructive interference then film will appear as dark.
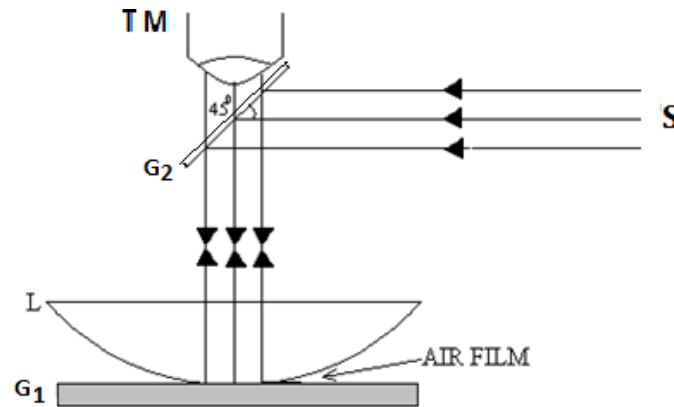
If **t = 0**, from equation (7), Path difference = $\pm\frac{\lambda}{2}$

➢ NEWTON'S RINGS EXPERIMENT .

Definition: *Concentric Circular interference fringes are called Newton's rings.*
Objective: Newton's rings experiment is used to find the radius of curvature of plano-convex lens, wave length of light source and refractive index of medium.
**Experimental Arrangement:**

1. The experimental arraignment is shown in the above figure.
2. L is a Plano convex lens.
3. G_1 is a plane glass plate.
4. S is monochromatic light source.
5. G_2 is a glass plate held at an angle 45^0 with horizontal.

Procedure:

When a monochromatic light is incident on the glass plate G_2, it gets reflect the light normally into the thin (air) film. The reflected light rays R_1 and R_2 from the thin film travels in the same direction and produce bright and dark alternative circular interference fringes arecalled Newton"s rings.
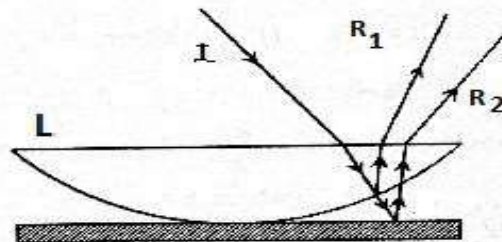
Theory: According to thin film concept, path difference between R_1 and R_2 =2μtcosr but here, μ=1 and r = 0^0, then

$$\text{Path difference} = 2t$$

When the light is reflected at denser-air medium, it gets additional path difference and is equal to $\lambda/2$.

Hence, the resultant path difference = $2t + \lambda/2$ ------ (1)

Case1: For bright ring:

Path difference = $n\lambda$ …..------(2)   here n = 1,2,3

from equations (1) and (2),

$$2t + \lambda/2 = n\lambda$$
$$2t = n\lambda - \lambda/2$$
$$2t = (2n - 1)\lambda/2 \quad \text{--------(3)}$$

Case2: For dark ring:

Path difference = $(2n + 1)\lambda/2$ --------(4)

from equations (1) and (4), $2t + \lambda/2 = (2n + 1)\lambda/2$

$$2t = (2n + 1)\lambda/2 - \lambda/2$$

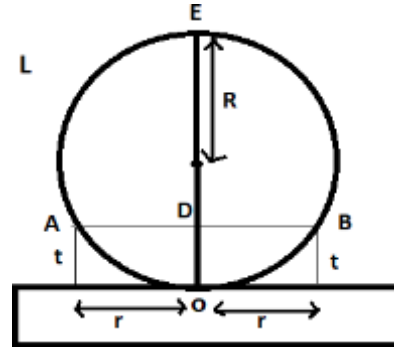$$2t = n\lambda \qquad \text{-------(5)}$$

Radius of curvature (R) of Plano-convex lens:

Let R is the radius of curvature of Plano-convex lens,

r is radius of the Newton ring,

t is thickness of air film of a newton ring is shown in the figure.

from the geometry of the circle,

$$\text{AD x DB} = \text{OD x DE,}$$

$$r \text{ x } r = t \text{ x}(2R - t)r^2$$

$$r^2 = 2Rt - t^2$$

since 't' is extremely small,

$$r^2 = 2Rt$$

$$\frac{d^2}{4} = 2Rt \qquad \text{(since } r^2 = d^2/4\text{)}$$
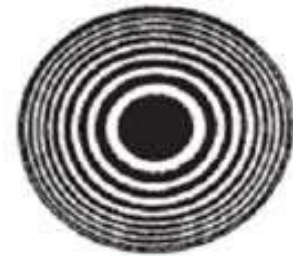
$$2t = \frac{d^2}{4R} \qquad \text{-----------(6)}$$

If AB lie on the nth bright ring, then from equations (3) & (6),

$$\frac{d_n^{\,2}}{4R} = (2n-1)\frac{\lambda}{2}$$

$$d_n^{\,2} = 2(2n-1)\lambda R \text{ ------(7)} \qquad \text{(or)} \qquad d_n = \sqrt{(2n-1)}$$

If A, B lie on the nth dark ring, then from equations (5) & (6),

$$\frac{d_n^{\,2}}{4R} = n\lambda$$

$$d_n^{\,2} = 4n\lambda R \qquad \text{------(8)} \qquad \text{(or)} \qquad d_n = \sqrt{n}$$

Similarly, If AB lie on the mth dark ring then

$$d_m^{\,2} = 4m\lambda R \qquad \text{------(9)}$$

from equations (8) & (9), we get

Radius of curvature of lens, $R = \dfrac{d_m^{\,2} - d_n^{\,2}}{4\lambda(m-n)}$

Wavelength of light, $\lambda = \dfrac{d_m^{\,2} - d_n^{\,2}}{4R(m-n)}\mu$

Refractive index of medium, $\mu = \dfrac{4\lambda R(m-n)}{d_m^{\,2} - d_n^{\,2}}$

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2) DIFFRACTION

DEFINITION:
 Bending of light at any edges or obstacles (or apertures or barriers) is called diffraction of light.

➢ **DISTINGUISH BETWEEN FRESNEL'S & FRAUNHOFER'S DIFFRACTION**

Diffraction phenomenon can be divided into two types

1. Fresnel's diffraction
2. Fraunhofer diffraction

	Fresnel's diffraction	*Fraunhofer's diffraction*
1.	Condition of fresnel's diffraction is $b^2/l\lambda \simeq 1$ Here 'b' is size of the aperture 'λ' is wave length of source 'l' is distance from source to screen.	Condition of fraunhofer diffraction is $b^2/l\lambda \ll 1$ Here 'b' is size of the aperture 'λ' is wave length of source 'l' is distance from source to screen.
2.	Source and screen are at finite distance from the aperture.	Source and screen are at infinite distance from the aperture.
3.	Incident wave fronts are either spherical or cylindrical.	Incident wave fronts are always plane wave fronts.
4.	Lenses not required to make the diffraction pattern.	Lenses must be required to make the diffraction pattern.

➢ **DISTINGUISH BETWEEN INTERFERENCE & DIFFRACTION**

|	*Interference*	*Diffraction*
1.	Superposition is due to two or more waves of same amplitude, same wavelength and coherence.	Superposition is due to secondary wavelets from single light source.
2.	Bright and dark fringes were formed.	Principal maxima, minima intensity positions and secondary maxima positions formed.
3.	All fringes having equal widths.	Not equal
4.	All bright fringes having same intensity.	Not same
5.	All Dark fringes having zero intensity.	Not zero intensity

➢ **FRAUNHOFER'S DIFFRACTION AT SINGLE SLIT**

Consider plane wave fronts from monochromatic light source of wavelength 'λ' are incident on the slit AB.

Let the width of the slit is 'e'. Let the secondary wave lets focused at a point P_1 on the screen (XY) by making diffracted angle 'θ' as shown in the figure.

According to Huygens- Fresnel's principle, each and every point on the primary wave front produce secondary wave lets in all directions.

To find the path difference between AP_1 and BP_1, draw a normal AC from A to BP_1. Hence the path difference is BC.
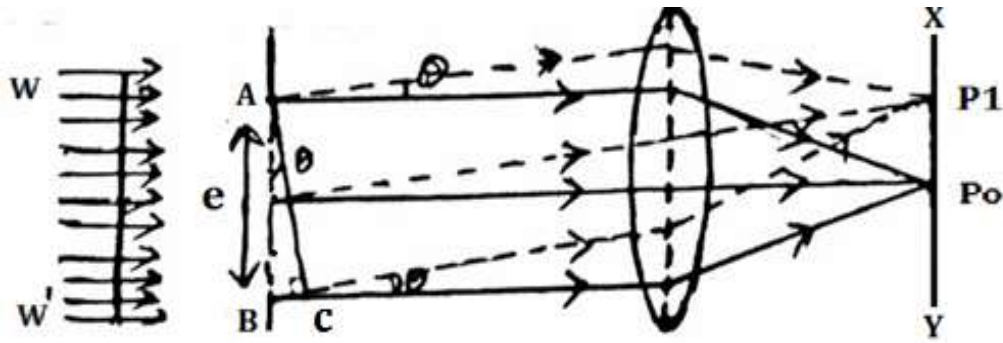
from Δle ABC,

$\sin \theta = BC/AB$

$BC = AB \sin \theta$

$BC = e \sin \theta$ $(\because AB = e)$

$\therefore$ Path difference $(BC) = e \sin \theta$

Phase difference $= (2\pi/\lambda) x$ path difference

$\therefore$ Phase difference $= (2\pi/\lambda) e \sin \theta$

Let width of the slit 'e' can be divided into 'n' equal parts and 'a' be the amplitude of light ray passing through each part.

phase difference of the light rays between any two successive parts (δ) = (total phase)/n

$$\delta = \frac{(2\pi/\lambda)e\sin\theta}{n} = d(say)$$

According to vector addition method, Resultant amplitude is, $R = \dfrac{a\sin(nd/2)}{\sin(d/2)}$

$$R = \frac{a\sin\left(n\dfrac{(2\pi/\lambda)e.\sin\theta}{2n}\right)}{\sin\left(\dfrac{(2\pi/\lambda)e.\sin\theta}{2n}\right)}$$

$$R = \frac{a\sin((\pi/\lambda)e.\sin\theta)}{\sin\left(\dfrac{(\pi/\lambda)e.\sin\theta}{n}\right)}$$

$$R = \frac{a\sin(\alpha)}{\sin(\alpha/n)} \qquad (\because (\pi/\lambda)e.\sin\theta = \alpha)$$

since (α/n) is very small, hence $\sin(\alpha/n) \simeq (\alpha/n)$

$$R = \frac{a\sin\alpha}{\alpha/n}$$

$$R = \frac{na\sin\alpha}{\alpha}$$

$$R = \frac{A\sin\alpha}{\alpha} \qquad (\because na = A)$$

But the Intensity of light $I = R^2$,

$$I = \frac{A^2\sin^2\alpha}{\alpha^2}$$

Case (1) : Principal maxima

When $\alpha = 0$ then $\theta = 0$ hence the resultant intensity will be maximum.

If $(\pi/\lambda) e \sin\theta = 0.$ then $\sin\theta = 0,$ $\therefore \theta = 0$

Case (2) : Minima intensity position

When $\sin\alpha = 0$ then the resultant intensity will be minimum.

$\therefore \sin\alpha = \pm m\pi$ here m=1,2,3,......

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$$\frac{\pi}{\lambda} e \sin\theta = \pm m\pi$$

$$\therefore e\sin\alpha = \pm m\lambda$$

Case (3) : Secondary maxima

In addition to the principal maxima at $\alpha = 0$, there is weak secondary maxima positions in between equally spaced minima.

$$\therefore \frac{dI}{d\alpha} = 0$$

$$\frac{d}{dx}[A^2(\frac{\sin\alpha}{\alpha})^2] = 0$$

$$A^2.2\frac{\sin\alpha}{\alpha}.\frac{\alpha\cos\alpha - \sin\alpha}{\alpha} = 0$$

since, $A^2 \neq 0$ and $\sin\alpha \neq 0$ so $\alpha\cos\alpha - \sin\alpha = 0$

$$\alpha\cos\alpha = \sin\alpha$$

$$\alpha = \frac{\sin\alpha}{\cos\alpha} \qquad \text{hence } \alpha = \text{Tan }\alpha$$

by plotting a graph for $y = \alpha$ & $y = \tan\alpha$ on same graph sheet,

the intersection points are $\alpha = 0, \pm\frac{3\pi}{2}, \pm\frac{5\pi}{2}$ ... ...

since $\alpha = 0$ gives principal maxima, so $\alpha = \pm\frac{3\pi}{2}, \pm\frac{5\pi}{2}$ ... ...
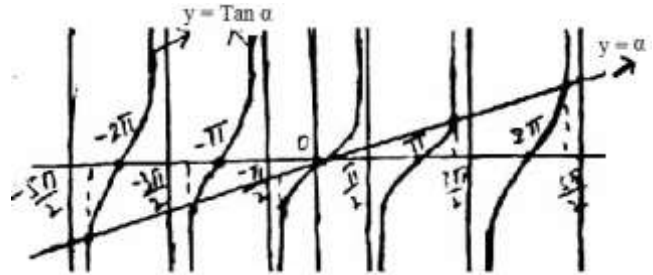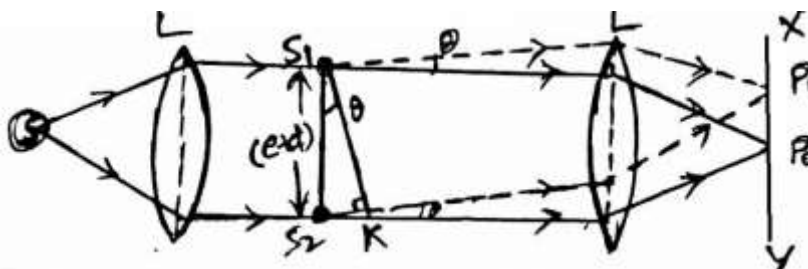
Resultant Intensity distribution graph :
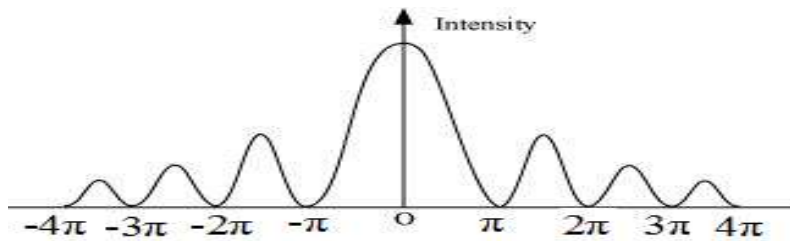
➢ FRAUNHOFER DIFFRACTION AT DOUBLE SLITS

Consider two parallel slits S_1, S_2 of equal width 'e' and are separated by an opaque distance (d). Let the distance between middle points of the two slits is (e+d).

Consider a beam of monochromatic light of wavelength 'λ' is incident on the two slits S_1 and S_2. All the points on the primary wave fronts within the slits are produce secondary wave lets.

Let the secondary wave lets focussed at a point P_1 on the screen (XY) by making diffracted angle 'θ' as shown in the figure.

According to fraunhofer diffraction at a single slit experiment, Resultant Amplitude

$$R = \frac{A\sin\alpha}{\alpha}$$

for finding the path difference between S_1P_1 & S_2P_1, draw a normal (S_1K) from S_1 to S_2P_1. Let the path difference is equal to S_2 K.

from Δle S_2S_1K,

$$\text{Sin }\theta = S_2K / S_1 S_2$$

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$$S_2\,K = S_1 S_2 \sin\theta$$
$$S_2\,K = (e + d)\sin\theta$$

Path difference $(S_2\,K) = (e+d)\sin\theta$

Corresponding Phase difference $(\delta) = \dfrac{2\pi\,(e+d)\sin\theta}{\lambda}$

The resultant amplitude 'R' at P_1

$R^2 = R_1{}^2 + R_2{}^2 + 2R_1 R_2 \cos\delta$

$R^2 = (\dfrac{A\sin\alpha}{\alpha})^2 + (\dfrac{A\sin\alpha}{\alpha})^2 + 2(\dfrac{A\sin\alpha}{\alpha})(\dfrac{A\sin\alpha}{\alpha})\cos\delta$

$R^2 = (\dfrac{A\sin\alpha}{\alpha})^2 (1+1+2\cos\delta)$

$R^2 = 2(\dfrac{A\sin\alpha}{\alpha})^2 (1+\cos\delta)$

$R^2 = 2(\dfrac{A\sin\alpha}{\alpha})^2 (1+2\cos^2\delta/2 - 1)$

$R^2 = 4(\dfrac{A\sin\alpha}{\alpha})^2 \cos^2\delta/2$

$$\boxed{\therefore I = R^2 = 4(\dfrac{A\sin\alpha}{\alpha})^2 \cos^2\delta/2}$$

Here, the terms $(\dfrac{A\sin\alpha}{\alpha})^2$ and $\cos^2\delta/2$ represents the diffraction and interference pattern.

Case (1) : **Depending on diffraction term** $(\dfrac{A\sin\alpha}{\alpha})^2$:-

a) *Principal Maxima*: when $\alpha = 0$ then $\theta = 0$.
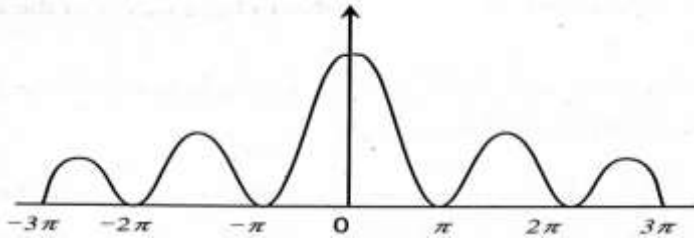
b) *Minima Position*: If $\sin\alpha = 0$ then $\alpha = \pm\, m\pi$ $(\because m=1,2,3...)$

c) *Secondary Maxima:* If $\alpha = \tan\alpha$ then $\alpha = \pm\dfrac{3\pi}{2}, \pm\dfrac{5\pi}{2}, \pm\dfrac{7\pi}{2}$ ...

Case (2) : **Depending on interference term** $\cos^2\delta/2$:-   Let $\delta/2 = \beta$
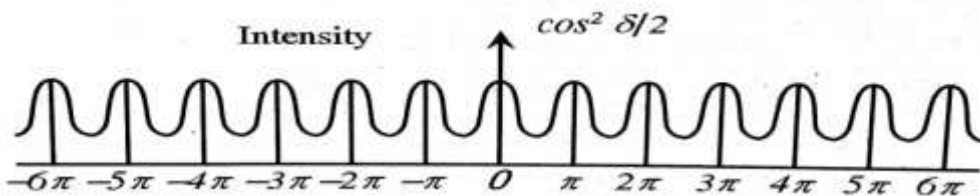
a) *for bright fringes* :- If $\cos^2\beta = 1$ then $\beta = n\pi$ (n=0,1,2,3...)
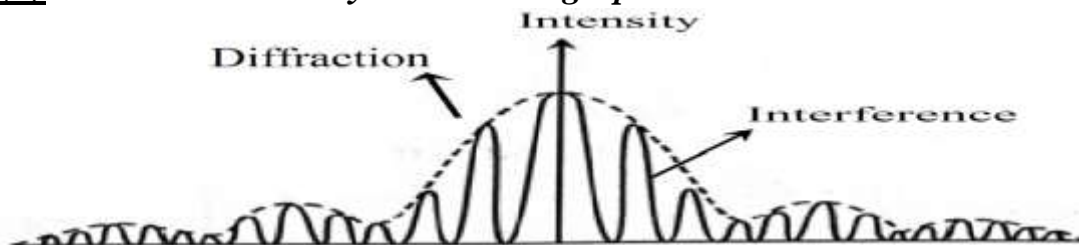
$$\dfrac{\pi(e + d)\sin e}{\lambda} = \pm n\pi$$
$$(e+d)\sin\theta = \pm\, n\lambda$$

b) *for dark fringes* :- If $\cos^2\beta = 0$, then $\beta = (2n \pm 1)\dfrac{\pi}{2}$

$\dfrac{\pi(e+d)\sin e}{\lambda} = (2n \pm 1)\dfrac{\pi}{2}$ hence $(e+d)\sin\theta = (2n \pm 1)\dfrac{\pi}{2}$


Case (3) : **Resultant Intensity distribution graph:**

➢ FRAUNHOFER DIFFRACTION AT 'N'- SLITS

Consider 'n' parallel slits of equal width 'e' separated by an opaque distance(d). Let the distance between mid points of any two slits is (e+d).

Consider a beam of monochromatic light of wavelength 'λ' is incident on 'n' slits, all the points on primary wave fronts within the slits are produce secondary wave lets.
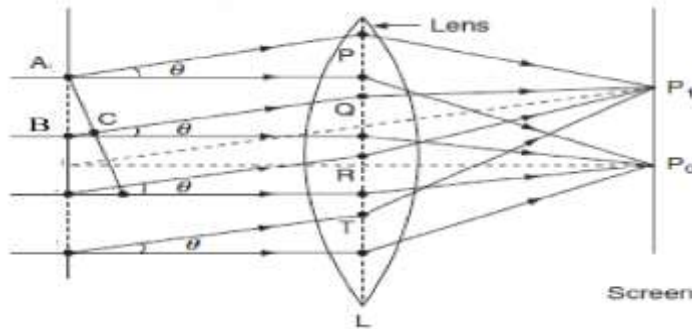
Let these secondary wave lets focused at a point P_1 on the screen by making an angle of diffraction 'θ' with respect to incident beam is shown in the figure.

According to vector addition method, Resultant amplitude is $R = \dfrac{a \sin(nd/2)}{\sin(d/2)}$

Let $a = \dfrac{A \sin \alpha}{\alpha}$,   n=N   and   d/2 = β

$$R = (\frac{A\sin\alpha}{\alpha})\frac{\sin N\beta}{\sin\beta}$$

$$\therefore I = R^2$$

$$I = (\frac{A\sin\alpha}{\alpha})^2(\frac{\sin N\beta}{\sin\beta})^2$$

Case(1): Principal maxima:

If $sin\,\beta = 0$, it gives maximum intensity.

$$\beta = \pm\, n\pi \text{ where } n = 0,1,......$$

π/λ(e+d)sin θ = ± nπ

(e+d) sinθ = ± nλ

Case(2): Minima Positions:

If $sinN\beta = 0$, it gives minimum intensity.

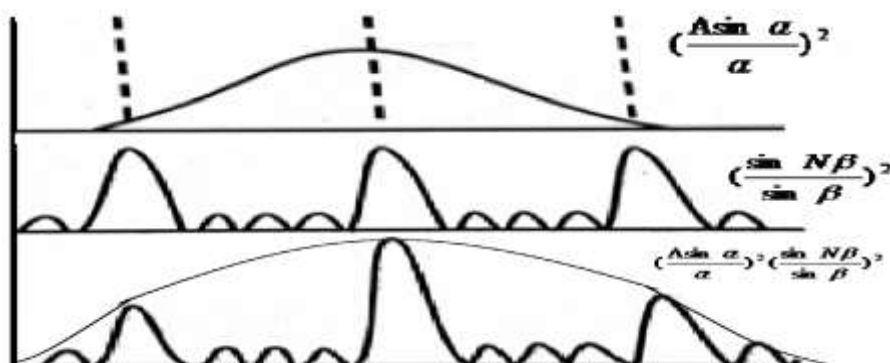Nβ = ± mπ   where m = 1,2,3........(N-1)

Nπ/λ(e+d)sin θ = ± mπ

N(e+d) sin θ = ± mλ

Case(3): Secondary maxima:

There are (N-1) minima in between two adjacent principal maxima.

So that there must be (N-2) secondary maxima between two adjacent principal maxima.

Resultant intensity Graph:

➢ DIFFRACTION GRATING

The plane transparent glass material consists of large number of equidistant, sharp, narrow, parallel lines is called plane diffraction grating.

When the white light passes through the grating, all slits diffracts the light and corresponding wavelengths produce diffracted pattern is also called as diffraction spectra or grating spectra.
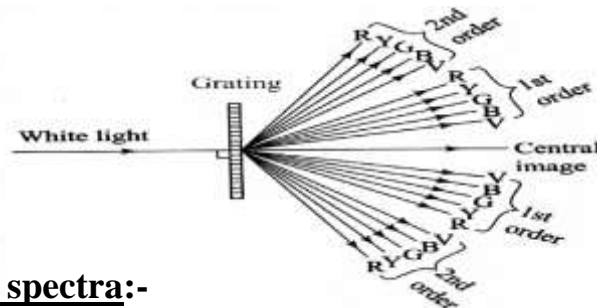
Characteristics of grating spectra:-

1. The spectral lines are almost straight and sharp.
2. Most of the incident light intensity goes to zero order image. It will appear as bright (white).
3. Spectra of different orders are situated symmetrically on both sides of zero order image.
4. In each spectrum, spectral colours are in the order from violet to red.
5. The spectral lines are more and more dispersed as order increases. i.e $\theta \alpha N$
6. *Maximum number of orders available with a grating is,* $n = \dfrac{(e+d)\sin\theta}{\lambda}$

Here, n - order of the spectrum, e - width of each slit, d - width of each opaque part, (e+d) - grating element (1/N), θ - angle of diffraction, λ - wavelength of light source.

If θ = 90⁰ , it gives maximum number of possible orders

∴ $n = (e+d)/\lambda$ or $n \leq 1/N\lambda$

➢ RESOLVING POWER OF GRATING

The capacity of grating to separate the spectral lines which have nearly same wave length. **(or)**

The ability of grating to form separate diffraction maxima of two wavelengths, which have very close to each other.

$$\textbf{Resolving power of grating } = \frac{\lambda}{d\lambda} = \text{Nn}$$

Proof: *According to Rayleigh's criterion, the wavelengths will be resolved when the first minima of one wave coincides with the principal maxima of another wave.*
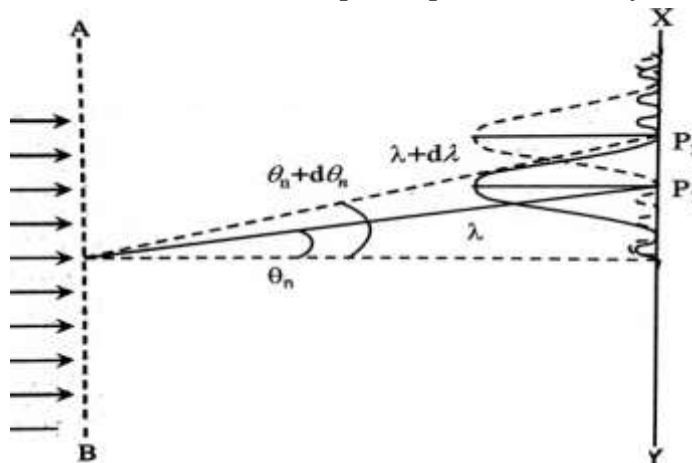
Consider a light which passes through the grating, the diffracted wave of different wave lengths λ and dλ form their principal maxima at P_1 and P_2 on the screen (XY) by making an angles θ and θ+dθ is as shown in the figure.

The condition of principal maxima of wavelength 'λ' in the direction 'θ' is

$$(e+d) \sin \theta = n\lambda \qquad \text{here } n = 0, 1, 2 \ldots \qquad \rightarrow (1)$$

The condition for minima of wavelength 'λ' is

$$N(e+d) \sin \theta = m\lambda \qquad \text{here } m = 1N, 2N, 3N \ldots = n\,N \qquad \rightarrow (2)$$

The condition for immediate minima after n^{th} maxima

Let $\theta = \theta + d\theta$, m=(nN+1) , from (2)equation

$$N (e+d) \sin (\theta + d\theta) = (nN+1)\lambda \qquad \rightarrow (3)$$

The condition for principal maxima of wavelength 'λ+dλ' in the direction 'θ+dθ' is

$$(e+d) \sin (\theta + d\theta) = n (\lambda + d\lambda)$$
$$N (e+d) \sin (\theta + d\theta) = Nn (\lambda + d\lambda) \qquad \rightarrow (4)$$

According to Rayleigh's criterion, from (3) & (4) equations

$$(nN+1)\lambda = N.n (\lambda + d\lambda)$$
$$nN\lambda + \lambda = Nn\lambda + Nnd\lambda$$
$$\lambda = N\,n\,d\lambda$$

$$\boxed{\dfrac{\lambda}{d\lambda} = N.n} \qquad \text{or} \qquad \boxed{\dfrac{\lambda}{d\lambda} = \dfrac{N.(e+d)\sin\theta}{\lambda}}$$

Resolving power (λ/dλ) of grating is directly proportional to the order of the spectrum.

➢ RAYLEIGH'S CRITERION FOR RESOLVING POWER

According to Rayleigh's criterion, it is possible to resolve the spectral lines which have nearly same wavelength.

It means that when the wavelength of the first minima of one wave coincides with the principal maxima of another wave, it should be resolvable by using an optical instrument.

The angle of resolution (dθ) = 1.22λ/d

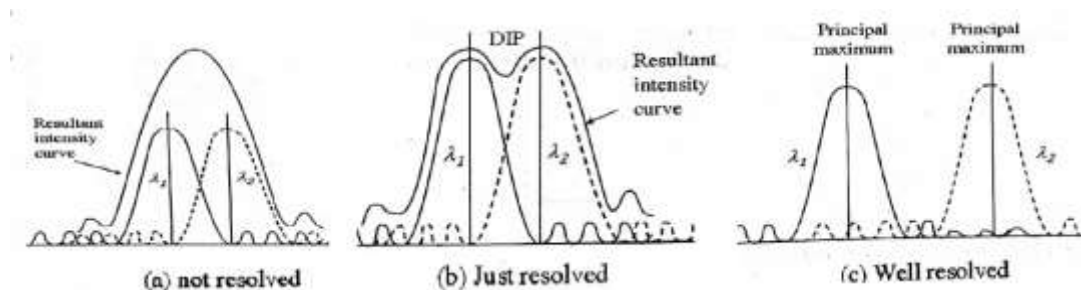(a) not resolved   (b) Just resolved   (c) Well resolved

Figure (a) – not resolved
Figure (b) – Just resolved
Figure (c) – well resolved

➢ GRATING EQUATION

Consider 'n' parallel slits of equal width 'e' are separated by an opaque distance 'd'. Let the distance between corresponding mid points of any two slits is (e+d).

Consider a beam of monochromatic light of wavelength 'λ' is incident on the 'n' slits, all the diffracted beam is focused on the screen.

From Δ le ABC

$\sin \theta = BC/AB$

$BC = AB \sin \theta$

$BC = (e+d) \sin \theta$

path difference (BD)= (e+d) sin θ   ---- (1)

for bright fringe p.d = nλ   ---- (2)

from equations (1) & (2),   **(e+d) sin θ= nλ**

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3) POLARIZATION

INTRODUCTION:

The phenomena of interference and diffraction shows that the light has wave nature, but they do not confirm that the light is a transverse wave or longitudinal wave. The phenomena of polarization proved that the nature of light is transverse wave nature.

Light is nothing but an Electromagnetic (EM) wave because of it has both electric and magnetic fields. Both electric field (E) vector and magnetic field (B) vectors are perpendicular to each other and also perpendicular to the direction of propagation.
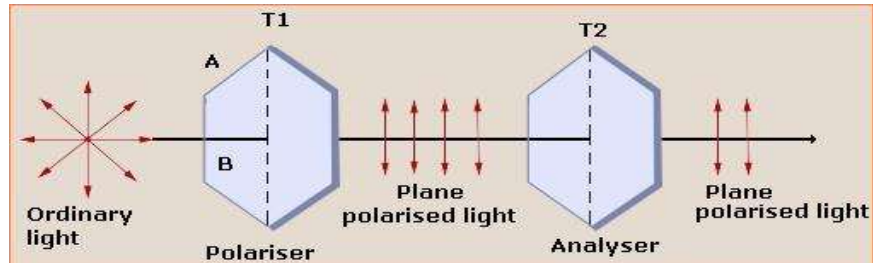
POLARISATION

The process of converting unpolarized light into polarized light is called polarization.
(or)
The process of converting Ordinary light into extraordinary light is called polarization.

The light which vibrates in a single plane is called polarized light.
The light which vibrates in more than one plane is called unpolarized.

Polarizer: The material which is used for polarization is called polarizer.
Analyzer: The material which is used to analyze the polarized light is called analyzer.
Calcites, Quartz, Tourmaline, Nichol's prism are examples of polarizer and analyzer.
Plane of Vibration:
The plane in which the electric vector (E) vibrates, is called plane of vibration.
Plane of Polarization:
The plane which is perpendicular to the plane of vibration is called plane of polarization.

➤ TYPES OF POLARISATIONS .

1) **Linearly plane polarized light**: When the amplitudes of electric (E) vectors of light changes, but orientation remains constant, then the path traced by electric vectors is a straight line. Hence, that polarized light is said to be linearly plane polarized light.

2) **Circularly polarized light:** When the amplitude of electric (E) vectors of light remains constant but orientation changes, then the path traced by the electric vectors is circular. Hence, that polarized light is said to be circularly polarized light.

3) **Elliptically polarized light:** When the amplitudes of electric vectors and orientation changes, then the path traced by electric (E) vectors is an ellipse and that polarized light is said to be elliptically polarized light.

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➢ **METHODS OF PRODUCTION OF PLANE POLARIZED LIGHT** .

1. Polarization by reflection from Di-Electric surfaces
2. Polarization by refraction (Pile of plates)
3. Polarization by double refraction (Birefringence)

1) **Polarisation by Reflection (Brewster's law):**

When an ordinary light is incident on the dielectric (glass) surface at a particular angle of incidence (θ_p), the light which vibrations are perpendicular to the crystal planes is reflected back as polarized light and the light which vibrations are parallel to the crystal planes is refracted into the glass. This refracted light is partially polarized.
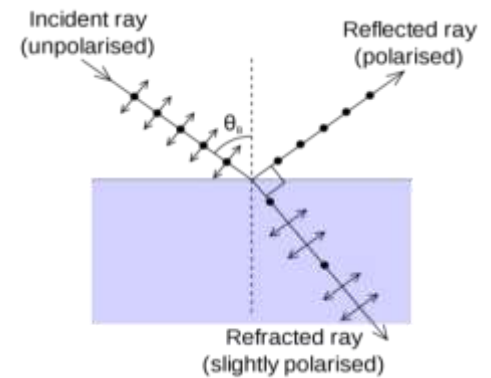

Brewster's angle (θ_p): It is the angle of incident light at which the reflected light is completely polarized. It is known as angle of polarization.

Brewster's law: The refractive index (μ) of a material is equal to the tangent of angle of polarization (θ_p). **$\mu = Tan(\theta_p)$**

2) **Polarisation by Refraction (Pile of Plates):**

When a beam of ordinary light is incident on the first glass plate of a pile of plates at Brewster's angle, some part of light is reflected up and some part of light is refracted. The light which vibrates perpendicular to the glass planes is reflected up as polarized light and the light which vibrates parallel to the glass planes is refracted as partially polarized light as shown in the figure.

Pile of plates
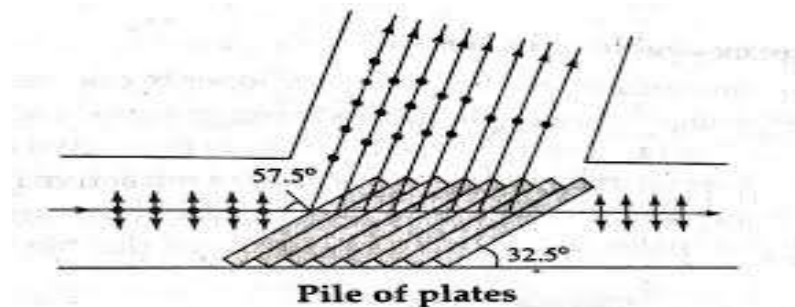
Partially polarized light is incident again on the second glass plate, some part of light gets reflected up as polarized light and some part of light gets transmitted as partially polarized light as said above.

Finally, the refracted light is also completely polarized after passing through the 15 (or) 20 glass plates. In this way, we get both reflected and refracted lights as polarized lights.

3) **Polarization by Double Refraction (Birefringence):**

When a beam of ordinary light is incident on a calcite or quartz crystal, the refracted light splits up into two refracted rays, one is ordinary ray (O-ray) and another is extraordinary ray (e-ray). This is called double refraction of light (or) birefringence.

Let grounded angles of principal section of calcite is 71^0 and 109^0. O-ray travels along PO making an angle of refraction r_1 and e-ray travels along PE making an angle r_2 is shown in the figure.

let the refractive indices of o - ray and e - ray are μ_0 and μ_e, then
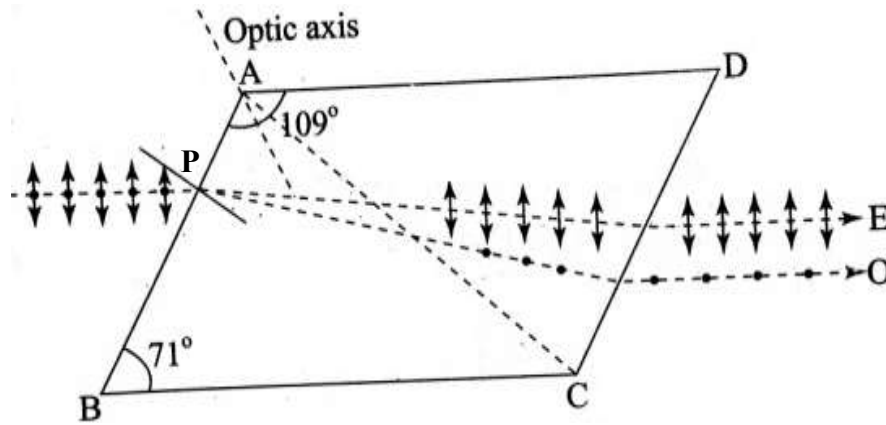
$$\mu_0 = \frac{\sin i}{\sin r1} \quad \text{and} \quad \mu_e = \frac{\sin i}{\sin r2}$$

here $r_1 < r_2$ and $\mu_0 > \mu_e$

for calcite crystal, $\mu_0 = 1.6504$, $\mu_e = 1.4864$,
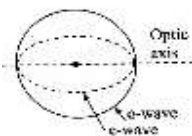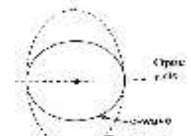
1. O-ray obey Snell's law and e-ray does not obey Snell's law.
2. Velocity of o-ray is same in all directions and velocity of e-ray is different in different directions.
3. The velocities of o-ray and e-ray are same along the optic axis inside the crystals.
4. The velocity of o-ray is more in quartz (positive) crystal and velocity of e-ray is more in calcite (negative) crystal.
5. For positive crystals ellipsoid is within the sphere and for negative crystals sphere is within the ellipsoid is shown in the figure.
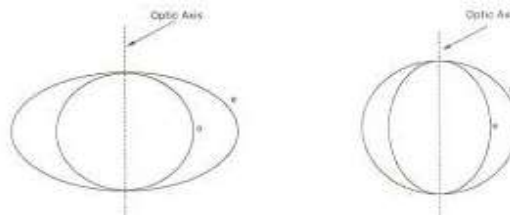
6. When the crystal is rotating about the beam of axis, e-ray rotates about the beam of axis around the fixed o-ray is shown in the below figure.
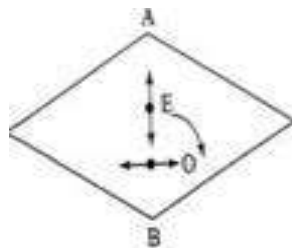
➤ DIFFERENCES BETWEEN UNPOLARISED LIGHT &POLARISED LIGHT

UNPOLARISED LIGHT (O-ray)	POLARISED LIGHT (e-ray)
1. O-ray obey Snell's law and other laws of refractions.	1. E-ray doesn't obey Snell's law and other laws of refractions.
2. Refracted angle of O-ray is less than the refracted angle of e -ray.	2. Refracted angle of e-ray is more than the refracted angle of O-ray.
3. Vibrations of electric vectors are perpendicular to the optic axis.	3. Vibrations of electric vectors are parallel to the optic axis.
4. O-ray travels with same speed in all directions in the crystals.	4. E-ray travels with different speeds in different directions in the crystals.
5. Velocity of O-ray is more in Quartz / positive crystals.	5. Velocity of e-ray is more in calcite / negative crystals.
6. Speed of o-ray and e-ray is same along the optic axis.	6. Speed of o-ray and e-ray is same along the optic axis.
7. For positive crystals, ellipsoid is within the sphere.	7. For negative crystals, sphere is within the ellipsoid.

➤ CONSTRUCTION AND WORKING OF NICOL's PRISM

Nicol's Prism is a good polarizer as well as good analyzer. Nicol's prism is working on the basic principle of Total Internal Reflection.

Working Principle: *Total Internal Reflection*

When the light travels from a denser medium to rarer medium, if the angle of   incidence is   greater than the critical angle,the light totally reflected in the   denser medium,   this phenomenon is called Total Internal Reflection.

Description of Nicol's Prism:

1. Nicol's prism is an important optical instrument, used to produce plane polarized light.
2. It was invented by William Nicol in 1828, hence it was called Nicol's prism.
3. It was made from calcite crystal by cemented two pieces of calcite with Canada balsam (μ=1.55).
4. Nicol's Prism eliminates O-ray by total internal reflection and produce only the polarized light.
5. Nicol's Prism is a good polarizer as well as good analyzer.

Construction of Nicol's Prism:

1. Length of the calcite crystal is taken 3 times of its width.
2. Grounded angles of principal section of calcite is 68^0 and 112^0 instead of 71^0 & 109^0.
3. The calcite crystal cuts along its diagonal. After polished two faces cemented together in its original positions with Canada balsam is called Nicol's Prism.
4. Canada balsam is a transparent cement with refractive index $\mu = 1.55$.
5. Canada balsam layer and optic axis makes an angles 90^0 and 48^0 with the end face of principal section is as shown in the figure.

Working of Nicol's Prism:

When a beam of ordinary light is incident on a Nicol's prism, the refracted light splits up into two refracted rays, one is ordinary ray and another is extraordinary ray. This is called double refraction of light.
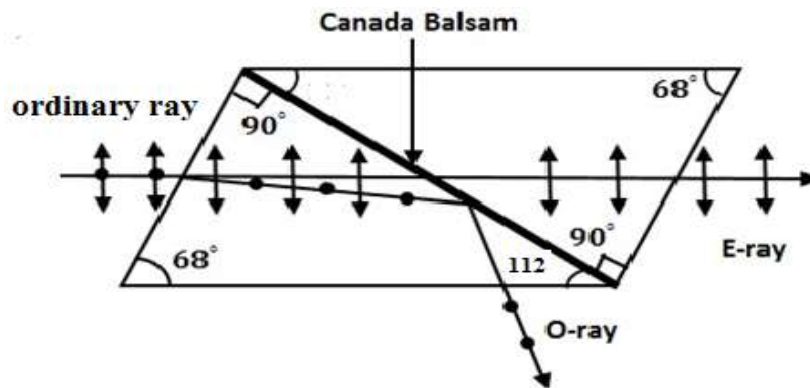
1. Both o-ray and e-ray travels towards the Canada balsam.
2. When the angle of incidence of o-ray is greater than the critical angle ($\theta_c = 69^0$) at Canada balsam, that o-rays totally reflects into same medium by total internal reflection.

        refractive index of Canada balsam is $\mu = 1.55$

        for calcite crystal, $\mu_0 = 1.6504$, $\mu_e = 1.4864$

        Critical angle $(\theta_c) = \sin^{-1}\left(\frac{1.55}{1.6584}\right) = 69^0$

3. When e-ray is incident on the Canada balsam, it can easily transmit through canada balsam.
4. Finally, by eliminating O-ray Nicol's prism produce e-ray only is shown in the figure.
5. Hence Nicol's Prism is a good polarizer as well as good analyser.

➢ HALF WAVE PLATE .

Half wave plate is the thickness of the crystal plate at which the path difference between o-ray and e-ray inside the crystal is equal to $\frac{\lambda}{2}$.

Consider a light of wavelength 'λ' falls normally on a crystal surface; the refracted light splits up into o-ray and e-rays.

Let 't' is the thickness of crystal at which path difference of o-ray and e-ray is $\frac{\lambda}{2}$, then

        Path difference of O-ray and e-ray = λ/2 --------- (1)

        optical path of o-ray = $\mu_o t$,

        optical path of e-ray = $\mu_e t$

optical path difference between o-ray & e-ray = $(\mu_o \sim \mu_e)\, t$ ------- (2)

from eqns (1) & (2),

$$(\mu_0 \sim \mu_e)\, t = \lambda/2$$

$$t = \frac{\lambda}{2(\mu_o \sim \mu_e)}$$

➢ QUARTER WAVE PLATE .

Quarter wave plate is the thickness of the crystal plate at which the path difference between o-ray and e-ray inside the crystal is equal to $\frac{\lambda}{4}$.

Consider a light of wavelength 'λ' falls normally on a crystal surface; the refracted light splits up into o-ray and e-rays.

Let 't' is the thickness of crystal at which path difference of o-ray and e-ray is $\frac{\lambda}{4}$, then

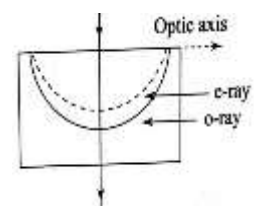Path difference of o-ray and e-ray $= \lambda/4$ --------- (1)

optical path of o-ray $= \mu_o t$,

optical path of e-ray $= \mu_e t$

optical path difference between o-ray and e-ray $= (\mu_o \sim \mu_e) t$ ------- (2)

from eqns (1) & (2),

$$(\mu_0 \sim \mu_e) t = \lambda/4$$

$$t = \frac{\lambda}{4(\mu_o \sim \mu_e)}$$
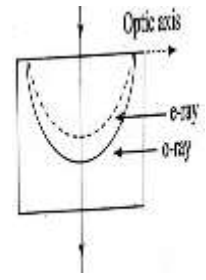
Malus Law: *The intensity of* polarized light by a polarizer is directly proportional to the square of cosine angle between polarizer and analyzer.

$I \alpha \cos^2 \theta$. Hence i.e $I = I_0 \cos^2 \theta$

Optical Activity: The property of rotating the vibrations of plane polarized light by a substance is called as optically activity and the substance is called as optically active substance.

Specific rotation: The angle of rotation of plane polarized light produced by 1decimeters length in an optically active substance of concentration of 1gr/cc.

Polari meter: The optical instrument which measure the angle of rotation of vibrations of plane polarised light by optically active substance.

Saccharimeter: The optical instrument used to determine the angle of rotation of polarised light by sugar solution is called as saccharimeter.

UNIT-II: LASERS AND FIBER OPTICS

1) LASERS: Introduction – Characteristics of laser – Spontaneous and Stimulated emissions of radiation – Einstein's coefficients – Population inversion – Lasing action - Pumping mechanisms– Ruby laser – He-Ne laser - Applications of lasers.

2) FIBER OPTICS: Introduction –Principle of optical fiber- Acceptance Angle - Numerical Aperture - Classification of optical fibers based on refractive index profile and modes – Propagation of electromagnetic wave through optical fibers - Applications.

1)   LASERS

LIGHT AMPLIFICATION BY STIMULATED EMISSION OF RADIATION

In 1916, Einstein gave the theoretical basics of Laser.

In 1954, C. H. Townes and his co-workers developed a Microwave Amplifier based

on Stimulated Emission of Radiations (MASER) from Einstein concept.

In 1958, C. H. Townes and A. Schawlow extended the principle of Maser to light.

In 1960, T. H. Maiman invented the first Laser (solid state laser).

In 1961, Ali Javan invented the first gas Laser (He-Ne laser).

➢ **CHARACTERISTICS OF LASER**   **.**

1) High Monochromatic

     Laser has high Monochromatic than compare to other conventional light sources.

2) High Intensity

     Laser has high intensity than compare to other conventional light sources.

3) High Coherence

     Laser has high Coherence than compare to other conventional light sources.

4) High Directionality

     Laser has high Directionality than other conventional light sources.

➢ **DIFFERENT PUMPING MECHANISMS TO CREATE POPULATION INVERSION**

     1) Optical pumping   *3) Chemical reaction*
     2) Electrical discharge   *4) Injection current*

1) Optical pumping:

Optical pumping is the first mechanism; it was used in Ruby laser (solid state laser). These materials have very broad band absorption.

Examples: Ruby lasers, glass lasers and etc…

2) Electric discharges:

Optical pumping process is not possible in all cases, so that in most of the cases population inversion is created by electric discharge method. It is used in gas lasers.

Examples: He-Ne laser, CO_2 laser…etc

3) Chemical reaction:

Chemical reaction may also result in excitation and creation of population inversion in HF, DF lasers.
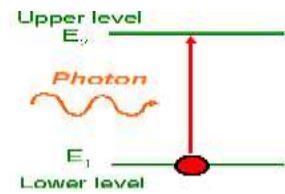
4) Injection current:

In semi conductors' lasers, population inversion takes place by passing injection current.

Examples: GaAs, Nd:YAG lasers…etc

➢ PROCESSES INVOLVED IN LASER .

Absorption:

By absorbing external energy, ground energy level particles excited to higher energy levels is called absorption.

Spontaneous Emission:

After completion of life time, the higher energy level particles spontaneously de-excited into lower levels by emitting energy is called spontaneous emission.

$$E = E_2 \sim E_1 = h\nu$$

Population inversion:

During the process, the number of particles is more at higher energy levels than compare to lower energy levels. This condition is called population inversion.

$$N_2 > N_1$$

According to Boltzmann distribution function, population inversion is

$$\frac{N_1}{N_2} = e^{\frac{E-E_f}{K_B T}} = e^{\frac{h\nu}{K_B T}}$$

Life time of particles at higher energy levels is about 10^{-8} s.
Life time of particles at lower energy (meta) levels is about 10^{-3} s.
Life time of particles at ground level is unlimited.

Stimulated Emission:

By the application of external energy (photon=hν), higher energy level particles de-excited into lower energy levels by emitting more energy is called stimulated emission.

$$E_2 \sim E_1 = 2 \ h\nu$$
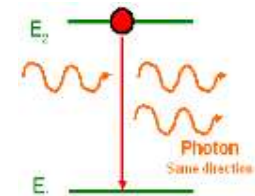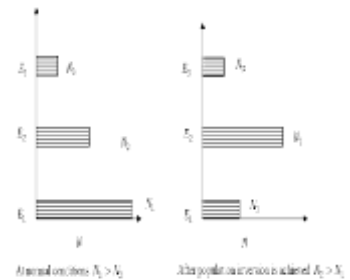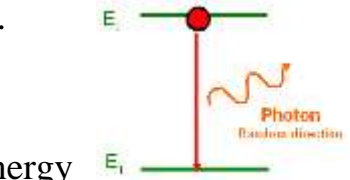
➢ DIFFERENCE BETWEEN SPONTANEOUS EMISSION AND STIMULATED EMISSION

Spontaneous Emission	Stimulated Emission
1. The transition occurs from higher energy level to lower energy level	1.The transition occurs from higher energy level to lower energy level
2. Incident photon is not required	2.Incident photon is required
3. Single photon is emitted	3.Double photon is emitted
4. This was postulated by Bohr	4.This was postulated by Einstein
5. The energy of emitted photon is equal to the difference of the energy levels. $E = E_1 \sim E_2 = h\nu$	6. The energy of emitted photon is equal to 2hν. $E = E_1 \sim E_2 = 2 \ h\nu$
7. It gives incoherent, low-intensity, non-directionality and non-monochromatic radiations.	7. This gives coherent, high intensity, directionality high mono chromatic radiations.
8. Examples: sodium vapor lamp and mercury vapor lamps ….	8.Examples: Ruby laser, He-Ne laser, CO_2 laser…etc

➢ EINSTEIN'S THEORY OF LASER .

Einstein derived the expression for the Ratio of probability of spontaneous emission rate to the probability of stimulated emission rate under equilibrium condition.

$$\frac{A_{21}}{B_{21}} < 1$$

Consider a two energy level system of energy levels E_1 and E_2. Let N_1 and N_2 are the number of atoms per unit volume in the energy levels E_1 and E_2 respectively.

Absorption:

By absorbing external energy, lower energy level particles excited to higher energy levels. The number of particles undergoing absorption per unit volume per second from E_1 to E_2 is

$$E_1 - E_2 = N_1 \rho(v) B_{12} \qquad \text{------ (1)}$$

Here B_{12} is the Einstein's coefficient of absorption and $\rho(v)$ is the radiation energy.
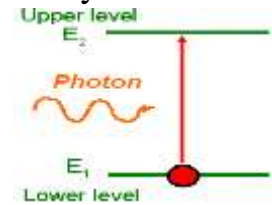
Spontaneous emission:

After completion of life time, the higher energy level particles spontaneously de-excited into lower energy levels by emitting energy.

The number of particles undergoing spontaneous emission per unit volume per second from E_2 to E_1 is

$$E_2 - E_1 = N_2 A_{21} \qquad \text{------- (2)}$$

Here A_{21} is the Einstein's coefficient of spontaneous emission rate.

Stimulated emission:

By the application of external energy (photon = hv), higher energy level particles de-excited into lower energy levels by emitting more energy.

The number of particles undergoing stimulated emission per unit volume per second from E_2 to E_1 is

$$E_2 - E_1 = N_2 \rho(V) B_{21} \qquad \text{------- (3)}$$

Here, B_{21} is the Einstein coefficient of stimulated emission rate.

Under the steady state condition, $\frac{dN}{dt} = 0$

The number of particles undergoing absorption per second = number of atoms undergoing emission per second.

from equations (1), (2) & (3), we have that

$$eq^n(1) = eq^n(2) + eq^n(3)$$

$$N_1 \rho(V) B_{12} - N_2 \rho(V) B_{21} = N_2 A_{21}$$

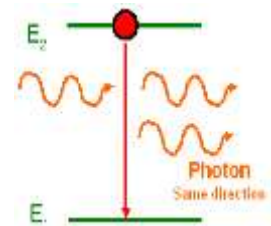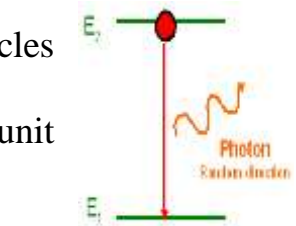$$\rho(V)(N_1 B_{12} - N_2 B_{21}) = N_2 A_{21}$$

$$\rho(V) = \frac{N_2 A_{21}}{(N_1 B_{12} - N_2 B_{21})}$$

$$\rho(v) = \frac{A_{21}}{\left(\dfrac{N_1}{N_2}\right) B_{12} - B_{21}}$$

According to Boltzmann distribution law, $\frac{N_1}{N_2} = e^{\frac{E - E_f}{K_B T}} = e^{\frac{hv}{K_B T}}$

$$\rho(v) = \frac{A_{21}}{\left(e^{\frac{hv}{K_B T}}\right) B_{12} - B_{21}}$$

let $B_{12} = B_{21}$, then

$$\rho(v) = \frac{A_{21}}{B_{21}\left(e^{\frac{hv}{K_BT}} - 1\right)} \quad \text{or} \quad \rho(v) = \frac{A_{21}}{B_{21}}\frac{1}{\left(e^{\frac{hv}{K_BT}} - 1\right)} \quad \text{------ (4)}$$

According to Planck's law, the energy density $\rho(v) = \frac{8\pi h}{\lambda^3}\frac{1}{\left(e^{\frac{hv}{K_BT}} - 1\right)}$ ------ (5)

From equations (4) & (5),

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h}{\lambda^3} \quad \text{or} \quad \frac{A_{21}}{B_{21}} = \frac{8\pi h}{\left(c/v\right)^3} \quad \text{or} \quad \frac{A_{21}}{B_{21}} = \frac{8\pi h v^3}{c^3}$$

$$\therefore \frac{A_{21}}{B_{21}} \infty v^3$$

Where A_{21} is the Einstein's co-efficient of spontaneous emission rate and B_{21} is the Einstein's co-efficient of stimulated emission rate.

Case (i): If there is no population inversion at steady state, $N_1 > N_2$

Case (ii): If stimulated emission is predominate, $\frac{A_{21}}{B_{21}} < 1$ so that $N_2 > N_1$

➢ APPLICATIONS OF LASER .

Industrial Applications
Commercial Applications
Scientific/Research Applications
Medical Applications
Military Applications

Industrial Applications:	Commercial Applications:	Scientific Applications:
Laser cutting, Laser welding, Laser drilling, Laser Nuclear Fusion, Semiconducting chip manufacturing, OLED display manufacturing.	Entertainment and recreation, CDs, DVDs, Blu-Ray and Optical discs, Laser printers, 3D laser scanners, Barcode scanners, Holographic Imaging.	Free-space optical communication, Surveying and ranging, Lunar laser ranging, Weather, Spectroscopy, Microscopy. Heat treatment, Photochemistry, Nuclear fusion,
Medical Applications: General Laser surgery, Cosmetic surgery, Cancer treatment, Laser therapy, Ophthalmology, gynecological, urology, laparoscopic.	**Military Applications:** Target designation and ranging, Defensive counter measures, Directly as an energy weapon, Disorientation, Fire arms.	

➤ **RUBY LASER** .

Description:

1. First laser was constructed by T. Maiman in 1960.
2. Ruby laser is a solid state laser.
3. Ruby laser is a three energy level laser system.
4. Active medium is pure Al_2O_3 with 0.05% of cr^{+3} ions.
5. The responsible element for laser action is Chromium (Cr^{+3}) ions.
6. Ruby laser gives the output wavelength (λ) = **$6943A^0$**.
7. It is a pulsed laser having very high power of hundreds of megawatt in a single pulse with 10 nano second duration.

Construction:
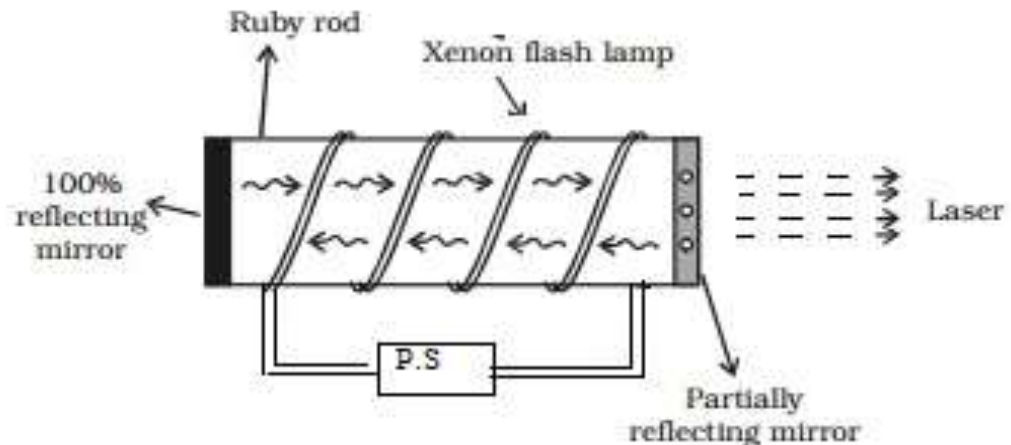
1) Ruby (Al_2O_3) is taken in the form of cylindrical rod of length and diameter is about 4cm and 1cm.

2) Ruby rod is surrounded by a helical xenon flash lamp tube, which provides the optical pumping to raise the cr^{+3}ions from ground energy level to higher energy levels.

3) The xenon flash lamp tube is connected to the power supply.

4) At the two ends of the ruby rod there are two reflectors (mirrors), one is partial reflector and another is perfect reflector is shown in the figure.

Working:
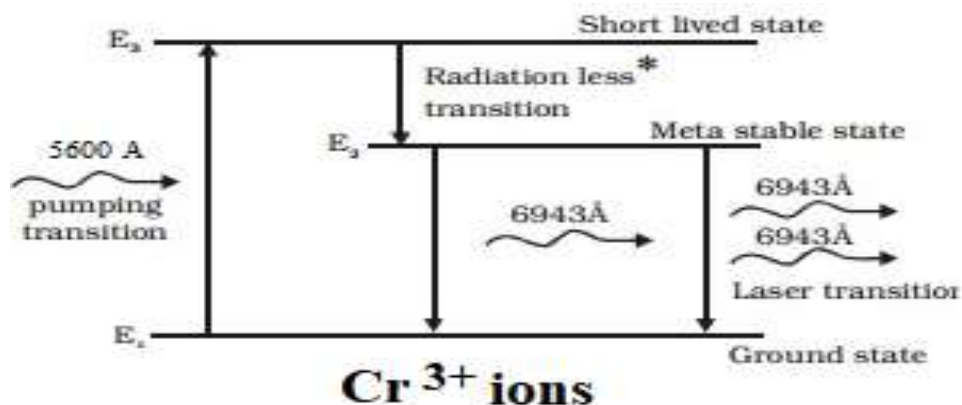
1) When the Xenon flash lamp is switched on, the ground energy level (E_1) Cr^{+3} ions excited to higher energy level (E_3) by absorbing the light energy of wavelength $5600A^0$ from xenon flash lamp through optical pumping.

2) After completion of life time the Cr^{+3} ions at higher energy level E_3, spontaneously de-excited into lower energy level E_2 and after that from E_2 to E_1 levels by emitting energy.

3) Life time of cr^{+3} ions at higher energy level is about 3×10^{-8}s, for meta stable states is about 3×10^{-3}s and for ground level of cr^{+3} ions life time is unlimited.

4) During this process, Population inversion (N2 > N1) takes place in between energy levels E_2 and E_1.

5) Spontaneously emitted energy travels along the axis of ruby rod and reflects at mirrors.

6) This reflected energy stimulate the Cr^{+3} ions at E_2.

7) E_2 level Cr^{+3} ions de-excited into E_1 energy level by emitting more energy is called stimulated emission.

8) After getting multi reflections between two reflectors (mirrors), the amplified high intense light energy emerges through the partially coated reflector as output.

9) Output wavelength of Ruby laser is 6943A^0 and it is pulsed mode laser.

Applications:

1. Ruby lasers used in pulsed holography.
2. Ruby lasers used to measure the distance in pulse echo technique.
3. Ruby lasers used for drilling and cutting the materials.

➢ He - Ne LASER .

Description:

1. First gas laser was constructed by Ali Javan in 1961.
2. In He-Ne laser, active medium is He-Ne.
3. The responsible element of laser action is Neon.
4. Pressure and quantity Ratio of He : Ne is 10 : 1.
5. He-Ne laser gives the output wavelength of *6328* A^0 as continuous waves (CW).

Constructions:
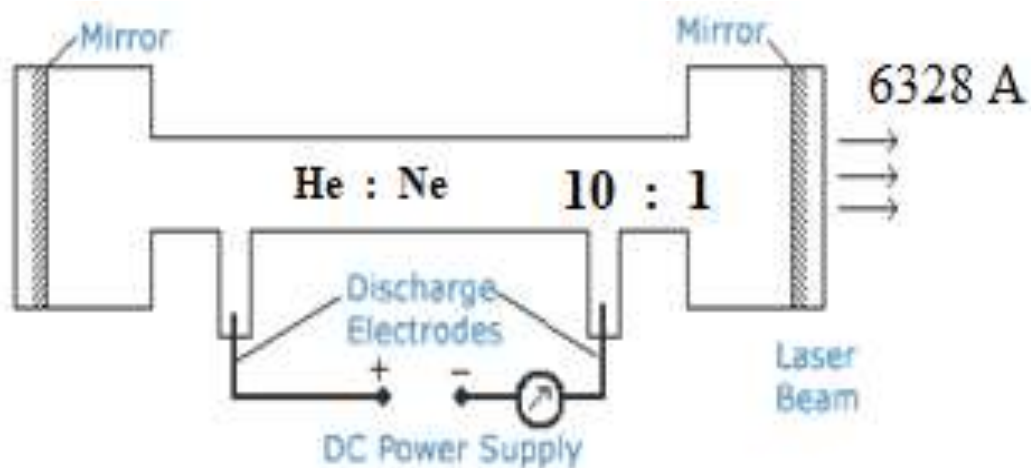
1. He-Ne gas mixture is taken in Quartz discharge tube.

2. Length and diameter of the discharge tube is 80cm and 1 cm.

3. He-Ne gas mixture is taken in the ratio of 10:1

4. Number of He atoms are more than the number of Neon atoms.

5. Radio frequency oscillator is connected to the electrodes of discharge tube to produce electrical discharge is as shown in the figure.

Working:

1. When the power is switched on, ground state (F_1) He atoms excited to higher energy states F_2 and F_3 respectively through electrical discharge.
2. He atoms at F_2, gives their excitation energy to the ground state (E_1) Ne atoms by atomic collisions. Thus E_1 level Ne atoms excited to higher energy state E_4 which is equal to energy state of F_2.
3. Similarly, He atoms at F_3, gives their excitation energy to the ground state (E_1) Ne atoms by atomic collisions then E_1 level Ne atoms excited to higher energy state E_6, which is equal to energy state F_3 as shown in the figure.
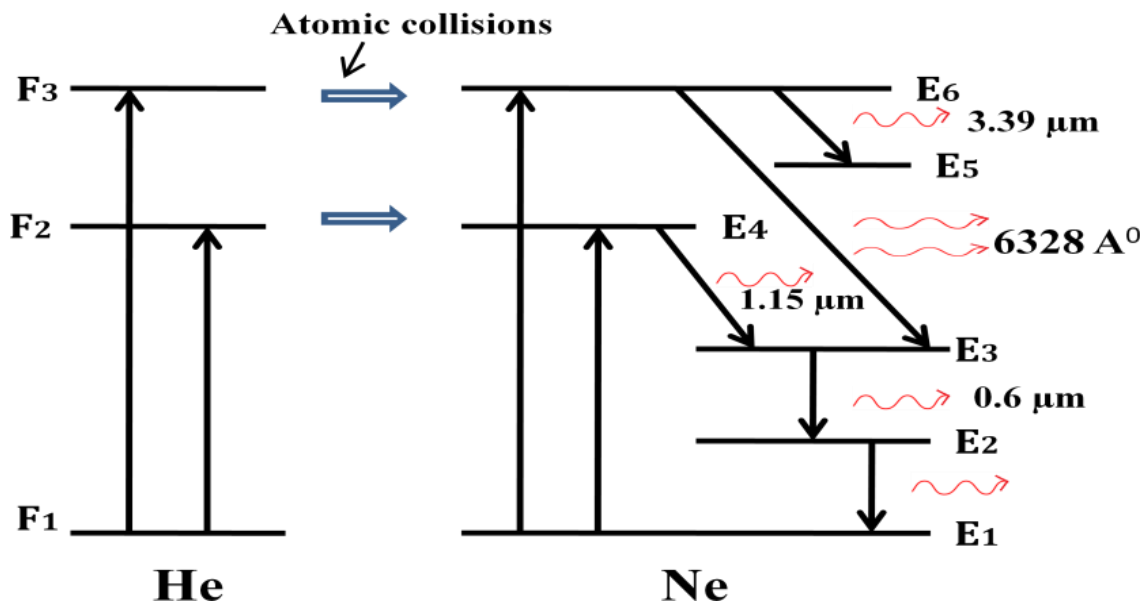
4. Population inversion takes place at E_6 and E_4 energy states.
5. By the process of Stimulated emissions,
    i)   3.39µm wavelength of radiations emitted from E_6 to E_5,
    ii)   6328A^0 wavelength of radiations emitted from E_6 to E_3,
    iii) 1.15µm wavelength of radiations emitted from E_4 to E_3,
6. Spontaneous emission can take place at E_3 to E_2 by emitting radiations of 6000 A^0.
7. Finally, Ne-atoms de-excited from energy state E_2 to ground state E_1 by non-radiative emissions.
8. After arriving the ground state (E_1), Ne atoms again excited to E_6 and E_4 states by continues He atomic collisions.
9. Some of the optical elements (absorbents) are used inside the discharge tube to absorb the wavelengths 3.39µm, 1.15µm and to get monochromatic radiations only.
10. Finally,He-Ne laser gives radiations of wavelength 6328 A^0 as Continues Waves(CW).
11. Output of He-Ne laser depends on the length of the discharge tube and pressure of gas mixture.

Applications:

1. He-Ne lasers are very useful in making holograms in CW modes.
2. He-Ne lasers are used in interferometric experiments.
3. He-Ne lasers are used in laser surgery.

2) FIBER OPTICS

The transmission of light in a long thin cylindrical glass fiber by total internal reflection was first demonstrated by a British physicist John Tyndall in 1870.

➢ **CONSTRUCTION AND WORKING OF OPTICAL FIBRE** .

Optical fibers are used to transmit the Electromagnetic waves from one place to another place by total internal reflection.

Construction: -

1) Optical fiber is a very thin and flexible having a cylindrical shape.
2) The optical fibers work on the basic principle of total internal reflection (T.I.R).
3) Optical fiber containing three regions, they are
   1. Core
   2. Cladding
   3. Sheeth

Buffer Jacket / Sheeth (Plastic)
Cladding $(SiO_2 + Ge/P)$
Core (SiO_2)
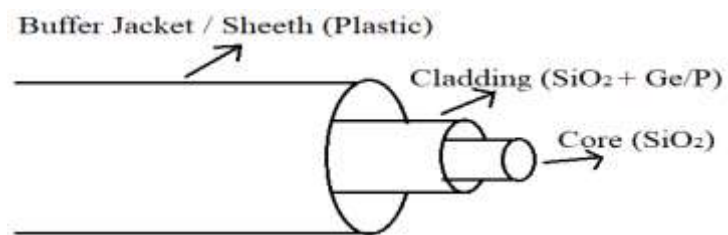
1) Core: -
i) The core is made up of silica (SiO_2).
ii) The diameter of the core is about 10 μm.
iii) Refractive index of the core(n_1) is maximum than refractive index of the Cladding (n_2).

2) Cladding: -
i) The cladding is made up of adding of small amount of Ge or P to silica (SiO_2).
ii) The diameter of the cladding is about 50μm to 200 μm.
iii) Refractive index of the cladding (n_2) is minimum than refractive index of the core (n_1).

3) Outer Jacket: -
i) The outer jacket is made of plastic.
ii) In between cladding and outer jacket there is silicon coating.
iii) Outer jacket gives the protection to the fiber by avoiding mechanical crushing's & so.

Working Principle: -

Optical fibers work on the basic principle of total internal reflection.

Total Internal Reflection (T.I.R):

When the light ray travels from denser medium to rarer medium, if the angle of incidence of the light is greater than the critical angle (i > θc), the light rays totally reflected into denser medium (same medium), this phenomenon is called total internal reflection.

rerer medium
denser medium
$r = 90$
$i < θc$ $i = θc$ $i > θc$
Total Internal Reflection

(i) When I = θc then the light travels along the interface.
(ii) When I < θc, then the light refracted into rarer medium.
(iii) When I > θc, then the light totally reflected into same (denser) medium.

Working Mechanism:-

Optical fiber is a dielectric waveguide. The total light signal transformation process takes place within the core of the optical fiber only and it is shown in the given figure.

1) Consider an optical fiber 'PQ' and let AO is the incident light is entering into the core with acceptance angle (ϕ_{max}). $\phi_{max} = \sin^{-1}\left[\sqrt{n_1^2 - n_2^2}\right]$
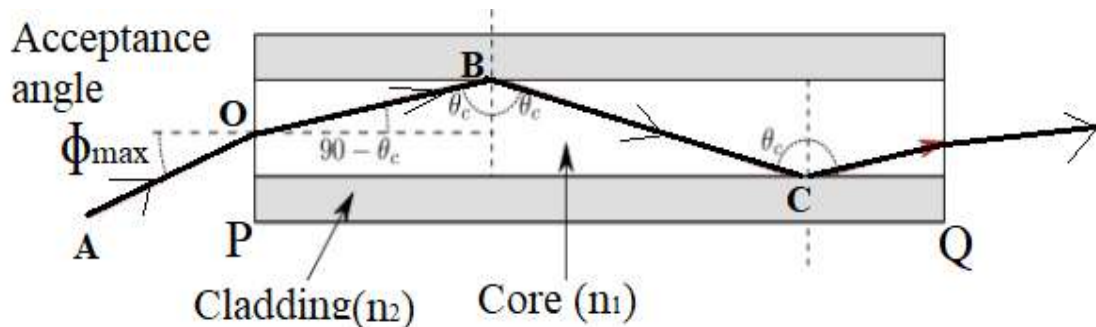
2) The refracted light OB strikes the core-cladding interface at B.
3) When the angle of incidence of the light OB is greater than the critical angle at B, then the light undergoes total inter reflection and travels along BC.

$$\text{Critical angle } \theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$

4) Similarly, the light BC again undergoes total internal reflection at C and so….on.
5) Finally, the light propagates through the optical fibers by total internal reflection.

➤ ROPAGATION OF E.M WAVES THROUGH OPTICAL FIBERS .

Optical fibers are used to transmit the Electromagnetic waves from one place to another place. Optical fibers work on the basic principle of total internal reflection.

Working Principle:

Total Internal Reflection: When the light travels from denser medium to rarer medium, if the angle of incidence of the light is greater than the critical angle ($i > \theta_c$), the light rays totally reflected into denser medium (same medium), this phenomenon is called total internal reflection.
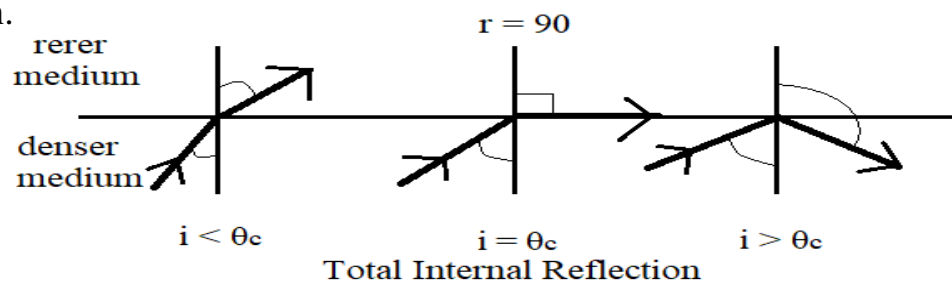

Propagation of E.M wave:

Light is nothing but an Electro-Magnetic (EM) wave. Optical fiber is a dielectric waveguide. The total signal transformation process takes place within the core only like as shown in the figure. Optical fiber is a dielectric waveguide. The total light signal transformation process takes place within the core of the optical fiber only and it is shown in the given figure.

1) Consider an optical fiber 'PQ' and let AO is the incident light is entering into the core with acceptance angle (ϕ_{max}). $\phi_{max} = \sin^{-1}\left[\sqrt{n_1^2 - n_2^2}\right]$

2) The refracted light OB strikes the core-cladding interface at B.

3) When the angle of incidence of the light OB is greater than the critical angle at B, then the light undergoes total inter reflection and travels along BC.

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$$ Critical angle

4) Similarly, the light BC again undergoes total internal reflection at C and so….on.
5) Finally, the Electromagnetic waves propagates through the optical fibers by total internal reflection.

Communication system:

Optical fibers used in communication system to transfer the signal (information) from one place to other place is shown in the given figure.
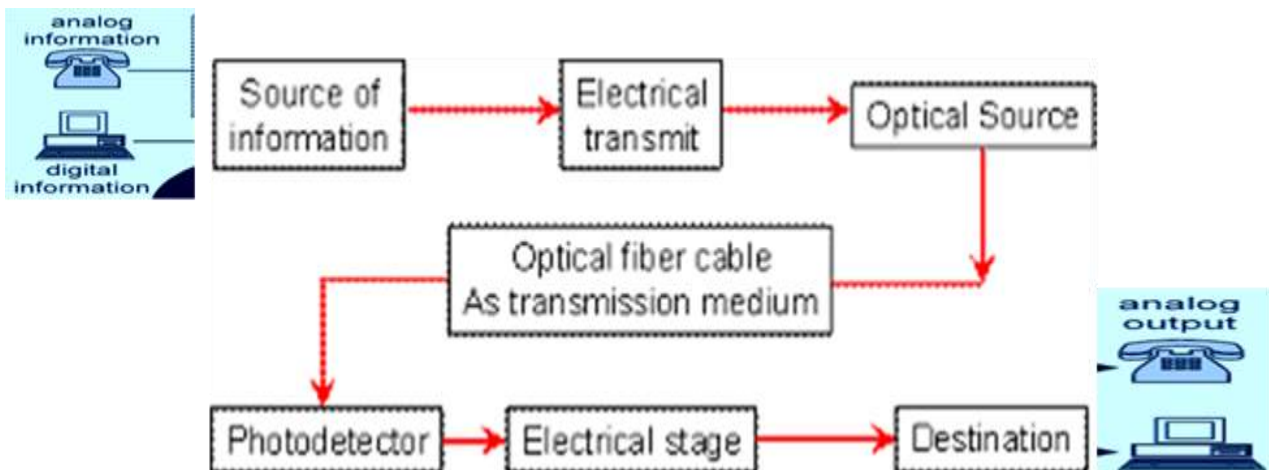
➢ ACCEPTANCE CONE

Acceptance cone is the cone (shape) of incident light into the optical fiber.

1. By rotating the acceptance angle about the axis of the fiber the acceptance cone be measured.
2. Acceptance angle of the fiber is called as half the angle of acceptance cone.
3. Acceptance cone = 2   x   Acceptance angle
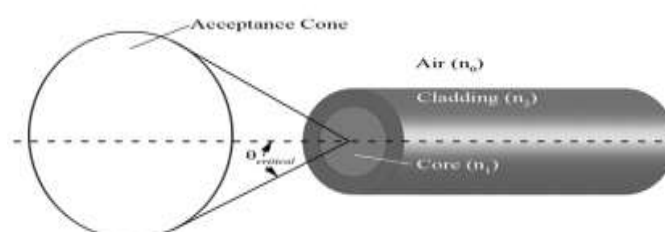
➤ ACCEPTANCE ANGLE (ϕ_{max})　　　　　　　　　　　　　　　　　　　　.

Definition:　　　**The maximum value of incident angle of the incident light at which enter into the core (or) optical fiber is called acceptance angle (ϕ_{max}).**

$$\sin \phi_{max} = \sqrt{n_1^2 - n_2^2}$$

Proof: - Consider the light propagation through the core of the optical fire 'PQ' by total internal reflection.
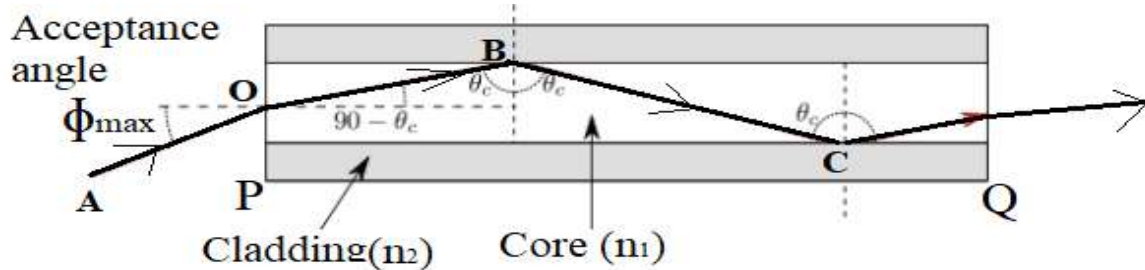
Consider a light (AO) is incident on a core at an angle of incidence ϕ_{max} and refracted into the core at an angle of refraction θ_r (= 90 - θ_c) along OB. The light undergoes total internal reflection at B and travels towards C. Like this way, at every reflection the light undergoes total internal reflection and transfers from one end to other end of fiber is as shown in the figure.

Let n_0, n_1 and n_2 are the refractive indices of air, core and cladding ($n_1 > n_2 > n_0$).

by applying snell's law at 'O', $n_0 \sin \phi_{max} = n_1 \sin \theta_r$ ------------ (1)

by applying snell's law at 'B', $\quad n_1 \sin \theta_c = n_2 \sin 90^0$ (since r = 90^0 then i = θ_c)

$$n_1 \sin \theta_c = n_2$$

$$\sin \theta_c = \frac{n_2}{n_1}$$

let θ_c = 90 - θ_r,　　　$\sin(90 - \theta_r) = \frac{n_2}{n_1}$

$$\cos \theta_r = \frac{n_2}{n_1}$$

$$\sin \theta_r = \sqrt{\left(1 - \frac{n_2^2}{n_1^2}\right)} \qquad \left[\because \sin \theta_r = \sqrt{(1 - \cos^2 \theta_r)}\right]$$

$$\sin \theta_r = \sqrt{\left(\frac{n_1^2 - n_2^2}{n_1^2}\right)} \qquad \text{------------ (2)}$$

by substituting equation (2) in (1),

$$n_0 \sin \phi_{max} = n_1 \sqrt{\left(\frac{n_1^2 - n_2^2}{n_1^2}\right)}$$

$$n_0 \sin \phi_{max} = \sqrt{n_1^2 - n_2^2}$$

$$\sin \phi_{max} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

since refractive index of the air $n_0 = 1$,

$$\sin \phi_{max} = \sqrt{n_1^2 - n_2^2} \qquad \text{(or)} \qquad \phi_{max} = \sin^{-1}\left[\sqrt{n_1^2 - n_2^2}\right]$$

➤ NUMERICAL APERTURE .

Definition: The light collecting efficiency of the optical fiber is called numerical aperture. **(or)**

Numerical aperture is directly proportional to the acceptance angle.

$$NA = \sin\phi_{max}$$

$$NA = \sqrt{n_1^2 - n_2^2}$$

$$NA = \sqrt{(n_1 + n_2)(n_1 - n_2)}$$

$$NA = \sqrt{2n_1(n_1 - n_2)} \quad \text{(since } n_1 \approx n_2\text{)}$$

$$NA = \sqrt{2n_1(n_1 - n_2)\frac{n_1}{n_1}}$$

$$NA = \sqrt{2n_1^2 \frac{(n_1 - n_2)}{n_1}}$$

$$NA = \sqrt{2n_1^2\Delta} \quad \text{(or)} \quad NA = n_1\sqrt{2\Delta}$$

here Δ is relative refractive (fractional) index, $\Delta = \dfrac{(n_1 - n_2)}{n_1}$

➤ APPLICATIONS OF OPTICAL FIBRES .
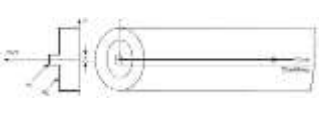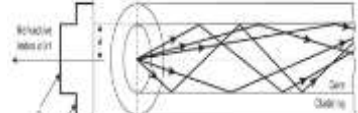
Optical fibers widely used in so many fields of applications.

1. **Communication:** Optical fibers are used in communication system to transmit the information from one place to another place with wider bandwidth.
2. **Medicine:** Optical fibers are used in medicine field like diagnostics, Surgery, therapy and in so many applications.
3. **Defense service:** Optical fibers are used in defense service because they maintained high privacy.
4. **Transmission:** Fiber system is used for transmit the digital data (signal) in computes.
5. **Laser:** Optical fibers are used to propagate the laser radiations.
6. **Cables:** Optical fibers used as cables in submarine, space ships, T.Vs & etc …
7. **Signaling purpose:** Optical fibers are used to propagates the number of modes than compare to copper wire.
8. **Easy maintenance:** Optical fibers are more reliable and very easy maintainance than copper cables.
9. **Low transmission loss**: Optical fibers possess low attenuation (transmission loss) about 0.002 dB/km than compare to copper cables.
10. **Alarm system:** Optical fibers are used in security and alarm systems.
11. **Rigidness and flexibility:** Optical fibers made from silica (SiO_2) and they bend easily without any damage and transfer the signal without losses.
12. **Sensors:** Optical fibers used in sensing applications such as displacement sensors, phase -modulated temperature sensors, intensity modulated sensors & ect…

➢ CLASSIFICATION OF OPTICAL FIBERS .

Classification of Optical fibers based on refractive index profiles and modes is as shown in the flowchart.
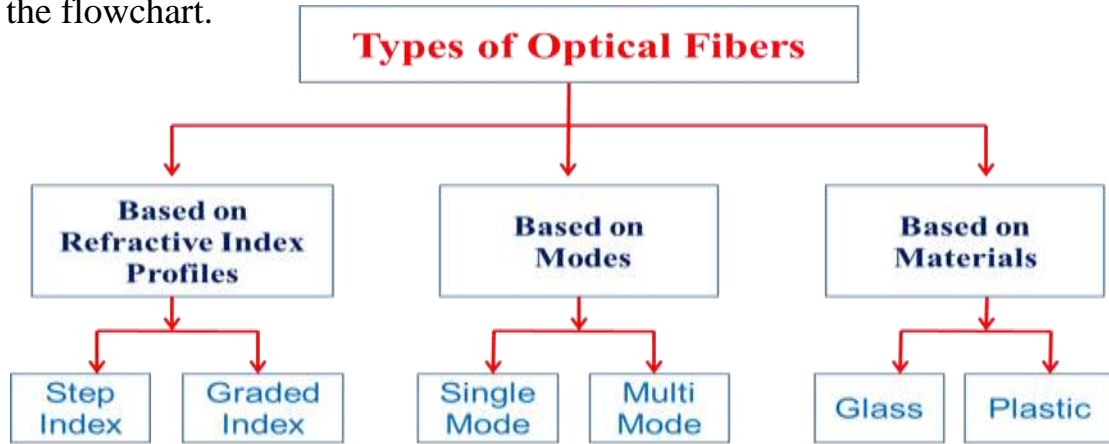
S.N.	Property	Step Index Single Mode Fiber	Step Index Multi Mode Fiber	Graded Index Multi Mode Fiber
1	Definition	Refractive index of the core is uniform and decrease stepwise at the core-cladding interface.	Refractive index of the core is uniform and decrease stepwise at the core-cladding interface.	Refractive index of the core is maximum at center & decreases gradually from the center of the core.
2	Size of Core	10 μm	50 to 100μm	50 to 100μm
3	Refractive Index Profile			
4	Ray Propagation	Axial ray propagation	Meridional ray propagation	Skew ray propagation
5	Number of modes (N_m)	Only one $N_m = V$	Multi modes $N_m = V^2/2$	Multi modes $N_m = V^2/4$
6	Numerical Aperture	Small	Large	Medium
	Attenuation	Very less	High	Medium
7	Data transfer rate	High	Low	Medium
8	Bandwidth	High (Above 3GHz)	Low (Below 200MHz)	Medium (200MHz to 3GHz)
9	Manufacturing	Difficult	Easy	More complex
10	Cost	High	Low	Expensive
11	Launching of light into fiber	Difficult	Easy	Easy
12	Advantages	Highly suitable for long range communication	Not suitable for long range communication, LED or laser used	Not suitable for long range communication, LED or laser used
13	Applications	Used under water cables	Used in Data links	Used in Telephone

UNIT- III : QUANTUM MECHANICS, FREE ELECTRON THEORY & BAND THEORY

1) **QUANTUM MECHANICS:** Dual nature of matter – Heisenberg's Uncertainty Principle – Significance and properties of wave function – Schrodinger's time independent and dependent wave equations– Particle in a one-dimensional infinite potential well.

2) **FREE ELECTRON THEORY:** Classical free electron theory (Qualitative with discussion of merits and demerits) – Quantum free electron theory– Equation for electrical conductivity based on quantum free electron theory- Fermi-Dirac distribution- Density of states (3D) - Fermi energy.

BAND THEORY OF SOLIDS: Bloch's Theorem (Qualitative) - Kronig - Penney model (Qualitative)- E vs K diagram - v vs K diagram - effective mass of electron – Classification of crystalline solids–concept of hole.

1) QUANTUM MECHANICS

INTRODUCTION

Classical Mechanics is a branch of physics, which deals with the motion of macroscopic objects (or particles), which are directly observable with the help of the instrument like microscope. Classical Mechanics totally depend on Newton Laws. Thus the classical mechanics is also called as Newtonian mechanics

Quantum Mechanics is a branch of physics, which deals with the motion of microscopic particles like electrons, which are not observable with the help of the instruments like microscopes.

Classical mechanics failed to explain the following concepts

1. *Hydrogen spectrum*
2. *Blackbody radiation*
3. *Specific heat*
4. *Stability atom*
5. *Motion of micro particles and etc…*

In 1900, Max Planck proposed the quantum theory to explain the spectrum of black body radiation. In 1905, Albert Einstein stated that the radiation was always in the form of light quanta or photons. In 1924, the Louis De-Broglie proposed matter wave concept. In 1926, Schrodinger developed wave mechanics using De-Broglie's idea. In 1927, Werner Heisenberg introduced Uncertainty principle. It was marked the final break of quantum mechanics from classical determinism and established quantum mechanics as a statistical theory. In quantum mechanics, particles and waves are not classes of objects. Every micro particle behaves like a particle and wave too.

Matter (Particle): The massive body is called the matter. Mass is one of the forms of energy. Any massive body can move from one place to another place. The particle is characterized by its mass, velocity, momentum, energy etc…

Wave: Wave is the disturbance created in the space or medium. Wave is also one of the forms of energy. The wave is characterized by its wavelength, amplitude, time period, frequency and energy etc…

➤ DUAL NATURE OF MATTER .

Matter-Wave: - The particle exhibit wave nature is called matter wave. (Or)

In 1924, Louis De-Broglie proposed that the material particles like electrons, protons, neutrons exhibit wave nature; these are called matter waves or De-Broglie's waves.

De-Broglie's wavelength, $\lambda = $ **h/mv**

De-Broglie's Wavelength: -

According to Planck's theory of radiation, the energy of a photon is

$E = h\upsilon$ -------- (1)

here 'h' is Planck's constant and 'υ' is frequency of photon

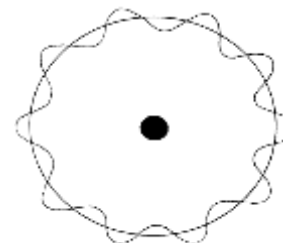According to Einstein's Mass-Energy relation,

$E = mc^2$ -------- (2)

here m & c is mass and velocity of photon

from eqns (1) & (2), $\quad h\upsilon = mc^2$

$hc/\lambda = mc^2$ (since $\upsilon = c/\lambda$)

$\lambda = h/mc$

i.e. $\lambda = $ **h/mv** here, λ is called De-Broglie's wavelength.

Bohr's orbit and de Broglie waves

Wave length of Charged Particle: -

According to De-Broglie's hypothesis, wavelength of a matter wave is

$$\lambda = h/mv \text{ --------(3)}$$

The kinetic energy of the electron is $\quad E = \frac{1}{2} mv^2$

$$2E = mv^2$$

$$2mE = m^2v^2$$

$$mv = \sqrt{2mE}$$

from eqn. (3), $\quad \lambda = \dfrac{h}{\sqrt{2mE}}$ (or) $\quad \lambda = \dfrac{h}{\sqrt{2meV}}$ (since E = eV)

i.e De-Broglie's wavelength for a charged particle is $\lambda = \dfrac{12.27}{\sqrt{V}} A^0$ here 'V' is potential.

➤ DE-BROGLIE'S HYPOTHESIS

1. As per De-Broglie's hypothesis electrons has wave - particle dual nature.
2. Nature loves symmetry. The energy exhibits wave-particle duality, matter wave also possesses dual nature.
3. Wavelength is associated with moving particle and independent of charge of the particles.
4. The wave length of matter waves is derived on the analogy of radiation.
5. wavelength of a matter wave is $\lambda = $ **h/mv**
6. Mass of the matter wave is Greater; the wavelength will be low.
7. Velocity of the matter wave, the wavelength will be low.
8. According to Bohr's atomic model electron behaves as matter wave. $2\pi r = n\lambda$

➤ HEISENBERG UNCERTAINTY PRINCIPLE .

According to classical mechanics, it is to find the position and momentum of a moving particle. In wave mechanics, there is a great uncertainty about finding the exact location of the particle.

In 1927, Heisenberg proposed the uncertainty principle.

"*It is impossible to determine both exact position and momentum of a moving particle at the same time.*"
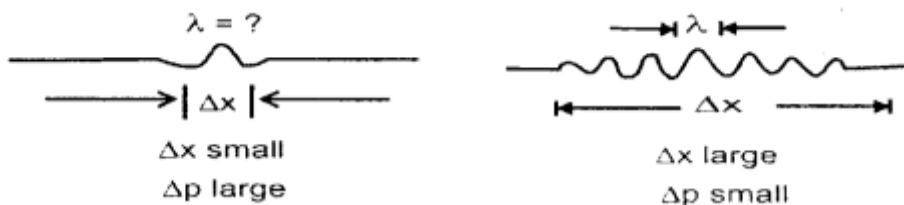
If Δx and Δp are the uncertainties of the position and momentum respectively then

$$\triangle x . \triangle p \leq \frac{\hbar}{2}$$

Another form of uncertainty concerns energy and time is

$$\triangle E . \triangle t \leq \frac{\hbar}{2}$$

➢ PHYSICAL SIGNIFICANCE (INTERPRETATION) OF WAVE FUNCTION (Ψ)

1. Wave function 'Ψ' satisfies the normalization condition.

$$\iiint \psi \psi * \, dxdydz = \iiint |\psi|^2 \, dxdydz = 1$$

2. Wave function 'Ψ' is satisfies the Ortho-normal condition.

$$\iiint \psi \psi * \, dxdydz = \iiint |\psi|^2 \, dxdydz = 0$$

3. Wave function 'Ψ' is used to find the probability of an electron at a point in the space.
4. $P = \Psi \Psi *$ or $P = |\Psi|^2$
5. Wave Function itself has no direct physical interpretation.
6. It is a complex quantity. $\psi_{(x,t)} = \psi_{(x)}, \phi_{(t)}$
7. There is only one Eigen value for wave function.

➢ PROPERTIES OF MATTER WAVES   .

1. Lighter is the particle; greater is the wave length of the matter wave. i.e. $\lambda \propto 1/m$
2. Smaller is the velocity of matter wave; longer is the wave length of the. i.e. $\lambda \propto 1/V$
3. Matter waves are not electromagnetic (EM) waves.
4. The velocity of matter wave is greater than the velocity of light. $\omega = c^2/v$
   hence matter waves travels faster than the light.
5. There is no physical phenomenon for matter wave.
6. The concept of matter waves is given for particles that are in motion.
7. If a particle is at rest, there is no meaning of matter wave.
8. Phase velocity of matter waves is given by $V_{ph} = \omega/k$

➢ DIFFERENCE BETWEEN MATTER WAVES & ELECTRO MAGNETIC WAVES

Matter Waves	Electro Magnetic Waves
1. Waves associated with material particles are called matter waves.	1. Electro Magnetic waves do not Require any medium.
2. Matter waves are produced by the motion of the particles whether they are charged or uncharged.	2. These waves are produced by motion of charged particles only.
3. Velocity of matter waves is not constant.	3. Velocity of these waves is Constant.
4. Velocity of matter waves is greater than velocity of light.	4. Velocity of these waves is equal to the velocity of light.

➢ SCHRODINGER'S TIME INDEPENDENT WAVE EQUATION .

Schrodinger's wave equation is a basic principle. As such that it cannot be derived from other basic principles.

Consider a particle of mass 'm', moving with a velocity 'V'. Let 'Ψ' is the wave function of matter wave and consider a simple form of progressing wave along X-axis, then

$$\Psi_{(x)} = \Psi_0 \sin(\omega t - kx) \text{ ----------- (1)} \quad \text{here, } \Psi_0 \text{ is amplitude.}$$

differentiating 'Ψ' partially with respect to 'x'

$$\frac{\partial \Psi_{(x)}}{\partial x} = \Psi_0 \cos(\omega t - kx)(-k)$$

differentiating Ψ partially with respect to 'x',

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} = \Psi_0 (-\sin(\omega t - kx))(-k)(-k)$$

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} = -k^2 \Psi_0 \sin(\omega t - kx)$$

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} = -k^2 \Psi_{(x)} \qquad \text{(from eqn (1), } \Psi = \Psi_0 \sin(\omega t - kx))$$

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} + k^2 \Psi_{(x)} = 0$$

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} + \frac{4\pi^2}{\lambda^2} \Psi_{(x)} = 0 \qquad \text{(since } k = 2\pi/\lambda)$$

since De-Broglie's wavelength, $\lambda = h/mv$

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} + \frac{4\pi^2}{\left(h/mv\right)^2} \Psi_{(x)} = 0$$

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} + \frac{4\pi^2 m^2 v^2}{h^2} \Psi_{(x)} = 0 \qquad \text{-------- (2)}$$

The total energy (E) of an electron is the sum of its kinetic energy (K) and potential energy(V),

$$\therefore \quad E = K + V$$
$$E = (\tfrac{1}{2} mv^2) + V \qquad (\text{'.' } K = \tfrac{1}{2} mv^2)$$
$$E - V = 1/2 \, mv^2$$
$$2(E - V) = mv^2$$

multiply with m on both sides,

$$2m(E-V) = m^2 v^2 \quad \text{-------- (3)}$$

substitute eqn.(3) in eqn.(2), we get

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} + \frac{8\pi^2 m(E-V)}{h^2} \Psi_{(x)} = 0 \qquad \text{(or)}$$

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} + \frac{2m(E-V)}{\hbar^2} \psi_{(x)} = 0 \qquad (\text{'.' } \hbar = h/2\pi)$$

This is one dimensional wave equation of matter wave. Similarly, 3-D wave equation of electron is

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{2m(E-V)}{\hbar^2} \Psi_{(x,y,z)} = 0 \qquad \text{(or)}$$

$$\therefore \nabla^2 \Psi + \frac{2m(E-V)}{\hbar^2} \Psi_{(x,y,z)} = 0 \quad \text{------(4)}$$

here '∇' is Laplacian operator & $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$

Equation (4) is the Schrodinger's time independent wave equation.

➢ SCHRODINGER'S TIME DEPENDENT WAVE EQUATION .

Schrodinger's wave equation is a basic principle. As such that it cannot be derived from other basic principles.

Consider an electron revolves around the nucleus in a stationary orbit.

Let the displacement of matter wave in One Dimension is

$$\Psi_{(x)} = \Psi_0 e^{-i\omega t} \qquad \text{-------- (1)}$$

differentiating $\Psi_{(x)}$ partially with respect to 't'

$$\frac{\partial \psi_{(x)}}{\partial t} = \psi_0 e^{-i\omega t}(-i\omega) + 0$$

$$\frac{\partial \psi_{(x)}}{\partial t} = -i\omega\, \psi_{(x)} \qquad \text{------ (2)} \qquad\qquad \text{since } \Psi_{(x)} = \Psi_0 e^{-i\omega t}$$

but $E = \hbar\omega$ then $\omega = \dfrac{E}{\hbar}$ from equation no.(2)

$$\frac{\partial \psi_{(x)}}{\partial t} = -i\frac{E}{\hbar}\psi_{(x)}$$

$$\frac{\partial \psi_{(x)}}{\partial t} = -i\frac{E}{\hbar}\psi_{(x)} x \left(\frac{i}{i}\right)$$

$$\frac{\partial \psi_{(x)}}{\partial t} = -i^2 \frac{E}{i\hbar}\psi_{(x)}$$

$$\frac{\partial \psi_{(x)}}{\partial t} = \frac{E}{i\hbar}\psi_{(x)} \qquad \text{'.' since i}^2=-1,$$

$$i\hbar\frac{\partial \psi_{(x)}}{\partial t} = E\psi_{(x)} \qquad \text{------ (3)}$$

According to Schrödinger's time independent wave equation $\quad \dfrac{\partial^2 \psi_{(x)}}{\partial x^2} + \dfrac{2m(E-V)}{\hbar^2}\psi_{(x)} = o$

$$\frac{\partial^2 \psi_{(x)}}{\partial x^2} + \frac{2m}{\hbar^2}(E\psi_{(x)} - V\psi_{(x)}) = o$$

from equation no. (3)

$$\frac{\partial^2 \psi_{(x)}}{\partial x^2} + \frac{2m}{\hbar^2}\left(i\hbar\frac{\partial \psi_{(x)}}{\partial t} - V\psi_{(x)}\right) = 0$$

multiply with $\dfrac{\hbar^2}{2m}$ on both sides,

$$\left(\frac{\hbar^2}{2m}\right)\frac{\partial^2 \psi_{(x)}}{\partial x^2} + \left(\frac{\hbar^2}{2m}\right)\frac{2m}{\hbar^2}\left(i\hbar\frac{\partial \psi_{(x)}}{\partial t} - V\psi_{(x)}\right) = 0$$

$$\left(\frac{\hbar^2}{2m}\right)\frac{\partial^2 \psi_{(x)}}{\partial x^2} + i\hbar\frac{\partial \psi_{(x)}}{\partial t} - V\psi_{(x)} = 0$$

$$\left(\frac{\hbar^2}{2m}\right)\frac{\partial^2 \psi_{(x)}}{\partial x^2} + i\hbar\frac{\partial \psi_{(x)}}{\partial t} - V\psi_{(x)} = 0$$

$$i\hbar\frac{\partial \psi_{(x)}}{\partial t} = V\psi_{(x)} - \left(\frac{\hbar^2}{2m}\right)\frac{\partial^2 \psi_{(x)}}{\partial x^2}$$

$$i\hbar\frac{\partial \psi_{(x)}}{\partial t} = -\left(\frac{\hbar^2}{2m}\right)\frac{\partial^2 \psi_{(x)}}{\partial x^2} + V\psi_{(x)}$$
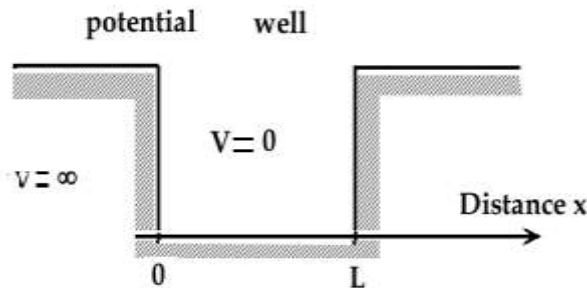
$$i\hbar\frac{\partial \psi_{(x)}}{\partial t} = \left[-\left(\frac{\hbar^2}{2m}\right)\frac{\partial^2}{\partial x^2} + V\right]\psi_{(x)}$$

$$E\psi_{(x)} = H\psi_{(x)} \qquad\qquad \text{Here, 'E' is Energy Operator and 'H' is Hamilton's Operator}$$

➢ **PARTICLE IN ONE DIMENSIONAL POTENTIAL WELL (BOX)** .

Consider a particle of mass 'm' in a one dimensional potential box of width 'L' with infinite height.

When an electron revolves nearer to the nucleus, the potential energy of electron becomes zero. i.e $V_{(x)} = 0$.

When an electron revolves longer to the nucleus, the potential energy of electron becomes maximum (infinity). i.e $V_{(x)} = \infty$.

The Schrodinger's time independent wave equation in one dimension is

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} + \frac{2m(E-V)}{\hbar^2}\psi_{(x)} = o$$

If the electron is inside the potential well, then $V_{(x)} = 0$

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} + \frac{2mE}{\hbar^2}\psi_{(x)} = o \qquad -------- (1)$$

Let the possible solution for eqn. (1) can be written as

$$\Psi_{(x)} = A \sin kx + B \cos kx -------- (2)$$

here A & B are constants.

by applying first boundary condition, at x = 0, then $\Psi_{(x)} = 0$,

from eqn. (2),

$$0 = A.\sin 0 + B.\cos 0$$
$$B = 0$$

from eqsn (2) $\Psi_{(x)} = A \sin kx$ --------- (3)

By applying secondary boundary condition, at x = L, then $\Psi_{(x)} = 0$

from eqn. (3),

$$0 = A \sin(kL)$$

either A = 0 or sin (kL) = 0.

but A # 0, because of A & B are constants, hence sin(kL) = 0

$$Sin(kL) = n\pi \quad here \ n = 0,1,2,3,4\ldots\ldots$$
$$kL = n\pi$$
$$k = n\pi / L \qquad ---------(4)$$

from eqns.(3) & (4), $\Psi_{(x)} = A \sin (n\pi / L)x$ ---------(5)

by using normalization condition $\int \psi^2 dx = 1,$ we get $A = \left[\sqrt{\dfrac{2}{L}}\right]$

from eqn (5), $\psi_{(x)} = \left[\sqrt{\dfrac{2}{L}}\right] \sin \left[\dfrac{n\pi}{L}\right] x$

This is 1-Dimensional wave equation of electron.

Similarly, 3-Dimensional wave equation of electron inside the potential box is

$$\psi_{(x,y,z)} = \left[\sqrt{\frac{2}{L}}\right]^3 \sin k_x x . \sin k_y y . \sin k_z z$$

here $K_x = \left[\dfrac{n_x \pi}{L}\right]$, $K_y = \left[\dfrac{n_y \pi}{L}\right]$, $K_z = \left[\dfrac{n_z \pi}{L}\right]$

Energy of Electron (Eigen values):

Differentiating the eqn. $\Psi_{(x)} = A \sin (n\pi /L)x$ w. r. to 'x' twice, we get

$$\frac{\partial^2 \Psi_{(x)}}{\partial x^2} + k^2 \Psi_{(x)} = 0 \quad \text{-------- (6)}$$

by comparing eqns.(1) & (6), $\dfrac{2mE}{\hbar^2} = k^2$

$$\frac{2mE}{\hbar^2} = \frac{n^2 \pi^2}{L^2} \qquad \left[\because k^2 = \frac{n^2 \pi^2}{L^2}\right]$$

$$\therefore E = \frac{n^2 \pi^2 \hbar^2}{2mL^2} \qquad \text{(or)}$$

$$E_n = \frac{n^2 \pi^2 \hbar^2}{2mL^2} \qquad \text{here} \quad n = 1, 2, 3, 4\ldots\ldots\ldots$$

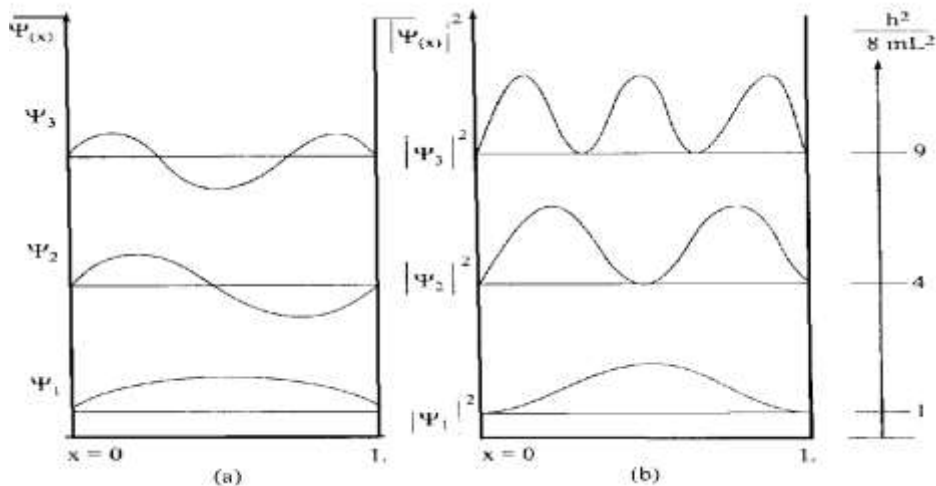$$E_n = \frac{n^2 h^2}{8mL^2} \qquad \text{since} \quad \hbar = h/2\pi,$$

If $n = 1$, $\quad E_1 = \dfrac{h^2}{8mL^2}$

If $n = 2$, $\quad E_2 = \dfrac{4h^2}{8mL^2}$ $\qquad$ or $\qquad E_2 = 4E_1$

If $n = 3$, $\quad E_3 = \dfrac{9h^2}{8mL^2}$ $\qquad$ or $\qquad E_3 = 9E_1$

If $n = 4$, $\quad E_4 = \dfrac{16h^2}{8mL^2}$ $\qquad$ or $\qquad E_4 = 16E_1$ and so on…..

The wave functions, energies of particle in a potential box is shown in the figures (a) & (b).

2) FREE ELECTRON THEORY & BAND THEORY

(A) FREE ELECTRON THEORY OF SOLIDS (METALS)

INTRODUCTION: *Electron theory of metals aims to explain the structure and properties of solids through their electronic structure. This theory is applicable to all solids i.e., both metals and non metals. It can explain the electrical, thermal and optical properties of solids. 'The electron theory of metals' has been developed in three main stages.*

CLASSICAL FREE ELECTRON THEORY: *Drude and Lorentz proposed the classical free electron theory in 1900. According to this theory, the metals contain free electrons and obey the laws of classical mechanics.*

QUANTUM FREE ELECTRON THEORY: *Somerfield developed this theory in 1928. According to this theory the free electrons obey quantum laws. According to this theory, the free electrons moves with a constant potential.*

ZONE (BAND) THEORY: *Bloch stated this zone theory in 1928. According to this theory, the free electrons move in a periodic field provided by the lattice. The concept of hole, origin of band gap and effective mass of electrons are the special features of this band theory.*

➢ **CLASSICAL FREE ELECTRON THEORY   (or)**
SALIENT FEATURES OF CLASSICAL FREEE ELECTRON THEORY

Classical free electron theory was proposed by Drude and Lorentz in 1900. According to this theory, the metals contain free electrons and obey the laws of classical mechanics. The classical free electron theory is known as free electron gas model and also called as Drude and Lorentz theory.

1. According to classical free electron theory, valence electrons moves freely inside the metals, like gas molecules in a container.
2. In the absence of electric field, free electrons move randomly in all possible directions by making collisions. The resultant velocity is zero and hence the net current is zero.
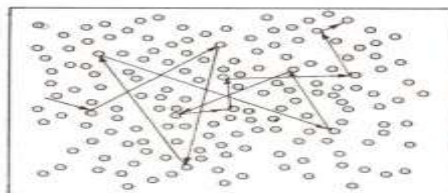
3. All the collisions are elastic in nature; therefore, there is no loss of energy.
4. The velocity of electrons in a metal obeys classical Maxwell-Boltzmann distribution of velocities. The root mean square velocity of an electron is $V_{rms} = \sqrt{\dfrac{3K_B T}{m}}$ and $V_{rms} = \sqrt{T}$
5. In the presence of electric field, free electrons accelerate opposite to the applied field direction as shown in the figure.

Drifting of electrons in an external field

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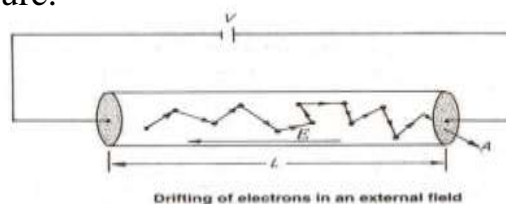
6. **Drift velocity (V_d):** The average velocity acquired by the free electron after two successive collisions in the presence of electric field. $\therefore V_d = \dfrac{e\tau}{m}E$

7. **Mean free Path (λ):** The average distance travelled by the free electron between two successive collisions in the presence of electric field. $\therefore \lambda = V_d\tau$

8. **Relaxation time (τ):** The time taken by the free electron between two successive collisions in the presence of electric field. $\therefore \tau = \dfrac{\lambda}{V_d}$

9. **Collision time (τ_c):** The average time taken by the free electron between two successive collisions in the presence of electric field.

10. For anisotropic solids, the relaxation time (τ) and collision time (τ_c) are same. $\therefore \tau = \tau_c$

11. **Mobility of electron (μ):** The mobility of an electron is the magnitude of drift velocity per unit electric field applied. $\therefore \mu = \dfrac{V_d}{E}$

12. **Current density (J):** The magnitude of current passing per unit area.   J =I/A

13. **Electrical Conductivity (σ):** According to Drude and Lorentz's classical free electron theory of metals, the electrical conductivity $\therefore \sigma = \dfrac{ne^2\tau}{m}$

    Where 'n' is number of electrons,   'e' is charge of electron,
    'τ' relaxation time of electron,   'm' mass of electron.

MERITS AND DE-MERITS
Merits:
1. It verifies ohm's law
2. It explains optical properties of metals.
3. It explains electrical conductivity of metals.
4. It explains thermal conductivity of metals.
5. It derives the Wiedemann-Franz law
   (i.e. the relation between electrical and thermal conductivity)

Demerits (Draw Backs):
1. It cannot Explain the Photoelectric Effect
2. It cannot Explain Compton Effect
3. It cannot Explain Black Body Radiation.
4. It cannot explain classification of solids into conductors, semiconductors & insulators.
5. It cannot Explain Electrical Conductivity of Semiconductors and Insulators.
6. It cannot Explain Ferromagnetism.

➢ **QUANTUM FREE ELECTRON THEORY**

Somerfield proposed the Quantum Free Electron theory in 1929

1. The electrons are free to move within the metal like gaseous molecules and bounded by the metallic bond.
2. These free electrons will not come out from the metal due to infinite potentials.
3. Free electrons would go into the different energy levels by following Pauli's exclusion Principle.

4. According to De-Broglie hypothesis, the motion of electrons is associated with a complex wave called matter wave.
5. Somerfield employed the Fermi-Dirac statistics to describe the distribution of electrons among different possible energy levels are called discrete energy levels.
6. The energy of electrons is quantized. i.e. $E = \dfrac{n^2 h^2}{8mL^2}$

Quantum energy levels of free electron in a metal
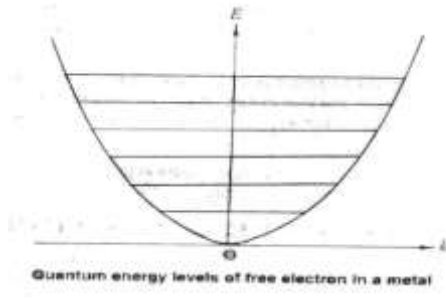
➢ DISTINGUISH BETWEEN CLASSICAL AND QUANTUM THEORY
(Distinguish Between Lorentz - Drude Theory and Sommerfeld Theory)

Classical free electron theory	Quantum free electron theory
1. It was proposed by Drude and Lorentz.	1. It was proposed by Sommerfeld.
2. This theory is applicable to macroscopic particles such as atoms or molecules.	2. This theory is applicable to microscopic particles such as electrons.
3. The valence electrons are loosely bound in the atom and obey classical mechanical laws.	3. The free electrons obey quantum laws such that wave nature of electrons is taken into account.
4. In the absence of electric field, the electrons move randomly and hence net current is zero.	4. Conduction electron is free to move inside the crystal and will not come out due to infinite potential at the surface. metallic bonding
5. In the absence of electric field, an electron makes collisions among themselves. All collisions are elastic.	5. The electrons are trapped in a constant potential.
6. In the presence of electric field, the free electrons accelerate opposite to the electric field.	6. The free electrons can go into different energy levels by following Pauli's exclusion principle.
7. The electrons acquire velocity due to application electric field known as 'drift velocity'.	7. The motion of free electron is associated with a wave called matter wave.
8. The root mean square velocity of the electrons $V_{rms} = \sqrt{\dfrac{3K_B T}{m}}$	8. Sommerfeld employed the Fermi-Dirac statistics according to quantum theory $E = \dfrac{n^2 h^2}{8mL^2}$

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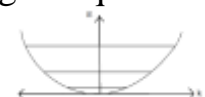
➤ **EQUATION FOR ELECTRICAL CONDUCTIVITY BASED ON QUANTUM FREE ELECTRON THEORY**

According to quantum free electron theory, electrons fallow Fermi-Dirac distribution function and obey Pauli Exclusion Principle.

The Fermi surface is the surface which separate occupied electron states from unoccupied electron states at zero temperature. The Fermi level electrons have maximum velocity and it is known as Fermi velocity V_F.

In two Dimensions the Fermi surface is a circle. All points inside the Fermi sphere are occupied.

At thermal equilibrium, all electrons move random directions and the resultant velocity of electrons-gas is zero. Therefore, there is no current flow across the material.

In the presence of electric field, the Fermi sphere displaced opposite to the field direction, then the force acting on the electrons is F.

$$F = -eE$$

$$\frac{dP}{dt} = -eE$$

since $P = \hbar k$,

$$\frac{d(\hbar k)}{dt} = -eE$$

$$\frac{dk}{dt} = -\frac{eE}{\hbar}$$

$$dk = -\frac{eE}{\hbar} dt$$

by integrating, we get,

$$k(t) - k(0) = -\frac{eE}{\hbar} t$$

let $k(t) - k(0) = \Delta k$ and $t = \tau_F$ then,

$$\Delta k = -\frac{eE\tau_F}{\hbar} \quad\text{--------- (1)}$$

If 'n' is the electron density per unit volume in the Fermi surface, the current density

$$J = n(-e)v$$

$$J = n(-e)\frac{P}{m} \qquad (\because v=P/m)$$

$$J = n(-e)\left[\frac{\hbar\Delta k}{m}\right] \qquad (\because P = \hbar k)$$

from equation (1)

$$J = n(-e)\left[\frac{\hbar\left(-\dfrac{eE\tau_F}{\hbar}\right)}{m}\right]$$

$$J = ne\left[\frac{eE\tau_F}{m}\right]$$

$$J = \frac{ne^2\tau_F}{m} E \qquad\text{----------- (2)}$$

Since the current density $J = \sigma E$ --------- (3)

Comparing equations (2) & (3), we get $\sigma = \dfrac{ne^2\tau_F}{m}$

∴ Electrical conductivity $\sigma = \dfrac{ne^2\tau_F}{m^*}$

here **m*** is effective mass of electron and 'τ_F' is relaxation time of electron at Fermi level.

➢ MERITS & DEMERITS OF QUANTUM FREE ELECTRON THEORY

Merits:

1. *It successfully explains the electrical and thermal conductivity.*
2. *It explains heat capacity of metals.*
3. *Temperature dependence of conductivity of metals can be explained by this theory.*
4. *It can explain the specific heat of metals.*
5. *It explains magnetic susceptibility of metals.*

Demerits (Drawbacks):

1. *It is failed to explain the distinction between conductors, semiconductors and insulators.*
2. *This could not be explaining the spectral lines of hydrogen molecules and helium atom.*
3. *It could not be explaining super conducting properties.*
4. *This model always predicts a negative Hall coefficient while some metals like Be, Zn, Cd exhibit positive coefficient. Or positive Hall metallic properties exhibited by only certain crystals.*

➢ FERMI ENERGY (E_F)

The highest energy level occupied by the electrons at '0' K temperature, is called the Fermi energy level or Fermi energy or simply Fermi level.

At '0' K temperature, all conductors are good insulators.

The expression for Fermi energy level is $E_F = \left(\dfrac{3}{\pi}\right)^{\frac{2}{3}} \dfrac{h^2}{8m^2} n^{\frac{2}{3}}$

here h, m and n are the Planck's constant, mass of electron and number of electrons.

➢ FERMI-DIRAC DISTRIBUTION FUNCTION

(Temperature Dependence of Fermi-Dirac Distribution Function)

The Fermi-Dirac distribution function is called as Fermi function.

According to Fermi-Dirac distribution, the probability of an electron occupies an energy

level (E) at thermal equilibrium is given by, $F(E) = \dfrac{1}{1+\exp\left(\dfrac{E-E_F}{k_B T}\right)}$

where '*F(E)*' is Fermi-Dirac distribution function, 'E_F' is Fermi energy level and 'k_B' is Boltzmann constant.

1. At T=0K, let E <E_F then F(E)=1

i.e. All energy levels below Fermi level (E_F), filled by the electrons.

2. At T=0K let E >E_F then F(E)=0

i.e. All energy levels above Fermi level (E_F), are Empty.

3. At T>0K let E =E_F then F(E)=1/2=0.5

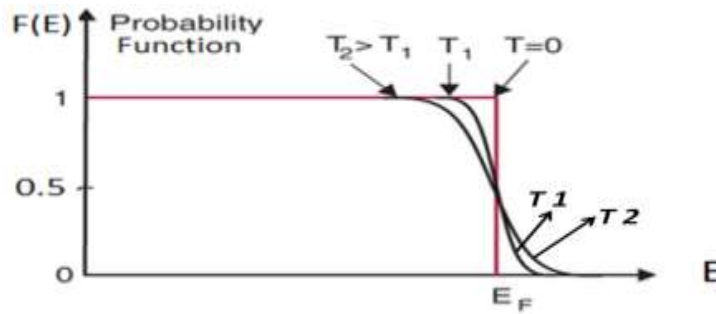i.e. At a temperature, Fermi level (E_F) filled with half of the electrons.

(Or)
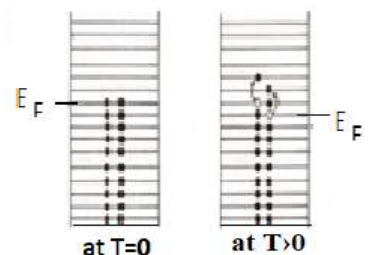
At T = 0K, let E <E_F, F(E) = 1	At T = 0K, let E >E_F, F(E) = 0	At T > 0K, let E = E_F, F(E) = 1/2
$F(E) = \dfrac{1}{1+\exp\left(\dfrac{E-E_F}{k_BT}\right)}$ $F(E) = \dfrac{1}{1+\exp(-\infty)}$ $F(E) = \dfrac{1}{1+\left(\dfrac{1}{\exp(\infty)}\right)}$ $F(E) = \dfrac{1}{1+\left(\dfrac{1}{\infty}\right)} = \dfrac{1}{1+0} = 1$ $F(E) = 1$	$F(E) = \dfrac{1}{1+\exp\left(\dfrac{E-E_F}{k_BT}\right)}$ $F(E) = \dfrac{1}{1+\exp(\infty)}$ $F(E) = \dfrac{1}{1+\infty}$ $F(E) = \dfrac{1}{\infty}$ $F(E) = 0$	$F(E) = \dfrac{1}{1+\exp\left(\dfrac{E-E_F}{k_BT}\right)}$ $F(E) = \dfrac{1}{1+\exp(0)}$ $F(E) = \dfrac{1}{1+1}$ $F(E) = \dfrac{1}{2}$

Graph:

The variation of Fermi-Dirac distribution function F(E) at different temperatures T, T_1 & T_2 is as shown in the figure.

➢ DENSITY OF STATES (3D)

Density of energy states is the number of energy states per unit volume.

Consider a spherical system of radius 'n'. Let the sphere contain number of energy levels in between E and E+dE.
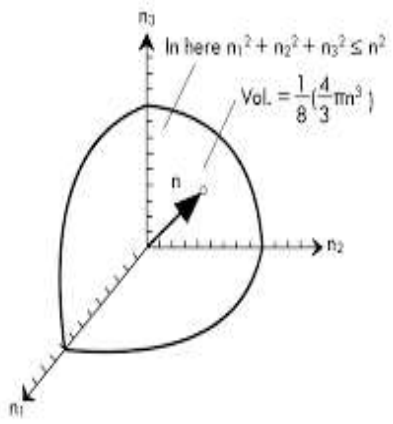The number of energy states available in the sphere of radius 'n' is 'dn'.

$$dn. = \dfrac{\dfrac{1}{8}\left(\dfrac{4}{3}\pi.n^3\right)}{1} \quad \text{and then} \quad dn. = \dfrac{1}{6}\pi.n^3 \text{------- (1)}$$

The energy of nth state,
$$E = \dfrac{n^2 h^2}{8ma^2} \quad \text{or} \quad E = \dfrac{n^2\hbar^2\pi^2}{2ma^2}$$

$$n^2 = \dfrac{2ma^2}{\hbar^2\pi^2}E$$

$$n = \left(\dfrac{2ma^2}{\hbar^2\pi^2}\right)^{\frac{1}{2}}E^{\frac{1}{2}}$$

from equation (1),
$$dn. = \dfrac{1}{6}\pi.\left[\left(\dfrac{2ma^2}{\hbar^2\pi^2}\right)^{\frac{1}{2}}E^{\frac{1}{2}}\right]^3$$

In here $n_1^2 + n_2^2 + n_3^2 \le n^2$

$Vol. = \dfrac{1}{8}\left(\dfrac{4}{3}\pi n^3\right)$

45

$$dn = \frac{1}{6}\pi \left(\frac{2ma^2}{\hbar^2 \pi^2} \right)^{\frac{3}{2}} E^{\frac{3}{2}}$$

$$dn = \frac{1}{6\pi^2} \left(\frac{2m}{\hbar^2} \right)^{\frac{3}{2}} a^3 E^{\frac{3}{2}}$$

The total number of energy states $g(E)$ available in the sphere of radius 'n' in between E and E+dE,

$$g(E) = \frac{d(dn)}{dE}$$

$$g(E) = \frac{1}{6\pi^2} \left(\frac{2m}{\hbar^2} \right)^{\frac{3}{2}} a^3 \left[\frac{d}{dE} E^{\frac{3}{2}} \right]$$

$$g(E) = \frac{1}{6\pi^2} \left(\frac{2m}{\hbar^2} \right)^{\frac{3}{2}} a^3 \left[\frac{3}{2} E^{\frac{3}{2}-1} \right]$$

$$g(E) = \frac{1}{4\pi^2} \left(\frac{2m}{\hbar^2} \right)^{\frac{3}{2}} a^3 E^{\frac{1}{2}}$$

According to Pauli's exclusive principle, an orbital contains maximum only two

electrons $\qquad g(E) = 2 \frac{1}{4\pi^2} \left(\frac{2m}{\hbar^2} \right)^{\frac{3}{2}} a^3 E^{\frac{1}{2}}$

$$g(E) = \frac{1}{2\pi^2} \left(\frac{2m}{\hbar^2} \right)^{\frac{3}{2}} a^3 E^{\frac{1}{2}}$$

from the definition, the density of energy states is

$$Z(E) = \frac{\frac{1}{2\pi^2} \left(\frac{2m}{\hbar^2} \right)^{\frac{3}{2}} a^3 E^{\frac{1}{2}}}{V}$$

$$Z(E) = \frac{\frac{1}{2\pi^2} \left(\frac{2m}{\hbar^2} \right)^{\frac{3}{2}} a^3 E^{\frac{1}{2}}}{a^3} \qquad\qquad (\text{ since } V = a^3)$$

$$Z(E) = \frac{1}{2\pi^2} \left(\frac{2m}{\hbar^2} \right)^{\frac{3}{2}} E^{\frac{1}{2}}$$

$\therefore$ **Density of energy states,** $\qquad Z(E) = \frac{4\pi}{h^2} (2m)^{\frac{3}{2}} E^{\frac{1}{2}}$

(B) BAND THEORY OF SOLIDS

The Band theory is a quantum model in solid state physics which gives the possible energies for electrons in solids and gives an understanding of electrical conductivity. This band theory of solids could explain the differences between conductors, semi conductors and insulators.

➤ BLOCH THEOREM

Bloch's theorem established the wave function ψ (x) of electron in crystals, obtained from Schrödinger's equation; hence it is called as Bloch wave function.

Statement:

The wave function of an electron is defined as the product of periodic function and wave part. $\therefore \psi_{(x)} = U_k(x).e^{\pm ikx}$

Here, $U_k(x)$ is periodic function, $e^{\pm ikx}$ is wave part.

Where 'k' is crystal momentum, 'e' is Euler's number and 'i' is imaginary number.

Explanation: Metals and alloys are crystalline in nature. The conduction electrons can move freely throughout the lattice (positive ion cores) is shown in the figure (a).
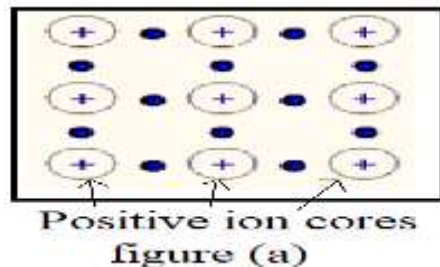
figure (a)

When an electron is near to the positive ion core, its potential energy becomes zero, i.e V= 0. While electron is at half of the distance between two positive cores, it has maximum potential energy, V= ∞ is shown in the figure (b).

figure (b)
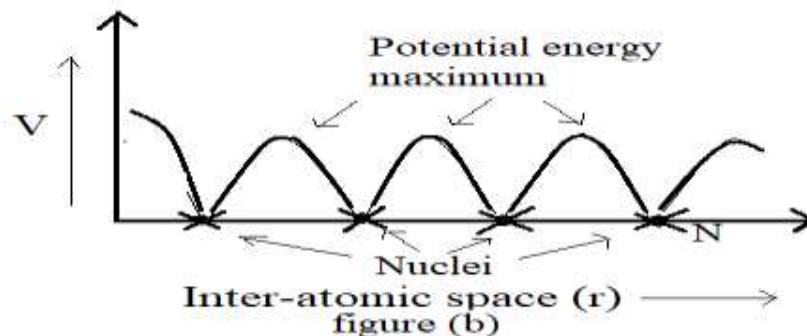
Consider an electron moves nearer to the positive ion core with constant potential. Schrödinger's time independent 1-D wave equation is

$$\frac{\partial^2 \psi_{(x)}}{\partial x^2} + \frac{2m(E-V)}{\hbar^2} \psi_{(x)} = o$$

Bloch showed the general solution for this Schrödinger's equation,

$$\therefore \psi_{(x)} = U_k(x).e^{\pm ikx}$$

This is only one dimensional wave equation. Hence 3-D wave equation is

$$\therefore \psi_{(r)} = U_k(r).e^{\pm ikr} \qquad \text{here, 'r' is position vector}$$

➢ KRONIG –PENNEY MODEL

In 1931, Kronig-Penney studied the essential behavior of an electron at periodic rectangular well in one dimension.

It was assumed that when an electron is nearer to the positive ion core, the potential energy is taken as zero, i.e $V = 0$. That means the electron is inside the well.

Whereas electron is at half of the distance between two positive cores, it has maximum potential energy, $V = \infty$

That means the electron is at outside the well.

Consider an electron inside the rectangular potential box of length 'a' and height 'V_0' is as shown in the figure.
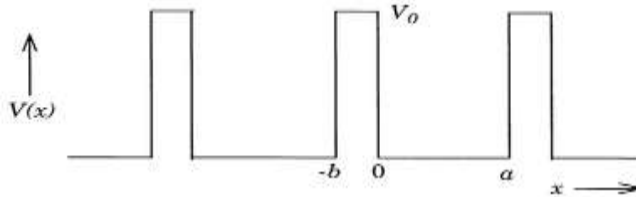
The nature of energies of electrons were determined by Schrodinger's wave equation.

The Schrodinger's time independent one-dimensional wave equation is

$$\frac{\partial^2 \psi_{(x)}}{\partial x^2} + \frac{2m(E-V)}{\hbar^2} \psi_{(x)} = o$$

If the electron is inside the potential well, then potential energy $(V) = 0$,

$$\frac{\partial^2 \psi_{(x)}}{\partial x^2} + \frac{2mE}{\hbar^2} \psi_{(x)} = o$$

let $\alpha^2 = \frac{2mE}{\hbar^2}$, then

$$\frac{\partial^2 \psi_{(x)}}{\partial x^2} + \alpha^2 \psi_{(x)} = o$$

Kronig-Penney derived the possible solutions for energies of electrons to the above equation by using Bloch theorem.

$$\therefore P \frac{\sin \alpha a}{\alpha a} + \cos \alpha a = \cos ka \qquad \text{-------- (1)}$$
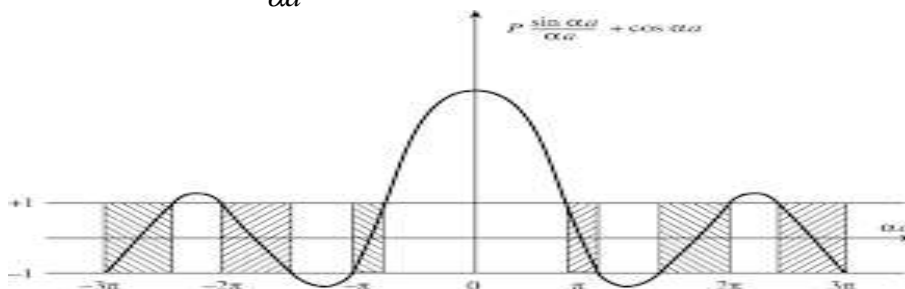
where 'P' is scattering power of barrier, $P = \frac{maV_0\omega}{\hbar^2} = \frac{4\pi^2 maV_0\omega}{h^2}$ and $\alpha = \sqrt{\frac{2mE}{\hbar^2}}$

Let the height (V_0) of the potential barrier increases then the width(ω) of the barrier decreases.

i.e. $V_0 \infty \frac{1}{\omega}$ $\qquad \therefore V_0\omega = \text{Constant}$

Kronig-Penney model Graph & conclusions:

The graph between 'αa' and '$P \frac{\sin \alpha a}{\alpha a} + \cos \alpha a$' is as shown in the figure.

1. The allowed energy band width increases with increasing 'αa'.
2. 'αa' is allowed the energy bands between the range of maximum values +1 and -1.
3. In solids, the electrons permitted to be in allowed energy bands and these are separated by forbidden gaps.
4. If scattering power P—›∞, is the case of electron trapped in a potential box.
5. If scattering power P—›0, is the case of classical free particle.

    If P = 0, from equation (1),

    $$0 + \cos\alpha a = \cos ka$$
    $$\cos\alpha a = \cos ka$$
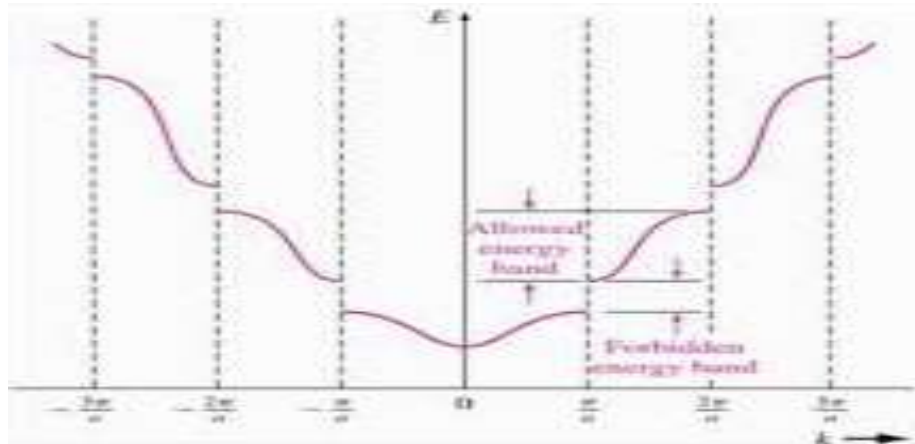 $$\alpha = k \quad \text{then}$$
    $$\alpha^2 = k^2$$

    since $\alpha^2 = \dfrac{2mE}{\hbar^2}$

    $$\therefore \frac{2mE}{\hbar^2} = k^2 \quad \text{then}$$

    $$E = \frac{\hbar^2 k^2}{2m} \quad \text{(or)} \quad E = \frac{n^2 h^2}{8ma^2}$$

BRILLOUIN ZONES:

The graph between energy (E) vs Phase values (K) gives the electrons permitted energy bands is as shown in the figure.


1. From the graph, the region between $-\pi/a$ to $+\pi/a$ is an energy band and is called first Brillouin zone.
2. After discontinuity, another allowed energy band (zone) extended from $-2\pi/a$ to $-\pi/a$ and π/a to $2\pi/a$. This is known as second brillouin zone.
3. After discontinuity, another allowed energy band (zone) extented from $-3\pi/a$ to $-2\pi/a$ and $2\pi/a$ to $3\pi/a$. This is known as third brillouin zone.
4. There are discontinuities at $\pm n\pi/a$, which gives rise to forbidden energy band gaps is shown in the above figure.

➤ ORIGIN OF ENERGY BANDS IN SOLIDS

According to quantum free electron theory, the free electrons move with constant periodic potentials and the atoms have independent energy levels (discrete energy levels).

According to Kronig -Penney model the free electrons moves in a rectangular potential wells. He predicts (tell in advance) the existence of allowed energy bands and forbidden energy gaps in solids.
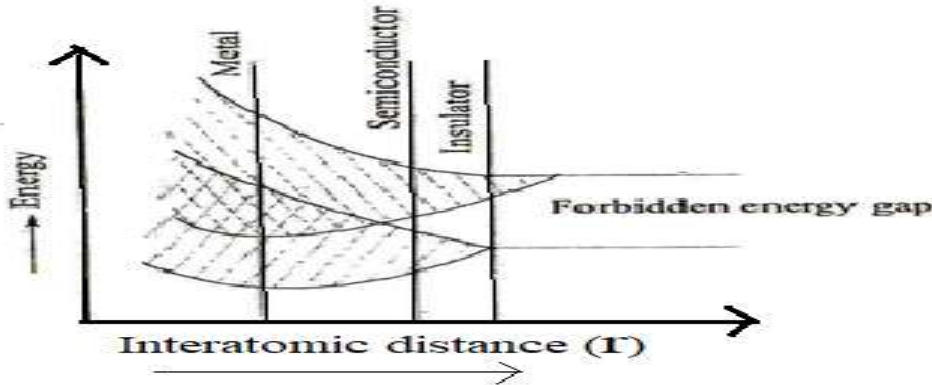
1. A solid contain large number of molecules or atoms.
2. In each atom, an electron tightly bounded in discrete energy levels.
3. The concentration of atoms in a gaseous medium is very low compared to the concentrations of atoms in a solid medium. As a result, in a gaseous substance the interatomic distance is very large.
4. In case of solids, inter-atomic distance is very small. Due to this interaction, the energy levels of atoms overlaps with each other, hence energy bands are formed.
5. The electrons first occupy at lower energy bands and no importance in determining many of the physical properties of solids are called valence band
6. These electrons present in higher energy bands are important in determining many of the physical properties of solids are called conduction band (or) the band corresponding to the outermost orbit is called conduction band.
7. The gap between the two allowed energy bands is called forbidden gap (or) energy band gap.
8. The conduction band is vacant at 0k temperature.
9. Depends on size of the forbidden gap, solids can be classified into three groups such as conductors, semi conductors and insulators.
10. The formation of energy bands is as shown in the above figure.

➤ EFFECTIVE MASS OF AN ELECTRON

When an electron in a periodic potential accelerates by the electric field (or) magnetic field, then the mass of the electron is called effective mass. According to relativistic theory, the relativistic mass of electron is

$$m = \frac{m_0}{\sqrt{1 - \left(\frac{V^2}{C^2}\right)}}$$

Here, 'm_0' and 'V' are the rest mass, velocity of electron and 'C' is the velocity of light.

Let us consider an electron of mass 'm' moving inside a crystal lattice, by the application of electric field E. The force acting on an electron is F,

$$F = e\,E$$
$$m\,a = e\,E \qquad\qquad (\because F = m\,a)$$

$\therefore$ acceleration $\quad a = \dfrac{F}{m^*} \qquad$ (or) $\qquad a = \dfrac{eF}{m^*}$ -------- (1)

according to quantum mechanics, the energy (E) of an electron, $E = \hbar\omega$

differentiating with respect to 'k', we get

$$\frac{dE}{dk} = \frac{d}{dk}(\hbar\omega)$$
$$\frac{dE}{dk} = \hbar\frac{d\omega}{dk}$$
$$\frac{d\omega}{dk} = \frac{1}{\hbar}\frac{dE}{dk}$$
$$V_{group} = \frac{1}{\hbar}\frac{dE}{dk} \qquad\qquad \left(\because V_{group} = \frac{d\omega}{dk}\right)$$

differentiating with respect to 't', we get acceleration of electron, $\quad a = \dfrac{d}{dt}(V_g)$

$$a = \frac{d}{dt}\left[\frac{1}{\hbar}\left(\frac{dE}{dk}\right)\right]$$

multiply and divide with 'dk' on right side, $\quad a = \dfrac{d}{dt}\left[\dfrac{1}{\hbar}\left(\dfrac{dE}{dk}\right)\right]\left(\dfrac{dk}{dk}\right).$

$$a = \frac{1}{\hbar}\frac{d^2E}{dk^2}\frac{dk}{dt} \text{--------- (2)}$$

In quantum theory, the momentum of an electron, $\quad P = \hbar k$

$$\frac{dP}{dt} = \hbar\frac{dk}{dt}$$

differentiating with respect to 't',

$$F = \hbar\frac{dk}{dt} \qquad \left(\text{since } \frac{dP}{dt} = F\right)$$
$$\frac{dk}{dt} = \frac{F}{\hbar}$$

from equation (2), we get $\quad a = \dfrac{1}{\hbar}\dfrac{d^2E}{dk^2}\left(\dfrac{F}{\hbar}\right)$

$$a = \frac{F}{\hbar^2}\frac{d^2E}{dk^2}$$
$$\therefore a = \frac{F}{\left[\hbar^2 \Big/ \dfrac{d^2E}{dk^2}\right]} \text{ ------- (3)}$$

from equations (1) & (3), the effective mass of electron is $\quad m^* = \dfrac{\hbar^2}{\left[\dfrac{d^2E}{dk^2}\right]}$

'm* Vs k' Diagram:- when an electron is in any of energy bands, the variation of 'E vs k', 'V vs k' and 'm* vs k' is shown in the figure.

1. When the electron is near the bottom of the band, $\dfrac{d^2E}{dk^2}$ is positive and

hence $m^* \approx m$. All conductors are examples.

2. When the electron is near the top of the band, $\dfrac{d^2E}{dk^2}$ is negative.

3. If $\dfrac{d^2E}{dk^2}$ is more, then the electron behaves like a lighter particle.

4. If $\dfrac{d^2E}{dk^2}$ is less, then the electron behaves like a heavy particle.
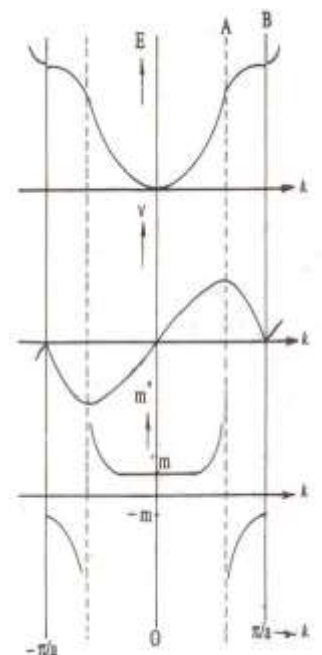
➤ CLASSIFICATION OF CRYSTALLINE SOLIDS (OR) CLASSIFICATION OF MATERIALS - CONDUCTORS, SEMICONDUCTORS AND INSULATORS

Crystalline solids are classified into three types based on the forbidden energy band gap. They are

1. Conductors 2. Semiconductors 3. Insulators

1. CONDUCTORS:

1. In case of conductors, the valence and conduction bands are overlapped to each other is as shown in figure.
2. Plenty of free electrons already existed in the conduction band at room temperature, hence conductivity is high.
3. In conductors, Charge carriers are only electrons.
4. The energy band gap is zero in conductors.
5. All metals are good conductors. Ex:- Cu, Al, Fe…
6. The resistivity of the conductors increases with of temperature.
    Ex: - all metals are good conductors.
7. Conductors have positive temperature coefficient.
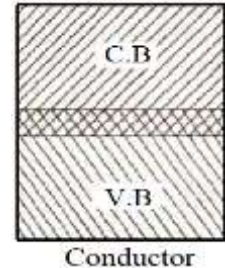
2. SEMICONDUCTORS:

1. In case of semi conductors, the valence and conduction bands are just separated to each other and the forbidden gap is small as shown in figure.
2. In these two bands electrons partially filled at room temperature.
3. In semiconductors, Charge carriers are both electrons and holes.
4. The energy band gap is small in semiconductors.
5. Silicon and germanium are good examples of semiconductors.
6. The resistivity of semiconductors decreases with increase of temperature. Ex:- Si, Ge,..
7. Semiconductors have negative temperature coefficient.
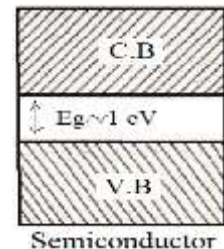
3. INSULATORS:

1. In case of insulators, the valence and conduction bands are separated to each other is shown in figure.
2. The conduction band is empty and the valence band is filled with electrons at room temperature, hence conductivity is zero.
3. No free electrons present in insulators.
4. The energy band gap is large in insulators.
5. Diamond is the best example of insulators (Energy gap is 7ev).
6. The resistivity of insulators decreases with increase of temperature. Ex:- Glass, Plastic, wood and synthetic materials.
7. Insulators have negative temperature coefficient.
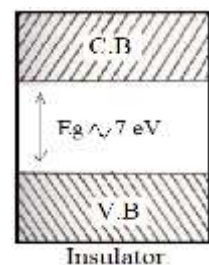
➤ 'E' VS 'K' DIAGRAM

1. The variation of 'E vs k' is shown in the figure.
2. The Energy (E) of electron is increases with increasing of phase (k).
3. The energy of electron is, $E = \dfrac{\hbar^2 k^2}{2m}$
4. The energy of electron is quantized. i.e. $E = \dfrac{n^2 h^2}{8mL^2}$
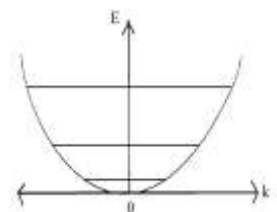
➤ CONCEPT OF HOLE

Hole is a vacancy position of an electron in a particular place in an atom.

1. A hole is only a theoretical concept to explain the deficiency of an electron and it does not exist in reality.
2. In physics, a hole is an electric charge carrier with a positive charge.
3. The charge of a hole is positive.
4. The magnitude of charge of a hole is equal to the charge of electron.
5. Holes and electrons are the two types of charge carriers responsible for the current in semiconductor materials.
6. When an electric field is applied to semiconductors, the lower valance band electrons escapes from valance band and excite to conduction band. Then the vacant site at valence band is called a hole.

UNIT-IV: DIELECTRIC & MAGNETIC MATERIALS

DIELECTRICS: *Introduction - Dielectric polarization - Dielectric polarizability, Susceptibility and Dielectric constant - Types of polarizations - Electronic (Quantitative), Ionic (Quantitative) and Orientation polarizations (Qualitative) - Lorentz internal field - Clausius-Mossotti equation - Piezoelectricity.*

➤ BASIC Definitions .

(1) Non-Polar dielectrics: If center of gravity of positive charges and negative charges coincide at a point that are called non polar dielectrics.

(2) Polar dielectrics: If center of gravity of positive charges and negative charges do not coincide at a point that are called non polar dielectrics.

(3) Electric Dipole: Two opposite charges of equal magnitude separated by a finite distance is called electric dipole.
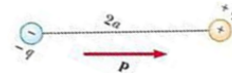
(4) Dipole moment (μ): It is the product of the charge and the distance between two charges.
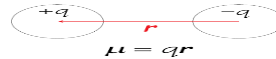
(5) Permittivity (ε): The ability of a material allow polarization.

(6) Relative Permittivity/Dielectric constant (ε_r): $\varepsilon_r = \varepsilon/\varepsilon_0$

The ratio of permittivity of the material to the permittivity of free space.

ε_0 = permittivity of free space (8.854×10^{-12} F/m)

(7) Dielectric Polarization: The displacement of negatively charged electrons and positively charged nucleus in the presence of electric field is called polarization.

Displacement of charges produce local dipoles in the material. The induced diploe moment (μ) is directly proportional to the electric field (E).

$$\mu \propto E$$

$$\mu = \alpha E \qquad \text{here, } \alpha \text{ is polarizability}$$

(8) Dielectric polarizability (α): The ratio of average dipole moment (μ) to the applied electric field (E). $\qquad \alpha = \mu / E \qquad$ **Unit:** Fm^2

(9) Polarization Vector (P):

The average dipole moment (μ) per unit volume (v). $\qquad P = \mu/v$

$$P = N \mu \qquad (\text{since } N=1/V)$$

$$P = N \alpha E$$

(10) Electric susceptibility (χ): Polarization is directly proportional to the product of 'ε_0' and applied electric field (E).

$$P \alpha \varepsilon_0 E$$

$$P = \chi \varepsilon_0 E$$

$$\chi = P/ \varepsilon_0 E$$

(11) Dielectric displacement (D):

The displacement of charges in the presence of electric field. $\therefore D \alpha E$.

➤ **Relation between Electric susceptibility (χ) and Relative Permittivity (ε_r)**

Dielectric displacement directly proportional to Electric field applied.

$$D = \varepsilon_o E + P$$
$$\varepsilon E = \varepsilon_o E + P \qquad \text{(since, } D = \varepsilon E)$$
$$\varepsilon_o \varepsilon_r E = \varepsilon_o E + P \qquad \text{(since, } \varepsilon = \varepsilon_o \varepsilon_r)$$
$$P = \varepsilon_o E(\varepsilon_r - 1)$$
$$P/\varepsilon_o E = (\varepsilon_r - 1)$$

$$\boxed{\chi = (\varepsilon_r - 1)}$$

➤ **TYPES OF POLARIZATIONS** .

1. **ELECTRONIC POLARIZATION: -**

 If positively charged nucleus and negatively charged electrons displaced by the application of electric field is called an electronic polarization.

 It is independent of temperature.

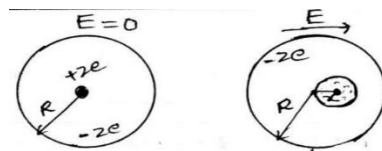 The displacement of charges produces local dipoles.

 The induced dipole moment is directly proportional to the applied electric field.

 $\mu_e \propto E$

 $\therefore \boldsymbol{\mu_e = \alpha_e E}$ ------ (1)   here, α_e is Electronic Polarizability

Electronic Polarisability (α_e):-

 Consider an atom of dielectric which contains the number of electrons of charge '-ze' and nucleus of charge +ze. R is radius of atom.

1) Charge density of the atom, $\rho = \dfrac{-ze}{^4/_3 \pi R^3}$ ------ (2)

2) By the application of electric field, electron cloud and nucleus separated by X.

3) When they are separated the coulomb attractive force and Lorentz repulsive forces develop between them.

 Lorentz force = - Ze E   ------ (3)

 Coulomb force = Ze × $\left[\dfrac{charge\ enclosed\ in\ sphere\ of\ radius\ x}{4\pi\varepsilon_o .x^2}\right]$ ------ (4)

4) Charge enclosed in sphere of radius 'x' = $\dfrac{4}{3}\pi x^3 . \rho$

$$= \dfrac{4}{3}\pi x^3 . \dfrac{-ze}{\frac{4}{3}\pi R^3} \quad \text{(since from (2))}$$

$$= -\dfrac{ze x^3}{R^3}$$

from equation (4), Coulomb force = Ze × $\dfrac{\left[\frac{-ze x^3}{R^3}\right]}{4\pi\varepsilon_o .x^2} = -\dfrac{z^2\ e^2\ x}{4\pi\varepsilon_o R^3}$ ------ (5)

5) At equilibrium Position, from equations (3) & (5),

Lorentz force = Coulomb force

$$-ZeE = -\frac{z^2 \, e^2 \, x}{4\pi\varepsilon_o R^3}$$

$$x = \left[\frac{4\pi\varepsilon_o R^3}{ze}\right]E$$

6) Induced dipole moment, $\mu_e = Zex$

$$\mu_e = ze\left[\frac{4\pi\varepsilon_o R^3}{ze}\right]E$$

$$\boldsymbol{\mu_e = 4\pi\varepsilon_o R^3 \, E} \quad \text{------ (6)}$$

7) from equations (1) and (6),

Electronic   Polarizability $\boxed{\alpha_e = 4\pi\varepsilon_o R^3}$ Fm^2

2. **IONIC POLARISATION**: -

If ions (anions and cations) are displaced by the application of electric field is called ionic polarization.

It is independent of temperature.

The displacement of charges produces local dipoles.

The induced dipole moment is directly proportional to the applied electric field.

$$\boldsymbol{\mu_i \propto E}$$

$$\therefore \boldsymbol{\mu_i = \alpha_i E} \quad \text{------ (1)} \qquad \text{here, } \alpha_i \text{ is Ionic Polarizability}$$

Ionic Polarizability(α_i):-

Consider an ionic material and assume that each unit cell contains one positive ion and one negative ion.

1) When an electric field is applied, positive ions displaced by 'x_1' and negative ions displaced by 'x_2'.

2) The resultant dipole moment per unit cell is

$$\mu_i = e[x_1 + x_2] \text{------ (2)}$$

3) In the presence applied field, the force acting on positive ion $F = \beta_1 x_1$

$$x_1 = \frac{F}{\beta_1}$$

since $F = e E$, β_1 is restoring force constant $= m\omega_o^2$, m is mass of positive ion

$$x_1 = \frac{e.E}{m\omega_o^2} \text{------ (3)}$$

4) Similarly, the force acting on the negative ion $F = \beta_2 x_2$

$$x_2 = \frac{F}{\beta_2}$$

since $F = e E$, β_2 is restoring force constant $= M\omega_o^2$, m is mass of negative ion

$$x_2 = \frac{e.E}{M\omega_o^2} \text{------ (4)}$$

5) from equations (2), (3) & (4), dipole moment $\mu_i = e\left[\frac{e.E}{m\omega_o^2} + \frac{e.E}{M\omega_o^2}\right]$

$$\mu_i = \frac{e^2}{\omega_0^2}\left[\frac{1}{m} + \frac{1}{M}\right].E \quad \text{------ (5)}$$

6) from equations (1) and (5),

Ionic Polarizability $\boxed{\alpha_i = \frac{e^2}{\omega_0^2}\left[\frac{1}{m} + \frac{1}{M}\right]}$ F-m^2

3. ORIENTATION POLARISATION: -

Already existing dipoles orient in the field direction by the application of electric field is called Orientation Polarization.

Orientation Polarization depends on temperature.

Polarization $P = N\,\mu_0$

since, $\mu_0 = \alpha_0\,E$

$$P = N\,\alpha_0\,E \text{ ------- (1)} \quad \text{here, } \alpha_0 = \text{Orientational Polarisability.}$$

Orientational Polarisability(α_0):-

Consider a dielectric contains number of dipoles.

1) In the presence of electric field, already existing dipoles orient in the field direction.

2) The polarization vector, $P = N\mu$ ------- (2)

Here, 'N' is number of atoms per unit volume,

μ is average dipole moment.

3) By solving we get the average dipole moment,
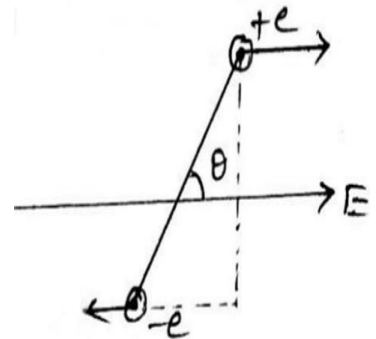
$$\mu = \frac{\mu^2 E}{3KT} \text{ ------- (3)}$$

Here 'K' is Boltzmam constant and 'T' is temperature.

4) From equations (2) & (3), we have that $P = N.\frac{\mu^2 E}{3KT}$

$$P = N\left[\frac{\mu^2}{3KT}\right]E \text{ ------- (4)}$$

5) from equations (1) and (4),

Orientation Polarizability $\boxed{\alpha_o = \frac{\mu^2}{3KT}}$ Fm^2

4.SPACE CHARGE POLARISTION: -

"Space charge polarization occurs due to the accumulation of charges at electrodes or interfaces in multiphase dielectrics.

It is found in ferrites and semi-conductors.

Space charge polarization is very small.

TOTAL POLARIZATION:

The total polarizability of a dielectric material is the sum of electronic, ionic, orientational and space charge polarizabilities.

$$\alpha_{total} = \alpha_e + \alpha_i + \alpha_o + \alpha_s$$

$$\alpha_{total} = 4\pi\varepsilon_0 R^3 + \frac{e^2}{\omega_0^2}\left[\frac{1}{m} + \frac{1}{M}\right] + \frac{\mu^2}{3KT}$$

Total Polarization of a dielectric material is $P = N\alpha E$

$$P_{total} = N\left[4\pi\varepsilon_0 R^3 + \frac{e^2}{\omega_0^2}\left[\frac{1}{m} + \frac{1}{M}\right] + \frac{\mu^2}{3KT}\right]E$$

This equation is called as *Langevin-Debye* equation.

➤ INTERNAL FIELD / LOCAL FIELD / LORENTZ FIELD .

Definition –
The field acting at a point Space in dielectric by application of electric field.

Consider a di-electric material placed in between two plates of parallel plate capacitor. Let a point 'P' in the spherical cavity 'A' in dielectric as shown in the figure.

The internal field acting at a point 'P' is
$$E_i = E_1 + E_2 + E_3 + E_4$$

Proof:-
Field E_1:
E_1 is the field acting in between two parallel plates of the capacitor.
$$E_1 = E + \frac{P}{\varepsilon_o}$$

Field E_2:
E_2 is the field intensity at a point 'P' due to the induced charges on surfaces of dielectric.
$$E_2 = -\frac{P}{\varepsilon_o}$$

Field E_3:
E_3 is the field intensity at a point 'P' due to neighboring atoms (or all the dipoles) in the spherical cavity.
$$E_3 = 0$$

Field E_4:
E_4 is the field intensity at a point 'P' due to polarized charges on the surface of spherical cavity.
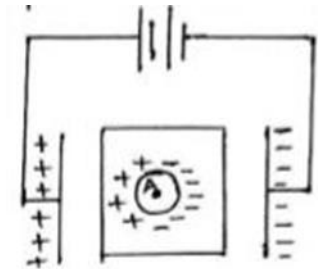$$E_4 = \frac{P}{3\varepsilon_o}$$

The internal field acting at a point 'P',
$$E_i = E_1 + E_2 + E_3 + E_4$$
$$E_i = \left[E + \frac{P}{\varepsilon_o}\right] + \left[-\frac{P}{\varepsilon_o}\right] + [0] + \left[\frac{P}{3\varepsilon_o}\right]$$
$$E_i = E + \frac{P}{\varepsilon_o} - \frac{P}{\varepsilon_o} + \frac{P}{3\varepsilon_o}$$

∴ **Internal field**
$$E_i = E + \frac{P}{3\varepsilon_o}$$

➢ CLAUSIUS MOSOTTI RELATION .

Consider a dielectric and assume there is no ions and permanent dipoles.
Hence the ionic polarizability (α_i) and orientational polarizability (α_0) are zero.

$$\alpha_i = \alpha_0 = 0$$

polarization $P = N \alpha_e E_i$

$$P = N \alpha_e \left[E + \frac{P}{3\varepsilon_o} \right] \qquad \left(\text{since, } E_i = E + \frac{P}{3\varepsilon_o} \right)$$

$$P = N\alpha_e E + \frac{N\alpha_e P}{3\varepsilon_o}$$

$$P - \frac{N\alpha_e P}{3\varepsilon_o} = N \alpha_e E$$

$$P\left[1 - \frac{N\alpha_e}{3\varepsilon_o}\right] = N \alpha_e E$$

$$\left[1 - \frac{N\alpha_e}{3\varepsilon_o}\right] = \frac{N \alpha_e E}{P}$$

$$\left[1 - \frac{N\alpha_e}{3\varepsilon_o}\right] = \frac{N \alpha_e E}{\varepsilon_o E(\varepsilon_r - 1)} \qquad (\text{ since, } P = \varepsilon_o E(\varepsilon_r - 1))$$

$$1 - \frac{N\alpha_e}{3\varepsilon_o} = \frac{N\alpha_e}{\varepsilon_o(\varepsilon_r - 1)}$$

$$1 = \frac{N\alpha_e}{3\varepsilon_o} + \frac{N\alpha_e}{\varepsilon_o(\varepsilon_r - 1)}$$

$$1 = \frac{N\alpha_e}{3\varepsilon_o} \left[1 + \frac{3}{(\varepsilon_r - 1)}\right]$$

$$\frac{N\alpha_e}{3\varepsilon_0} \left[\frac{(\varepsilon_r - 1) + 3}{\varepsilon_r - 1} \right] = 1$$

$$\frac{N\alpha_e}{3\varepsilon_0} \left[\frac{(\varepsilon_r + 2)}{\varepsilon_r - 1} \right] = 1$$

$$\boxed{\frac{N\alpha_e}{3\varepsilon_0} = \left[\frac{(\varepsilon_r - 1)}{\varepsilon_r + 2} \right]} \qquad \text{This is called Clausius Mosotti equation.}$$

➢ APPLICATIONS OF DIELECTRICS .

Dielectrics widely used as insulating materials.

1) **Plastic or Rubber:** Used as outer jackets of electrical conductors.
2) **Ceramics:** Ceramics widely used as insulators for switches, plug holders etc...
3) **PVC Materials:** Used as wires and cables, PVC films, tapes....
4) **Mica:** Mica used as an insulator in the form of paper, tape, cloth and boards….
5) **Mineral Insulating Oil:** Used as Transformer oil, cable oil, capacitor oil etc.
6) **Inert gases:** Used in electronic tubes and discharge tubes as insulators.
7) **Air:** Air condensers. It is the most important insulating material.
8) **Capacitors:** Dielectric materials used in capacitors to store the energy.
9) **High Voltage Applications:** Used in high voltage applications.
10) **Asbestos:** Asbestos insulation is providing to prevent the flow of electric current.

➢ PIEZO ELECTRICITY

When mechanical stress is applied to the material (crystal), it can electrically have polarized. This is called piezo electric effect.   Or

The materials exhibit electronic polarization when the mechanical stress is applied.

When a piezo electric crystal like quartz is subjected to compressions, an opposite kinds of charges developed at the end faces perpendicular to the direction of applied force.
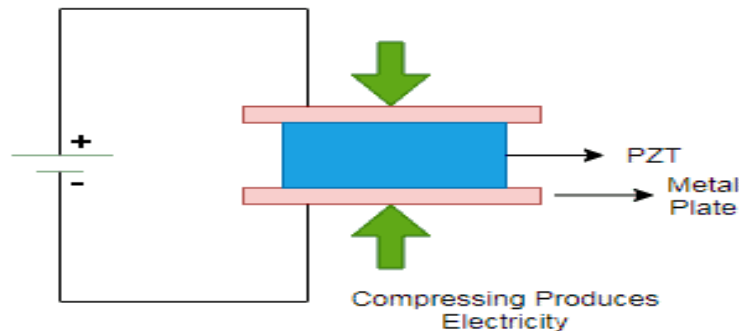
Applications of Piezo electric materials

1) Piezo electric materials exhibit piezo electricity
2) Piezo electric materials used for high voltage generators
3) Piezo electric materials used as amplifiers
4) Piezo electric materials used as filters
5) Microphones.
6) Piezoelectric Motors.
7) Actuators in Industrial Sector.
8) Sensors in Medical Sector.
9) Actuators in Consumer Electronics (Printers, Speakers)
10) Piezoelectricity Buzzers
11) Piezo electric materials used to produce ultrasonic.

2) MAGNETIC MATERIALS

Introduction - Magnetic dipole moment - Magnetization-Magnetic susceptibility and permeability - Origin of permanent magnetic moment - Classification of magnetic materials: Dia, para, Ferro, antiferro & Ferri magnetic materials - Domain concept for Ferromagnetism & Domain walls (Qualitative) - Hysteresis - soft and hard magnetic materials- Eddy currents- Engineering applications.

➢ **BASIC DEFINITIONS**

1. Magnetic dipole moment

It is the product of length and pole strength of magnetic material.

$$M = 2\,l\,m$$ **Units:** Am^2

2. Magnetic Induction or Magnetic flux density (B)

Number of magnetic flux passing per unit area of the material   (Or)

It is the product of permeability of the medium and applied magnetic field intensity.   **B = μ H**   **Units:** Weber / m²

3. Magnetic Field Intensity (H)

The force acting at a point in the magnetic field by unit north pole.   (Or)

It is the ratio of Magnetic Induction (B) to the permeability of the material.

$$H = \frac{B}{\mu}$$ **Units:** A/m

4. Permeability (μ)

The ability of medium which allows magnetic flux.   (Or)

The ratio of magnetic field intensity to magnetic induction of the medium.

$$\mu = \frac{B}{H}$$ **Units:** H/m

5. Relative Permeability (Hr)

The ratio of permeability(μ) of medium to permeability of free space (μ_0).

$$\mu_r = \frac{\mu}{\mu_0}$$ **Units:** H/m $\mu_0 = 4\pi \times 10^{-7}$ henry/m

6. Magnetization:
The process of converting non-magnetic material into a magnetic material is called Magnetization.

7. Intensity of Magnetization (M or I):
Magnetic moment per unit volume of the material is called intensity of magnetization. **Units - A/m**

8. Magnetic Susceptibility (χ):
The ratio of intensity of magnetization(M) to the applied magnetic field intensity (H).

$$\chi = \frac{M}{H}$$ **Units:** No Units

➢ **B = μ_0 (H+M) and χ = (μ_r-1)**

Magnetic induction of the material,

$B = \mu H$ *(or)* $\mu = B/H$ *---- (1)*

$B = \mu_0\, \mu_r\, H$ *(since* $\mu = \mu_0\, \mu_r$*)*

$B = \mu_0\, \mu_r\, H + \mu_0\, H - \mu_0\, H$

$B = \mu_0\, H\,(\mu_r - 1) + \mu_0\, H$

$B = \mu_0\, M + \mu_0\, H$ *(since M=H(μ_r-1))*

$B = \mu_0\, (H + M)$

$\mu_0 = \dfrac{B}{H+M}$ *--------(2)*

Relative permeability, $\mu_r = \dfrac{\mu}{\mu_0}$

from equations (1) & (2),

$\mu_r = \dfrac{B/H}{\frac{B}{H+M}} = \dfrac{H+M}{H} = 1 + \dfrac{M}{H}$

$\mu_r = 1 + \chi$ *(since* $\chi = M/H$*)*

$\chi = (\mu_r\, -1)$

➢ ORIGIN OF MAGNETIC MOMENT .

The permanent magnetic moment in the material is due to the following

        1. Orbital magnetic moment of electron

        2. Spin magnetic moment of electron

        3. Spin magnetic moment of nucleus

1) Orbital Magnetic Moment of Electron:

Consider an electron of mass 'm' which revolves around the nucleus with an angular velocity 'ω' in a stationary orbit of radius 'r'.

The current due to motion of electrons in orbit is

$$I = \frac{q}{t} = \frac{-e}{2\pi/\omega} \qquad ----- (1)$$

magnetic moment, $\mu_m = I.A$

$$\mu_m = \frac{-e\omega}{2\pi} \pi r^2 \qquad (since\ A = \pi r^2)$$

$$\mu_m = \frac{-e\omega r^2}{2} \ x \ \frac{m}{m}$$

$$\mu_m = \frac{-em\omega r^2}{2m}$$

$$\mu_m = \frac{-e}{2m} L \qquad (since$$

here, $L = m\omega r^2$ is orbital angular momentum of electron.

The minus sign indicates that the magnetic moment μ_m is anti-parallel to the angular momentum L.

According to Bohr's theory, orbital angular momentum $L = m_l \frac{h}{2\pi}$

here 'm_l' is the quantum number; 'h' is Planck's constant,

$$\mu_m = \frac{-e}{2m} (m_l \frac{h}{2\pi})$$

$$\mu_m = \frac{-eh}{4\pi m} m_l$$

$$\mu_m = -\mu_B m_l$$

here μ_B is Bohr's Magneton, $\quad \mu_B = \frac{eh}{4\pi m} = 9.27 x 10^{-24} Am^2$
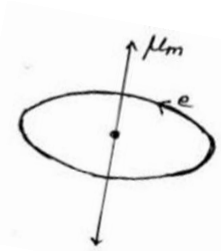
2) Spin Magnetic Moment of Electron

$$\mu_s = g \ (\frac{eh}{4\pi m}) m_s \qquad Am^2$$

here, g is Lande's function, 'h' is Planck's constant.

3) Spin Magnetic Moment of Nucleus

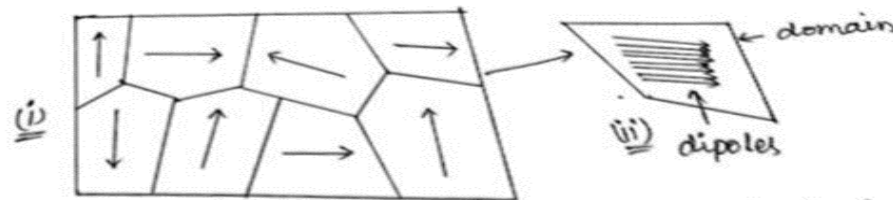$$\mu_n = \frac{eh}{4\pi Mp} = 5.05 \ x \ 10^{-29} Am^2$$

here, M_p is mass of the proton.

➢ DOMAIN THEORY OF FERRO MAGNETISM .

Domain theory of Ferro magnetism was proposed by Weiss in 1907.

1. According to Weiss theory, any Ferro magnetic material contains large number of smallest regions are called domains shown in figure (i).

2. Size of each domain is one micro meter ($1\mu m = 10^{-6}$ m).
3. Each domain contains number of dipoles in ferromagnetic materials shown in above figure (ii).
4. Each domain is spontaneously magnetised in a particular direction.
5. The direction of magnetisation is different for domain to domain.
6. But the resultant magnetization of the Ferro magnetic material is almost zero.
7. **In the presence of external magnetic field**: The orientation of domains and dipoles will change in two possible ways by the applied field.
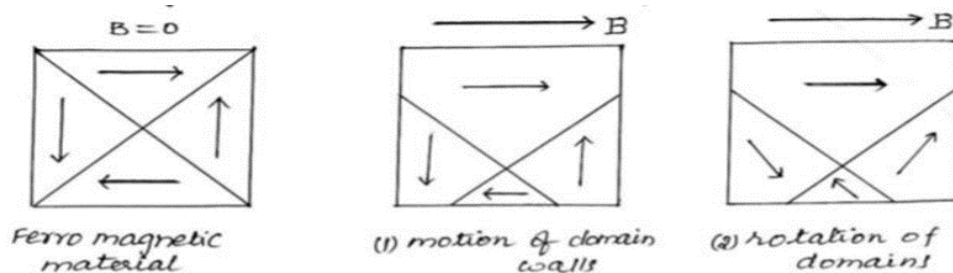
8. *1) Motion of Domain Walls*
   By the application of magnetic field, initially volume of the domains will be changes according to their magnetisation directions.
   i) If the magnetisation of the domain is in the direction of applied magnetic field, then that domain walls will increase.
   ii) Similarly, if the magnetisation of the domain is not in the applied field direction, that domain walls will changes associated with their magnetisation directions is as shown in the figure.

9. *2) Rotation of Domains*
   By the application of magnetic field, at final stage, all the domains/dipoles orient along the applied magnetic field as shown in the above figure.

10. Finally, after application of magnetic field, all the dipoles orient along the field direction and then the ferromagnetic material can be magnetised.

11. This is called the Weiss domain theory of ferromagnetism.

➤ HYSTERESIS LOOP (OR) CURVE   .

Hysteresis of Ferro magnetic materials refers to the lag of magnetisation (or) magnetic induction behind the magnetizing field.

When the temperature of the Ferro magnetic material is below the Ferro magnetic curie temperature, they exhibit hysteresis only.

1. When an external magnetic field (H) is applied to the Ferro magnetic material, the intensity of magnetisation (M) will be increased first rapidly and then slowly up to a certain maximum value of +Ms along OP as shown in the below figure.
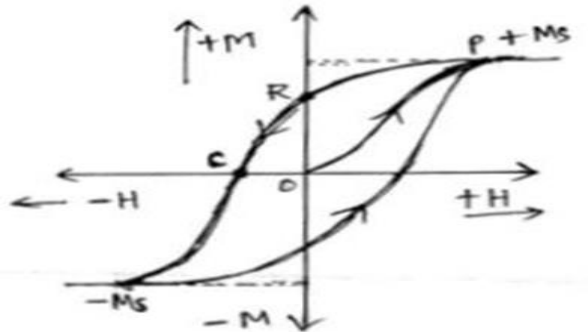
2. At '+Ms' all the domains completely polarised. So it is called as Saturated Magnetisation.
3. **Retentivity (R):** When the magnetic field (H) is decreased to zero gradually, 'M' does not come to zero is called Retentivity (R).

   ∴ **H = 0 and M ≠ 0**

   Retentivity means retain some amount of magnetisation.
4. During the de-magnetization, even H is decreasing, M does not retrace the original path OP.
5. **Coercivity (C):** If H is increased gradually in reverse direction, M becomes to zero at particular value of H is called Coercivity (C).
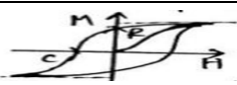
   ∴ **M = 0 and H ≠ 0**

6. Further increasing H in the same direction, M increases to a certain maximum value of –Ms is called saturated magnetisation in reverse direction as shown in the above figure.
7. And again H is decreased in the reverse direction, M does not retrace the original path is as shown in the figure.
8. By study of hysteresis loop of different magnetic materials helps to know the magnetic properties and applications.
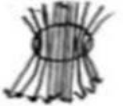
The area of hysteresis loop gives the energy loss during the magnetisation and de-magnetisation.
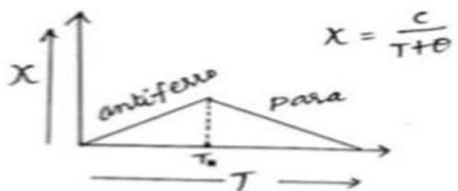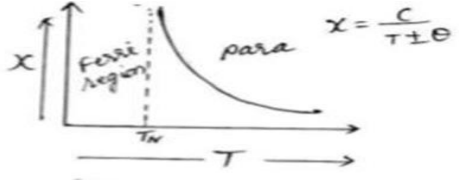
The hysteresis loop is thin for soft magnetic materials and fat for hard magnetic materials.

➤ DISTINGUISH BETWEEN SOFT & HARD MAGNETIC MATERIALS

SOFT MAGNETIC MATERIALS	HARD MAGNETIC MATERIALS
1) Hysteresis loop is very thin	1) Hysteresis loop is very fat
2)	2)
3) Example : Soft iron	3) Example : Steel
4) Retentivity is very low	4) Retentivity is high
5) Coercivity is very low	5) Coercivity is high
6) Magnetic susceptibility is high	6) Magnetic susceptibility is low
7) Relative permeability is high	7) Relative permeability is low
8) *Energy lost is very low during magnetisation & demagnetisation*	8) *Energy lost is very high during magnetisation & demagnetisation*
9) *Examples - Ferrites*	9) *Examples- Copper-nickel-cobalt alloy (cunico), Copper-nickel,-ferrous alloy (cunife).*

10) *Applications:*
   a) *to make electro-magnets*
   b) *used in switching circuits*
	10) *Applications:*
	   a) *to make permanent magnets*
	   b) *used in Microphones*

➤ CLASSIFICATION OF MAGNETIC MATERIALS .

| Dia	Para	Ferro
1) Materials in which no dipole moment are called diamagnetic materials.	1) Materials in which permanent dipole moment.	1) Materials in which enormous permanent dipole moment.
2) No spins	2) Random spins	2) Orderly spins
3) $\mu_r < 1$ Relative permeability is less than unity	3) $\mu_r \approx 1$ Relative permeability is equal to unity	3) $\mu_r >> 1$ Relative permeability is greater than unity
4) χ is small	4) χ is small	4) χ is high
5) χ is negative	5) χ is positive	5) χ is positive
6) Repels the magnetic flux	6) Attract magnetic flux	6) Heavily attract flux
7) $B_{in} < B_{out}$	7) $B_{in} > B_{out}$	7) $B_{in} >> B_{out}$
8) Independent of temperature	8) Dependent of temperature $\chi = \frac{C}{T}$	8) Dependent of temperature $\chi = \frac{C}{T + \theta c}$
9) Induced magnetic moment is opposite to applied field	9) Parallel	9) Anti-parallel
10) Examples - gold, Ge, Si,	10) Ex - Alkali metals	10) Ex - Fe, Co, Ni.

Anti - Ferro Magnetism	Ferri Magnetism
1. The materials in which opposite spins with equal magnitudes.	1. The materials in which opposite Spins with unequal magnitudes.
2. Spin Alignment ↑↓↑↓↑	2. Spin Alignment ↑↓↑↓↑
3. Net magnetization is zero due to equal magnitudes.	3. Net magnetization is not zero due to unequal magnitudes.
4. χ is small	4. χ is large
5. χ is positive	5. χ is positive
6. Temperature dependent of 'χ' $x = \frac{c}{T+\theta}$	6. Temperature dependent 'χ' $x = \frac{c}{T\pm\theta}$
7. Initially 'χ' increases slightly and after Neel's temperature(T_N), 'χ' decreases with increasing temperature. i) Below T_N, it is a antiferro material ii) Above T_N, it is a para material	7. 'χ' decreases with increasing temperature. i) Below T_N, it is a ferri material ii) Above T_N, it is a para material
8. *Neel's temperature:* The temperature at which 'χ' is maximum.	8. *Neel's temperature:* The temperature at which 'χ' is maximum.
9. Examples - MnO, FeO, Cr_2O_3….	9. Examples- Ferrites ($Me^{2+} Fe_2^{3+} O_4$).

➢ EDDY CURRENT .

Definition: *An electric current induced by an alternating magnetic field is called Eddy current.*

The currents can be induced not only in conducting coils but also in conducting sheets and blocks.

The power loss due to eddy current is directly proportional to I^2R

Here, I is the magnitude of eddy current,   R is resistance.
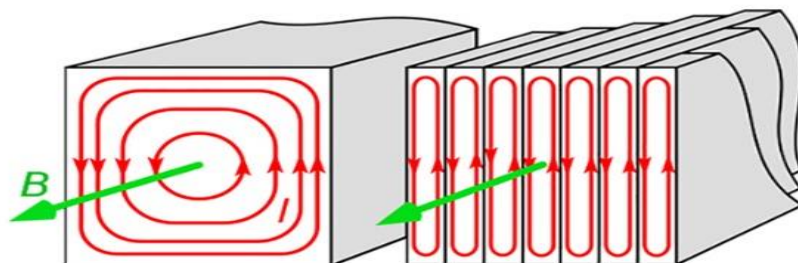
UNIT-V: SEMICONDUCTORS AND SUPER CONDUCTORS

SEMICONDUCTORS: Introduction- Intrinsic semiconductors – Density of charge carriers – Electrical conductivity – Fermi level – extrinsic semiconductors – density of charge carriers – dependence of Fermi energy on carrier concentration and temperature - Drift and diffusion currents – Einstein's equation- Hall effect – Hall coefficient – Applications of Hall effect.

SUPERCONDUCTORS: Introduction – Properties of superconductors – Meissner effect – Type I and Type II superconductors – BCS theory (Qualitative) – Josephson effects(AC&DC)-SQUIDs-High T_c superconductors – Applications of superconductors.
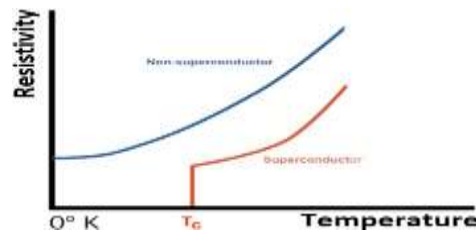
1) SUPER CONDUCTORS

SUPERCONDUCTIVITY:

Electrical resistivity (ρ) of metals and alloys suddenly drops to zero when they cooled down to sufficient low temperature. ∴ $\boxed{\rho = 0}$

It was discovered by H.K.Onnes in 1911 for Mercury at 4.2 K temperature.

The materials obey superconductivity are called superconductors

(or)

Some of the metals and alloys exhibit zero electrical resistivity (ρ = 0) and infinite electrical conductivity (σ = ∞) when they cooled down to sufficient low temperatures is called superconductivity.

The materials obey superconductivity are called superconductors

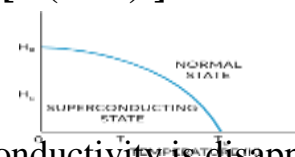➢ **GENERAL PROPERTIES / CRITICAL PARAMETERS** .
   1) *Critical Temperature (T_c)*: The temperature at ρ = 0. For mercury Tc is 4.2 K.
   2) *Critical Magnetic Field (H_c)*: The magnetic field at which superconductivity is disappeared. $H_c(T) = H_c(O)[1-(T/T_c)^2]$
      $H_c(T)$ = Critical Field at T temperature
      $H_c(O)$ = Critical Field at O'K temperature T_c
        = Critical Temperature
   3) *Critical Current (I_c):* The current at which Super conductivity is disappeared.
      $I_c = 2\pi r\, H_c$
      I_c= Critical current, H_c = Critical magnetic field, r = Radius of super conductor.
   4) *Isotope Effect*: Critical temperature is different for various superconductors.
      $M^\alpha T_c = K$ M = Mass of isotope of superconductor,
      T_c = Critical temperature, α = Isotope effect co-efficient = 0.5, K = Constant.
   5) *Occurrence of Superconductivity*: Valence electrons in between 2 to 7.
   6) *Zero electrical resistivity:* Electrical resistivity is zero. (ρ = 0)
   7) *High electrical conductivity:* Infinite electrical conductivity (σ = ∞).
   8) *High Normal Resistivity:* Superconductors are high normal resistive materials.
   9) *Good conductors*: All superconductors are good conductors but all conductors are not superconductors.
   10) *Meissner Effect:* Below the critical temperature (T_c), superconductor repels the magnetic flux is called Meissner Effect. **χ = -1**
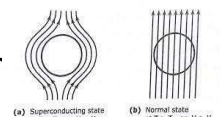
11) *Diamagnetic:* These are perfect diamagnetic materials.

12) For structurally perfect superconductors the transitions are very sharp and for structurally imperfect specimens' transitions are broad

➢ MEISSNER   EFFECT   .

Below the critical temperature (T_c), superconductor repels the magnetic flux is called Meissner Effect.

Consider a superconductor at below its critical temperature and placed in uniform magnetic field then it can repel the magnetic flux.

According to magnetic field theory, $B = \mu_0$ (H+M) for superconductor B = 0,
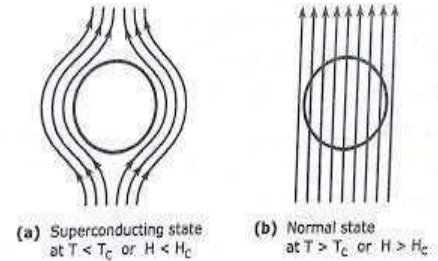
$$0 = \mu_0 (H+M)$$
$$(H+M) = 0$$
$$M = -H$$
$$M/H = -1$$
$$\boxed{\chi = -1}$$

(a) Superconducting state at $T < T_c$ or $H < H_c$

(b) Normal state at $T > T_c$ or $H > H_c$

It means that super conductor is a perfect diamagnetic material.

➢ TYPE – I & TYPE – II SUPERCONDUCTORS   .

Based on Meissner effect superconductors are classified into two categories,

(1) Type – I Superconductors   (2) Type – II Superconductors

	Type – I Superconductors	Type – II Superconductors
1	Soft superconductors.	Hard superconductors.
2	Obey Meissner effect.	Does not obey Meissner effect.
3	Pure metals.	Alloys.
4	Critical temperature (T_c) is sharp.	Critical temperature (T_c) is not sharp.
5	Critical magnetic field (H_c) is sharp.	Critical magnetic field (H_c) is not sharp.
6	Exhibits One critical magnetic field.	Exhibits Two critical magnetic fields.
7		
8	If $H < H_c$, it is a super conductor, If $H > H_c$, it is a normal conductor.	If $H < H_{c1}$, it is a super conductor, If $H_{c1} < H < H_{c2}$, it is in vortex state, If $H_{c2} < H$, it is a normal conductor.
9	Perfect diamagnetic.	Not perfect diamagnetic.
10	Low-temperature Superconductors.	High-temperature Superconductors.
11	Examples: Hg, Pb, Zn, etc.	Examples: Nb-Ti, Nb-Sn, Nb-Zr etc.

➢ JOSEPHSON EFFECTS   .

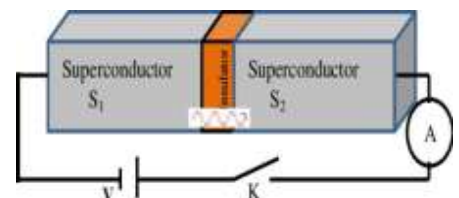*DC Josephson Effect:*

A direct current (DC) flows through the junction in the absence of electric field is called DC Josephson effect.

$$\boxed{I = I_0 \; \text{Sin} \; \theta}$$

(i) I_0 is maximum current flows at the junction.

(ii) I_0 depends on thickness of junction and temperature.

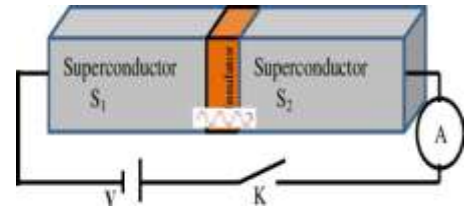(iii) Phase difference (θ) is constant. $\therefore \theta = \theta_2 - \theta_1 = $ Constant.

AC Josephson Effect:

An alternating current (AC) flows through the junction in the presence of electric field is called AC Josephson effect.

$$\boxed{I = I_0 \, Sin \, (\theta + \Phi)}$$

(i) I_0 is maximum current flows at the junction.
(ii) I_0 depends on thickness of junction and temperature.
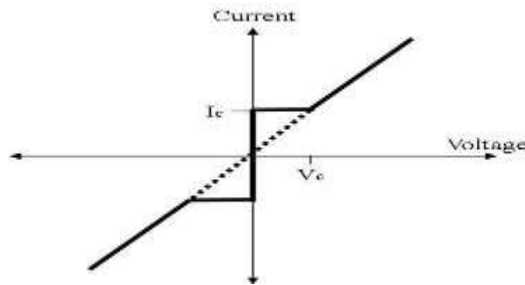(iii) Phase difference is not constant.

When external voltage (V_0) is applied, the additional phase difference(Φ) is produced at near the junction.

$$I = I_0 \, Sin \, (\theta + \omega t)$$

Angular frequency $(\omega) = 2ev_0 \, / \, \hbar$

Current – Voltage Characteristics of Josephson Effect:

(i) If $V_0 < V_c$ then DC flows through the junction is calledDC Josephson effect.
(ii) If $V_0 > V_c$ then AC flows through the junction is calledAC Josephson effect.

Application of Josephson Effect:

1. Josephson effect is used to generate microwaves with frequency $\omega = 2ev_0 / \hbar$
2. AC Josephson effect is used to define standard volt.
3. Josephson junction is used for switching the signals from one circle to other.

➢ **SQUIDs** .

SQUID is a superconducting quantum interference device.

SQUIDs are usually fabricated from lead or pure niobium. And Lead/niobium layer ismixed with 10% of Gold or Indium. SQUIDs are mainly two types.
1). DC SQUIDs   2). AC (or RF) SQUIDs

DC SQUID:

It contains two Josephson junctions shown in the figure.These are more difficult and expensive.

AC SQUID:

It contains only one Josephson junction.

SQUIDs -Applications

These are extremely sensitive magnetometers and used to measure smallest electricaland magnetic measurement applications in various living organisms.

1. MCG – Magneto Cardio Graphy
2. MEG – Magneto Encephalo Graphy
3. MPG – Magneto Plethismo Graphy
4. MRI – Magnetic Resonance Imaging
5. Threshold for SQUID   : 10^{-14} T
6. Magnetic field of heart   : 10^{-10} T
7. Magnetic field of brain   : 10^{-13} T
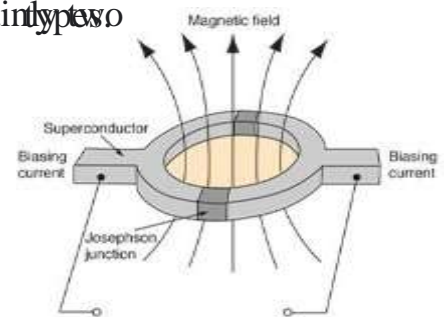
➢ **B C S – THEORY** .

In 1972, The Nobel Prize awarded jointly to **Bardeen**, **Cooper** and **Schrieffer**for their theory of superconductivity called **BCS theory.**

1. BCS theory was developed by Bardeen, Cooper and Schrieffer.

2. BCS theory states that the electron experiences a special kind of attraction insuperconductors.

3. BCS theory explained microscopic mechanisms of superconductors.

4. Electrons in the superconductors are called super electrons.

5. According to BCS theory, electrons are paired by exchanging phonons.

6. Pair of electrons are called cooper pairs.

7. At low temperature, electron pairs move without scattering and without any resistance throughout the lattice points.

8. In superconductors, interaction among the electrons is electron – lattice – electroninteraction.

9. Electron – lattice – electron interaction is stronger than electron – electron interaction.

10. **Electron –Lattice –Electron Interaction:**

i) When any (1ˢᵗ) electron moves through the lattice, it will be attracted by thepositively charged (+ ve) core of the lattice.
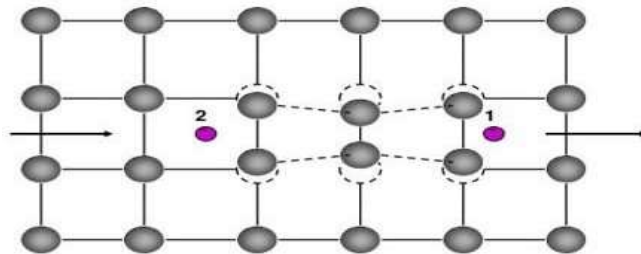
ii) Due to this attraction, ion core is disturbed and produce lattice vibrations withphonons. Then increased concentration of positive charge.

iii) If another (2ⁿᵈ) electron moves through this region as shown in figure. It willbe attracted by the greater concentration of positive charge.

iv) In this way the two electrons interact with the lattice is called 'electron – lattice – electron' interaction.

11. **Cooper pair:**

i) Cooper pair is formed due to electron – lattice – electron interaction.

ii) This interaction is very strongly when these two electronshave equal and opposite spin momentum.
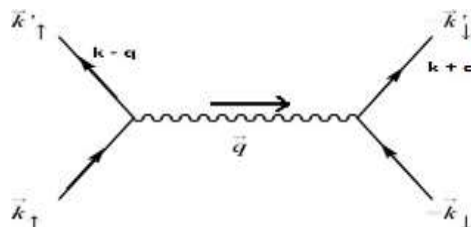
iii) Two electrons represented as +k↑ and -K↓ spins.

iv) Two electrons with wave vectors 'k – q' and 'k + q' forma Cooper pairs.

v) Cooper pairs have a spin zero.

12. Energy gap:

i) The energy of cooper pair is lower than two unpaired electrons.

ii) The Energy gap represents the energy required to break up the cooper pair.

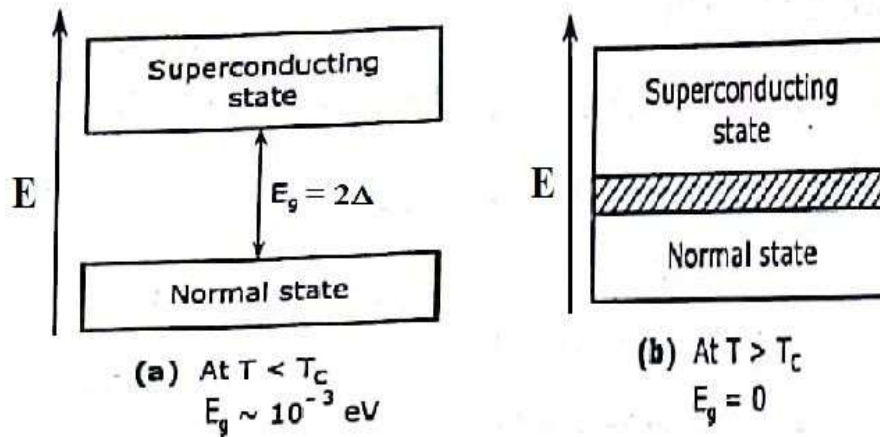iii) Energy gap of superconductor at various temperatures is shown in the figure.

13. Fermi-Dirac distribution function is

$$F(E) = \cfrac{1}{1 + \exp\left(\cfrac{E - E_F}{k_B T}\right)}$$

➢ HIGH Tᴄ SUPERCONDUCTORS – APPLICATIONS　　　　　.

Applications of High Temperature Superconductors divided into two groups:

　　　1. Large scale applications (Large magnetic fields)

　　　2. Small scale applications (Small magnetic fields)

1. Large scale applications:

　　　a. High-voltage and High-power transmission lines cables

　　　b. MAGLEV vehicles

　　　c. MRI

　　　d. Energy storage devices

　　　e. Fabrication of electric generators and motors

　　　f. Medicine and applications

2. Small scale applications:

　　　a. Generators

　　　b. Amplifiers

　　　c. Mixers

　　　d. Detectors switch

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SET - 1

I B. Tech I Semester Regular Examinations, April-2022
APPLIED PHYSICS
(Common to CSE, CSE-CS&T, IT , CSE-CS, CSE-IOT&CS incl BCT, CSE-CS & BS, CSE-IOT)

Time: 3 hours   Max. Marks: 70

Answer any five Questions one Question from Each Unit
All Questions Carry Equal Marks
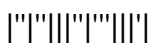~~~~~~
UNIT-I

1. a) Differentiate between interference and diffraction intensity patterns. How do you differentiate the Fresnel diffraction to that of Fraunhofer diffraction?   (10M)

   b) A slit of width 1.5mm is illuminated by a light of wavelength 500nm, and diffraction pattern is observed on a screen 2m away. Calculate the width of the central maxima.   (4M)

Or

2. a) What are the necessary conditions for obtaining interference fringes? Explain the colours in a thin film when exposed to sunlight.   (10M)

   b) A parallel beam of light of wavelength 5890Å is allowed to incident on a thin glass plate with refractive index 1.5 and the angle of refraction is 60°. Calculate the smallest thickness of the glass plate which will appear dark in reflected system.   (4M)

UNIT-II

3. a) What is laser? What are the important characteristics of lasers?   (6M)

   b) Derive the expression for energy density of radiation in terms of Einstein coefficients.   (8M)

Or

4. a) Explain the principle of Optical fiber. Describe different types of fibers by giving the refractive index profiles and propagation details.   (10M)

   b) The numerical aperture of an optical fiber is 0.39. If the difference in refractive index of the material of its core and cladding is 0.05, calculate the refractive indexof material of the core.   (4M)

UNIT-III

5. a) Explain the de Broglie hypothesis.   (4M)

   b) Derive time dependent Schrodinger wave equation for a free particle.   (10M)

Or

6. a) Explain with theory the formation of allowed and forbidden energy bands on the basis of the Kronig-Penny model.   (10M)

   b) Explain the concept of hole.   (4M)

|"|"|||"|"|||'|

UNIT-IV

7. a) Obtain an expression for the internal field inside a crystalline (cubic) dielectric medium which is subjected to an external electric field of intensity E.   (8M)

   b) Derive Clausius-Mosotti equation for the molar polarizability of a dielectric material with cubic crystalline structure.   (6M)

Or

8. a) What is ferromagnetism? Explain the properties of ferromagnetic materials.   (6M)

   b) Explain the Hysteresis curve in magnetism on the basis of domains. Distinguish between Soft and Hard magnetic materials.   (8M)

UNIT-V

9. a) State and explain Hall effect. Show that for n-type semiconductor the Hall coefficient $R_H = -\dfrac{1}{n_e}$.   (10M)

   b) Explain the applications of Hall effect.   (4M)

Or

10. a) What are super conductors? Explain BCS theory.   (8M)

    b) Explain Meissner effect. Distinguish between type I and type II superconductors.   (6M)

2 of 2

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SET - 2

I B. Tech I Semester Regular Examinations, April-2022
APPLIED PHYSICS
(Common to CSE, CSE-CS&T, IT , CSE-CS, CSE-IOT&CS incl BCT, CSE-CS & BS, CSE-IOT)

Time: 3 hours   Max. Marks: 70

Answer any five Questions one Question from Each Unit
All Questions Carry Equal Marks
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UNIT-I

1. a) Obtain the expressions for diameters of dark and bright rings in Newton's rings experiment and hence obtain the expression for wavelength of light used.   (10M)

    b) Calculate the thickness of the thinnest film (μ=1.4) in which interference of violet component (λ=4000AU) of incident light can take place by reflection.   (4M)

Or

2. a) With the help of neat diagrams, explain how Nicol's prism is used to produce and analyze plane polarized light.   (10M)

    b) Define a quarter-wave plate and derive the expression for its thickness.   (4M)

UNIT-II

3. a) Explain in detail the spontaneous and the stimulated Emissions of radiation?   (6M)

    b) With neat diagram, describe the construction and working of Ruby laser.   (8M)

Or

4. a) Explain the construction of optical fiber. Derive the expression for acceptance angle for an optical fiber. How is it related to numerical aperture?   (10M)

    b) Calculate the angle of acceptance of a given optical fiber, if the refraction indices of the core and the cladding are 1.563 and 1.498 respectively.   (4M)

UNIT-III

5. a) What are the drawbacks of classical free electron theory of metals? Explain Fermi–Dirac distribution function and also its variation with temperature.   (10M)

    b) Find the relaxation time of conduction electrons in a metal of resistivity 1.54×10^8 ohm- m. If the metal has 5.8×10^{28} conduction electrons m^{-3}.   (4M)

Or

6. a) Explain with theory the formation of allowed and forbidden energy bands on the basis of the Kronig-Penny model.   (10M)

    b) Derive the expression for effective mass of electron.   (4M)
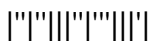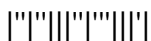
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UNIT-IV

7. a) Discuss in detail the electronic, ionic and orientational polarizations and their dependence on temperature.   (6M)

   b) Deduce an expression for Lorentz field relating to a dielectric material.   (8M)

Or

8. a) Explain magnetic flux density, B, magnetic field strength, H and Magnetisation M. Derive the relation between them.   (7M)

   b) Describe dia, para and ferromagnetic materials. Explain their classification on the basis of permanent magnetic moment.   (7M)

UNIT-V

9. a) Explain Hall effect. Derive the expression for Hall coefficient of p-type semiconductor.   (9M)

   b) Explain the applications of Hall effect.   (5M)

Or

10. a) Discuss the parameters that destruct the Superconductivity.   (9M)

   b) Describe the BCS theory of Superconductivity.   (5M)
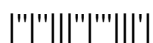
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I B. Tech I Semester Regular Examinations, April-2022
APPLIED PHYSICS
(Common to CSE, CSE-CS&T, IT , CSE-CS, CSE-IOT&CS incl BCT, CSE-CS & BS, CSE-IOT)

Time: 3 hours　　　　　　　　　　　　　　　　　　　　　　　　Max. Marks: 70

Answer any five Questions one Question from Each Unit
All Questions Carry Equal Marks
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UNIT-I

1. a) Obtain the conditions for central maximum, secondary maxima and minima in the case of Fraunhofer diffraction due to single slit. (10M)

   b) Calculate the thickness of a quarter wave plate of quartz for sodium light of wavelength 5893Å. The ordinary and extraordinary refractive indices for sodium light are 1.54425 and 1.5533 respectively. (4M)

Or

2. a) What is Interference of Light? What are the conditions for clear vision of interference fringes? (4M)

   b) With ray diagram discuss the theory of thin films and derive the condition for constructive and destructive interference in the case of reflected system. (10M)

UNIT-II

3. a) Explain the purpose of an active medium and cavity Resonator in a laser. (6M)

   b) With the help of suitable diagram, explain the principle, construction and working of a Ruby laser. (8M)
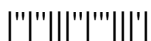
Or

4. a) Explain Acceptance angle and derive expression for it. Write notes on Step Index and Graded Index fibers. (10M)

   b) For an optical fiber fractional index change is 0.14 and refractive index of cladding is 1.3. Calculate refractive index of core. (4M)

UNIT-III

5. a) Derive the time independent Schrodinger's wave equation for a free particle. (10M)

   b) Find the second excited state energy of an electron confined in a box of length 0.1 nm. (4M)

Or

6. a) Discuss the origin of energy bands in solids. (7M)

   b) How does the band theory of solids lead to the classification of solids into conductors, semiconductors, and insulators? (7M)
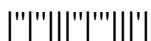
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UNIT-IV

7. a) What is meant by polarization in dielectrics? Derive the relation between dielectric constant and atomic polarizability.   (7M)

    b) Obtain an expression for electronic polarizability in terms of radius of the atoms.   (7M)

Or

8. a) Discuss on the origin of magnetism in materials. Write the differences between diamagnetic, paramagnetic, and ferromagnetic substances.   (10M)

    b) The magnetic field intensity in a place of ferric oxide is 10^6 amp/meter. If the susceptibility of the material is 1.5×10^{-3}, calculate the magnetization of the material and the flux density.   (4M)

UNIT-V

9. a) Derive an expression for the number of electrons per unit volume in the conduction band of an N-type semiconductor.   (8M)

    b) Explain the effect of temperature and dopant on Fermi level in N-type semiconductor.   (6M)

Or

10. a) What is Meissner effect? Show that superconductors exhibit perfect diamagnetism.   (7M)

    b) Describe Josephson effects. Explain the applications of Josephson effect.   (7M)

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SET - 4

I B. Tech I Semester Regular Examinations, April-2022
APPLIED PHYSICS
(Common to CSE, CSE-CS&T, IT , CSE-CS, CSE-IOT&CS incl BCT, CSE-CS & BS, CSE-IOT)

Time: 3 hours   Max. Marks: 70

Answer any five Questions one Question from Each Unit
All Questions Carry Equal Marks
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UNIT-I
1. a) Discuss various methods by which polarized light can be produced.   (7M)

    b) What are Quarter and Half wave plates? Derive the expressions for thickness of   (7M)
        quarter and half wave plates.

Or

2. a) Account for the circular shape of 'Newton's rings' in interference pattern.   (10M)
        Obtain an expression for the diameter of the nth dark ring in the case of
        Newton's rings.

    b) The diameter of 9th dark ring in newton's rings experiment is 0.28 cm. What is   (4M)
        the diameter of 16th dark ring when $\lambda = 6000$Å.

UNIT-II
3. a) What is meant by population of an energy state? What is Population inversion?   (6M)
        How can it be achieved?

    b) With neat diagram, describe the construction and working of Ruby laser.   (8M)

Or

4. a) Show that the ratio of Einstein's coefficient of spontaneous emission to   (10M)
        Einstein's coefficient of absorption is proportional to the cube of the frequency
        of the incident photon.

    b) Mention some important applications of lasers.   (4M)

UNIT-III
5. a) Explain the de Broglie hypothesis.   (4M)

    b) Derive time independent Schrodinger wave equation for a free particle.   (10M)

Or

6. a) State and explain Bloch theorem.   (4M)

    b) Discuss the Kronig Penny model for the motion of an electron in a periodic   (10M)
        potential.
UNIT-IV
7. a) What do you understand by dielectric constant? Define dielectric susceptibility.   (6M)
        Derive the relation between dielectric constant and dielectric susceptibility.

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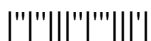
b)   Explain electronic polarisability and show that electronic polarisability for a   (8M) mono atomic gas increases as the size of the atom becomes larger.

Or

8. a)   Explain the origin of magnetic moment. Find the magnetic dipole moments due   (10M) to orbital and spin motions of an electron.

b)   A magnetic material has a magnetization of 3300A/m and flux density of 0.044   (4M) wb/m^2. Calculate the magnetizing force and relative permeability of the material.

UNIT-V

9. a)   What do you understand by drift and diffusion currents in the case of a   (9M) semiconductor? Deduce Einstein's relation relating to these currents.

b)   Distinguish between n- and p-type semiconductors.   (5M)

Or

10. a)   What is superconductivity? Explain Meissner effect. Describe type-I and type-II superconductors.   (10M)

b)   Discuss the applications of superconductors.   (4M)