

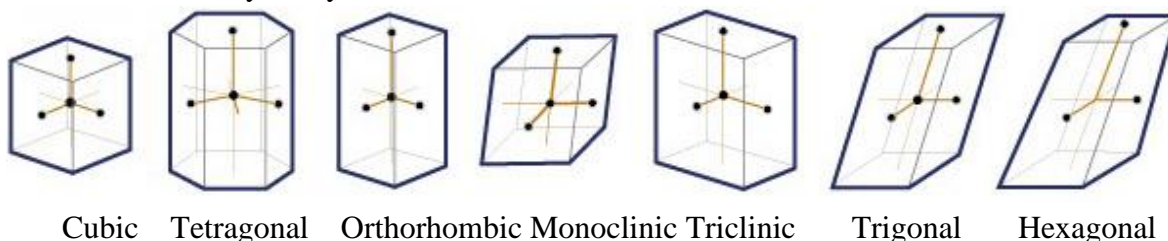
UNIT.1 Crystallography

1. Write a short note on crystal systems (3M) (BTL 2)

S.No	Crystal System	Lattice Constants	Interfacial Angles	Examples
1	Cubic	$a=b=c$	$\alpha=\beta=\gamma=90^\circ$	Gold, copper
2	Tetragonal	$a=b \neq c$	$\alpha=\beta=\gamma=90^\circ$	Zircon, SnO_2
3	Orthorhombic	$a \neq b \neq c$	$\alpha=\beta=\gamma=90^\circ$	MgSO_4 , KNO_3
4	Rhombohedral (Trigonal)	$a=b=c$	$\alpha=\beta=\gamma \neq 90^\circ$	Arsenic, Bismuth
5	Hexagonal	$a=b \neq c$	$\alpha=\beta=\gamma=120^\circ$	Quartz, zinc
6	Monoclinic	$a \neq b \neq c$	$\alpha=\beta=\gamma < 120^\circ$	Gypsum, FeSO_4
7	Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90^\circ$	Potassium dichromate

Depending upon lattice parameters, crystals are classified into seven types

The Unit cells of all the crystal systems are shown below



2. Explain Bravais lattice [3M] (BTL 2)

According to Bravais, there are fourteen independent ways of arranging points in three-dimensional space, such that the environment about each lattice point is identical. Thus, there are fourteen (14) possible types of space lattices among the seven crystal systems and are called Bravais Lattices.

S.NO	CRYSTAL SYSTEM	Bravais Lattices	Name of Bravais Lattice
1	Cubic	3	Simple, Body centered and face centered
2	Tetragonal	2	Simple, Body centered
3	Rhombic	4	Simple, Body Centered, face centered Base Centered
4	Monoclinic	2	Simple Base Centered
5	Triclinic	1	Simple
6	Rhombohedral	1	Simple
7	Hexagonal	1	Simple

3. Write short notes on crystal planes and miller Indices [3M] (BTL 2)

Crystal lattice consist of parallel and equidistant planes passing through the lattice points. They are known as Lattice planes; these planes are specified by 3 indices (h k l) called **Miller indices**.

Miller Indices are defined as three smallest integers which have the same ratio as the reciprocals of the intercepts of the concerned plane along crystallographic axes

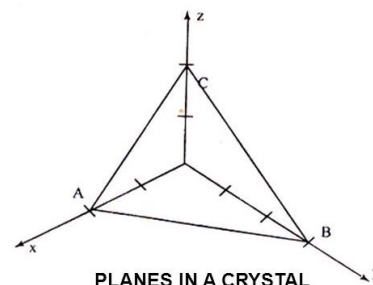
- ❖ The three indices are not separated by commas and are enclosed in open brackets.
- ❖ If the intercept is negative, put a bar on the miller index.
- ❖ If the plane is parallel to any axis, intercept of that axis is taken as infinity and the miller index will be 0.

Procedure for determining miller indices (h k l):

1. Take intercepts of the concerned planes.
2. Take reciprocals of the intercepts.
3. Convert the reciprocals into a whole number by taking L.C.M of denominators.

Example:

Plane ABC has intercepts of 2 units along X- axis, 3 units along Y-axis and 2 units along Z – axis. Find the miller indices f

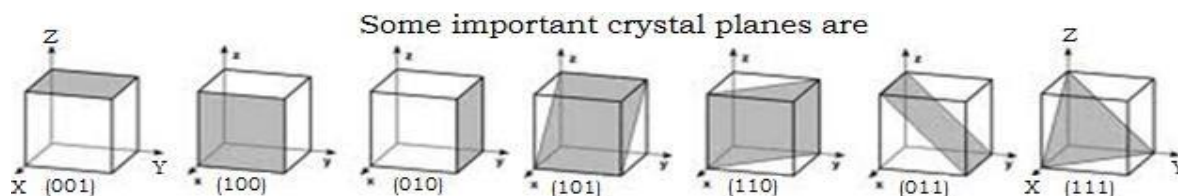


Solution:

Intercepts are (2 3 2)

Reciprocal of the three intercepts are $\left(\frac{1}{2} \frac{1}{3} \frac{1}{2}\right)$

Convert reciprocals into small integers by multiplying with LCM of denominators i.e., with 6. Then we get miller indices of the plane ABC is (3 2 3)



4. Derive interplanar spacing in crystals (2M) (BTL 1)

Let (h k l) be the miller indices of the plane ABC. Let ON= d be a normal to the plane passing through the origin O. Let ON make angles α, β, γ along crystallographic axes (x, y, z). If OA = a/h; OB = b/k; OC = c/l

$$\cos \alpha = d / OA; \cos \beta = d / OB; \cos \gamma = d / OC$$

$$\cos \alpha = dh / a; \cos \beta = dk / b; \cos \gamma = dl / c$$

Using Law of Direction Cosines

$$\cos^2 \alpha + \cos^2 \beta + \cos^2 \gamma = 1 \dots\dots\dots (1)$$

Hence, substituting and simplifying the values of the $\cos \alpha, \cos \beta, \cos \gamma$ in equation (1) we obtain

$$\text{i.e., } d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$$

5. Derive Bragg's Law (3M) (BTL 1)

Let a wave front of monochromatic x-ray beam of wavelength ' λ ' fall at an angle ' θ ' on the atomic planes. Each atom scatters the x-rays in all directions. If AM and AN are parallel to the incident and scattered wave front. Total path travelled by RBS is longer than the Path PAQ by an amount $\Delta = 2GE$.

Using right angle triangle BGE, we have

$$MB = d \sin \theta$$

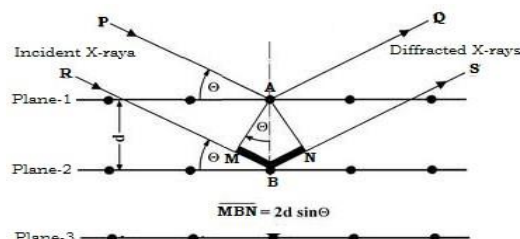
We know that $\Delta = 2MB$. Now, $\Delta = 2d \sin \theta \dots (1)$

If two consecutive planes scatter in phase with each other, we know that the path difference $\Delta = n\lambda$ (2)

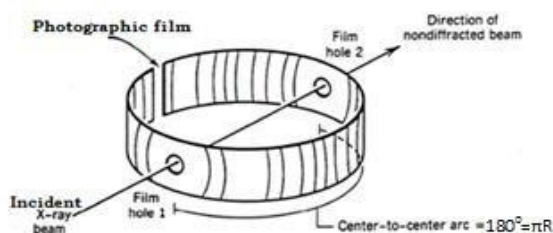
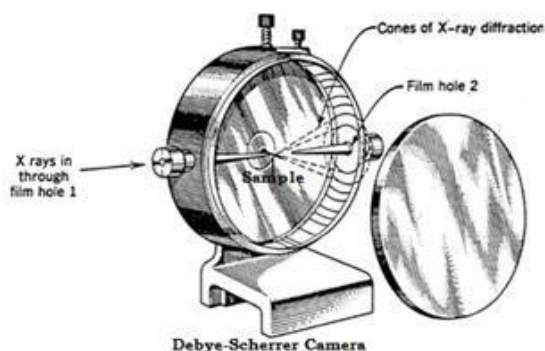
From equation [(1), (2)] we have,

$$2d \sin \theta = n\lambda$$

Where, $n=1,2,3$



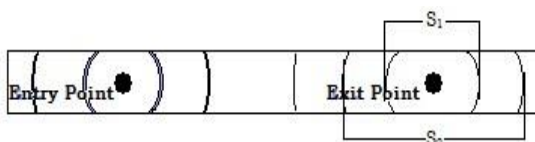
6. Explain powder diffraction method for determination of lattice constant. (Debye-Scherrer method) (5M) (BTL 2)



Construction: The experimental arrangement of powder method is shown in the above figure. A Specimen holder is placed at the center of the cylindrical camera. A sample of fine grained polycrystalline solid is mixed with a little adhesive material which is placed on the sample holder than the camera along with the sample is taken to the dark room, where a thin strip of x-ray film is loaded in the cylindrical cassette in such a way that the two ends of the film meet midway between entry and exit points.

Working: A monochromatic x-ray beam is incident on the powder sample. The X-ray diffracts in accordance with Bragg's condition and give rise to cones(arcs) of diffracted beams on the X-ray film. If the Bragg angle is 45° the corresponding cones opens out into a circle whose intersection with the

sphere give rise to a straight line and is recorded at the midpoint of the film between incident and exit points. When the Bragg angle is greater than 45° back reflection occurs, As Bragg angle varies from 0° to 90° its pattern is shown on a cylindrical camera as



Mathematically, various diffraction angles θ with a known camera radius R can be calculated as $4\theta = S/R$

$$\Rightarrow \theta = \frac{S}{4R} \text{ radians}$$

$$\theta = \left(\frac{180}{\pi}\right) \left(\frac{S}{4R}\right) \text{ degree}$$

By substituting ' θ ' values in Bragg's formula, interplanar planar spacing ' d ' can be calculated.

Applications

1. It is used to calculate lattice constant ' a ' of the given polycrystalline material.
2. It is used for identification of materials (ex: mineral or inorganic compound).
3. It is used for analysis of structural imperfection in crystals.

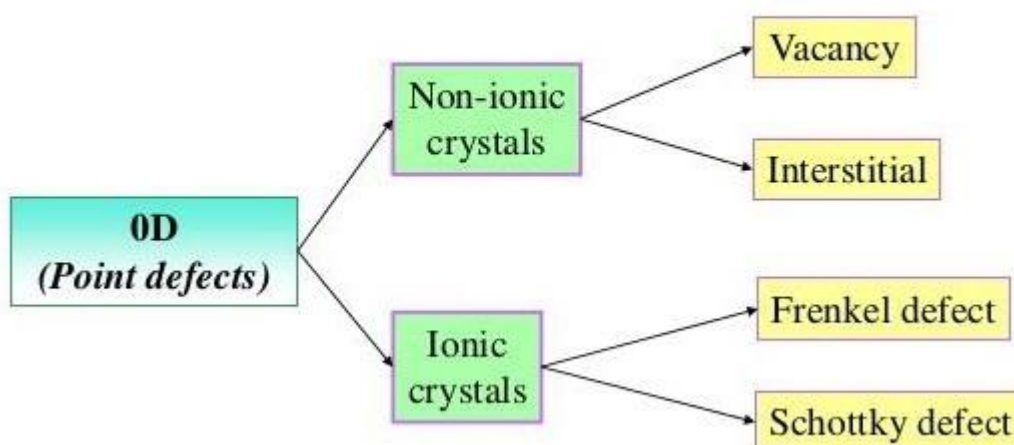
Chapter No. 2 Crystal Defects

1. Write a short note on classification of defects (2M) (BTL 2)

Any deviation from periodic arrangement of atoms is known as imperfection or defects in crystals.

Classification of defects in crystals			
1. Point Defects (0-Dimensional defects)	2. Line Defects (1-Dimensional defects)	3. Surface Defects (2-Dimensional defects)	4. Volume Defects (3-Dimensional defects)
a.	a. Edge dislocation	a. Grain Boundaries	a. Cracks
b.	b. Screw dislocation	b. Tilt Boundaries	b. Voids or Air bubbles
c.		c. Twin Boundaries	
		d. Stacking Faults	

POINT DEFECTS

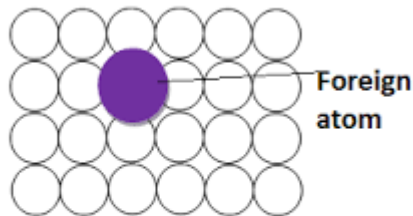


2. Write a short note on classification of point defects (5M) (BTL 2)

1. Point Defects: It is localized disruption in regularity of the lattice on and between lattice sites. Point defects are of three types:

(i) **Substitutional impurity:** when a foreign atom replaces a parent atom in the lattice, substitutional defect is generated inside the crystal.

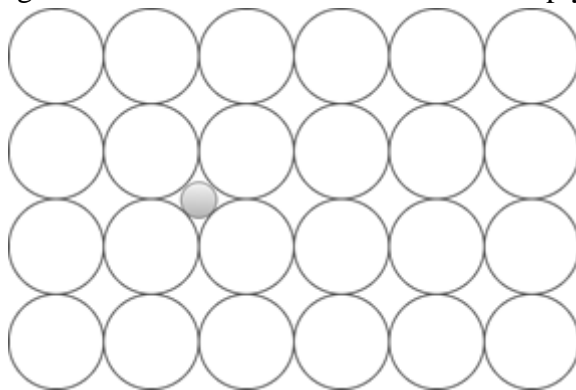
If the impurity atom has roughly same size and valency as the parent atoms, then substitutional impurity is created. Ex: phosphorous in silicon



Substitutional defects

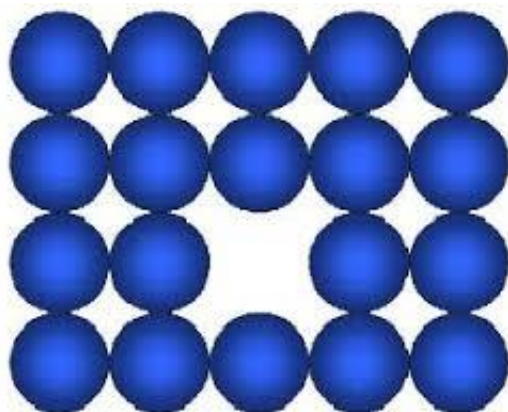
(ii) **Interstitial impurity:** when a small sized atom occupies the empty space in between the parent atom. Ex: Alloying element carbon in Iron.

It occupies position between lattice sites and the impurity is generated, if the volume of the crystal remains unchanged with the atom fits itself at void or empty space between lattice sites.



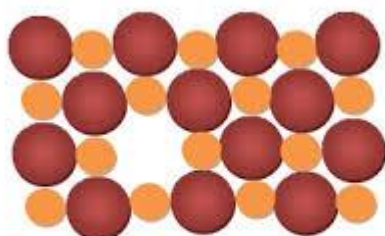
(iii) **Vacancy:** A vacancy or vacant site implies on occupied atom position within the crystal sites. They are also known as unoccupied lattice sites. Ex: Hole in semiconductor.

It occurs as a result of imperfect packing during crystallization and if atom leaves its site and dissolves interstitially into the structure.



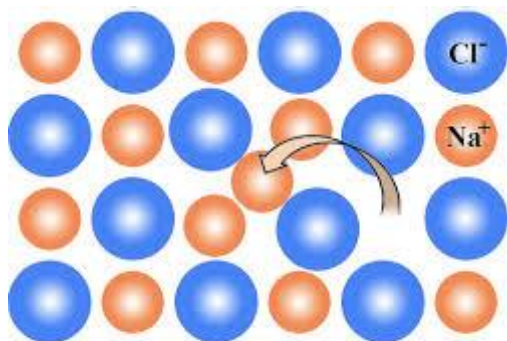
Schottky Defect: It is the combination of one cation vacancy and one anion vacancy.

Ex: NaCl, KCl.



Schottky's Defects

Frenkel Defect: Vacancy created if an atom leaves its site and dissolve interstitially into the structure is known as Frenkel defect. Ex: silver halides etc.,



Frenkel defect

2. Write any three application of point defects. (BTL 3)

Applications of point defects:

1. Mechanical and electrical properties of crystals are improved by point defects.
2. Addition of trivalent and pentavalent impurities in Silicon and Germanium semiconductors increases their electrical conductivity.

3. Addition of carbon atoms in gold increases the ductility of gold, so that it can be drawn into wires for making ornaments.
4. Impurity defects produces the diffusion and phase transformation processes.

3. Derive equilibrium Concentration of Schottky defects in metal (5M) (BTL 1)

Let E_v = Energy of formation of a Schottky defect

N = Number of atoms in metallic crystal and

n = number of Schottky defects

By considering probability concept $P = \frac{N!}{n!(N-n)!}$

The change in Entropy is given by $S = k \log P$

$$S = k \log \frac{N!}{n!(N-n)!}$$

$$S = k [\log N! - \log n! - \log(N-n)!]$$

We get

$$S = k [N \log N - N - n \log n + n - (N-n) \log (N-n) + N - n]$$

$$S = k [N \log N - n \log n - (N-n) \log (N-n)]$$

From the law of thermodynamics, the change in free energy is given by

$$F = U - TS \quad (U = nE_v)$$

At equilibrium, the change in free energy is minimum,

$$\text{i.e., } \frac{\partial F}{\partial n} = 0$$

$$\begin{aligned} 0 &= E_v - kT \left[-n \frac{1}{n} - \log n - (N-n) \frac{1}{(N-n)} (-1) - \log(N-n)(-1) \right] \\ &= E_v - kT [-\log n + \log(N-n)] \end{aligned}$$

$$E_v = kT [-\log n + \log(N-n)]$$

$$\frac{E_v}{kT} = [-\log n + \log(N-n)]$$

$$\frac{E_v}{kT} = \log \frac{N-n}{n}$$

$$e^{\frac{E_v}{kT}} = \frac{N-n}{n}$$

$$e^{\frac{E_v}{kT}} = \frac{N}{n} \quad (\text{Since } n \ll N, n \text{ is neglected}) \therefore n = N e^{\frac{-E_v}{kT}}$$

6 . Explain line defects. (BTL 2)

Any deviation from perfectly periodic arrangement of atoms along a line is called line defects or line imperfection.

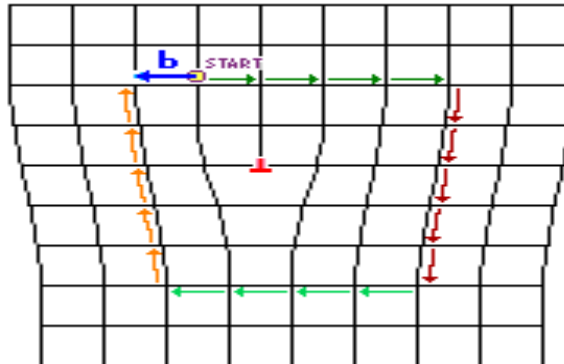
Imperfection can be considered as the boundary between two regions of a surface. The line imperfection acting as boundary between slipped and unslipped region lies in the slip plane is known as dislocation.

There are two types of dislocation

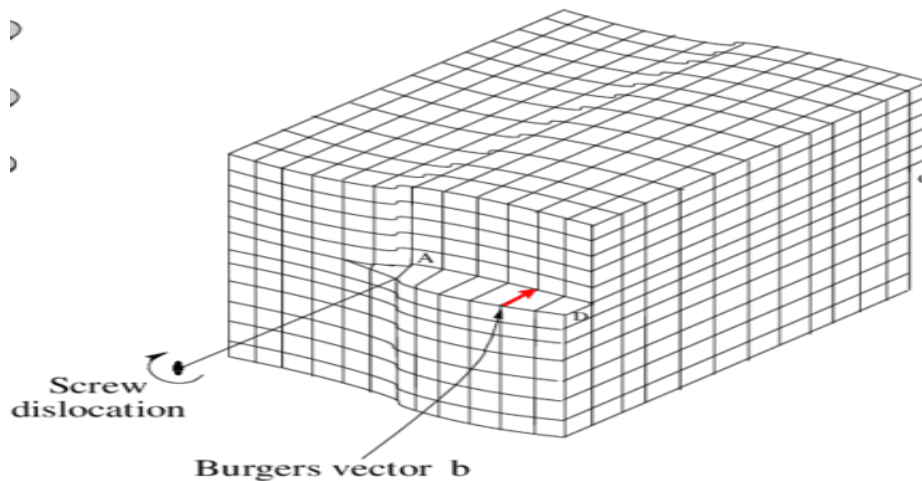
(i) Edge dislocation (ii) Screw dislocation

6(a) Write short notes on Edge and Screw Dislocation (3M) (BTL 2)

In ideal crystal, atoms are arranged in both vertical and horizontal planes parallel to the side faces. If one of these vertical planes does not extend to the full length, but ends in between, within the crystal it is termed as edge dislocation. Because of dislocation, just above the discontinuity atoms are squeezed and are in a state of compression. Hence, below the discontinuity the atoms are pulled apart and are in a state of tension. The region of maximum imperfection is termed as edge dislocation. It is represented by ∇ or \perp .



Edge dislocation



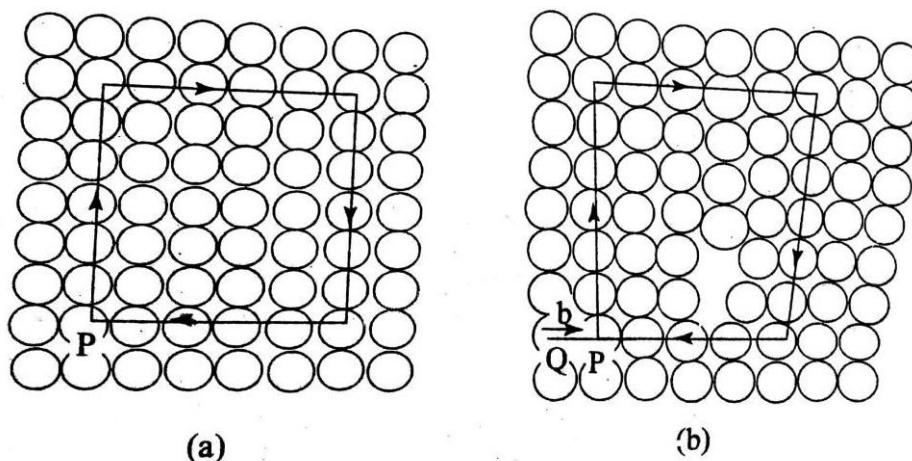
Screw Dislocation: Screw dislocation results from a displacement of the atoms in one part of a crystal relative to the rest part of the crystal, forming a spiral ramp around the dislocation line as shown in the figure. It shows a method of determining the burgers vector applied to an edge dislocation.

7. What is Burger's vector and illustrate with a neat diagram? (2M) (BTL 2)

The magnitude and the direction of lattice distortion in crystal lattice due to dislocation is defined by a vector called Burger's vector. To understand the concept of Burger's vector let us draw a Burgers Circuit in two crystals i, e ideal crystal and other crystal with edge dislocation as shown in the figure (a), figure (b). In figure (a) starting from the point P, we go up by 6 steps, then move towards right by 5 steps and move down by 6 steps and finally move towards left by 5 steps to reach the starting point P; the Burgers circuit is closed. When the same operation is performed on the crystal with edge dislocation as shown in the figure (b) we end up at Q instead of the starting point P. Now, we must move an extra step QP to return to P in order to close the Burger's circuit.

The magnitude and the direction of the step defines the Burger's vector (BV)

$$BV = \overrightarrow{QP} = b$$



8. Write any three applications of line defects (2M) (BTL 3)

1. The dislocation is responsible for the phenomenon of slip by which most metals deform plastically.
2. Dislocations are helpful in explaining crystal growth and electrical conductivity.
3. In case of high temperature superconductors, the presence of dislocations creates holes or vacancies which will increase the value of superconducting transition temperature.

NIT.2

Chapter No.1 Band theory of solids

1. Explain Drude – Lorentz free electron theory. (BTL 2)

Introduction: In 1900 Drude proposed electron gas model to explain the electrical conduction in metals. It was modified by Lorentz in 1909 and the theory is termed as Drude-Lorentz theory or classical free electron theory.

Postulates:

1. Metal crystal consists of positive metal ions whose valence electrons are free to move between ions as if they constitute an electron gas.
2. The crystal is then held together by electrostatic forces of attraction between positive charged ions and negative charged electron gas.
3. The mutual repulsion between the electron is ignored.

4. The potential field due to positive ions is completely uniform, so that electron can move from place to place in the crystal without any change in their energy.
5. They collide occasionally with the atoms, at given temperature and their velocities could be determined according to Maxwell – Boltzmann distribution. The free electrons are treated equivalent to gas molecules, and thus are assumed to obey the laws of kinetic theory of gases.

Advantages:

1. It is used to verify ohm's law
2. It is used to explain the electrical and thermal conductivities of metals
3. It is used to explain the optical properties of metals
4. It is used to explain Ductility and malleability of metals.

Failures:

1. It is failed to explain why some solids are conductors and some are insulators.
2. It is failed to explain the properties of solids which are determined by their internal structure.
3. It is failed to explain the electrical conductivity of semiconductors and insulators.
4. Photoelectric effect, Compton Effect and black body radiation cannot be explained by this theory.

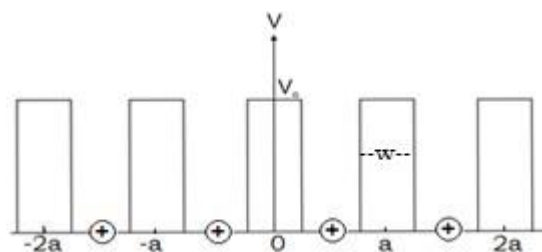
2.Explain Kronig - Penny model. (BTL 2)

According to Kronig and Penny periodic potential in a crystal is in the form of an array of square wells as shown in the figure.

The corresponding Schrodinger wave equation for one dimensional periodic potential is related as

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}[E - V(x)]\psi = 0$$

↑.... (1)



One Dimension Periodic Potential

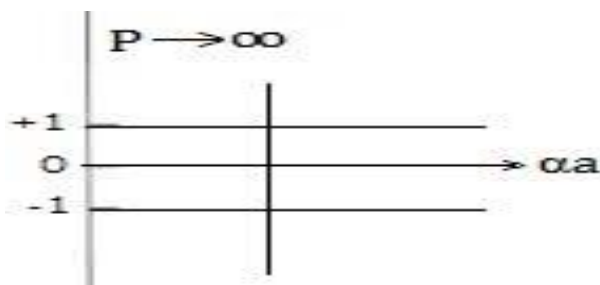
The solution of the equation (1) according to Bloch is given as $\psi(x) = U_k(x) \exp(ikx) \dots (2)$

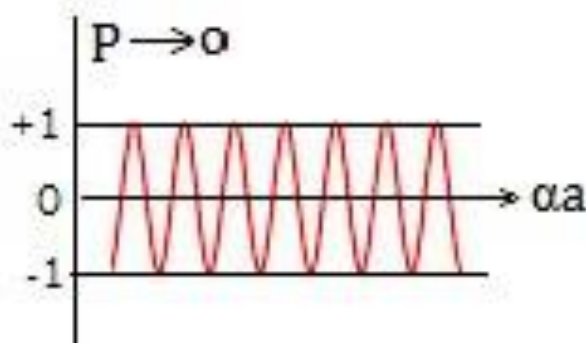
where $U_k(x) = U_k(x + a)$ (Bloch function) where 'a' is lattice constant of the crystal. The simplified solution for possible energy can be treated as $\cos ka = \frac{P \sin \alpha a}{\alpha a} + \cos \alpha a \dots (3)$ where $P = \frac{4\pi^2 m a V_0 W}{h^2}$; $\alpha = \frac{2\pi}{h}(\sqrt{2mE})$; 'E' is energy with permissible values [-1 to +1]. As 'Vo'(potential)

increases 'w' (width of barrier) decreases and $V_0 w$ remains constant. $P \rightarrow$ Scattering power of potential barrier, $V_0 w \rightarrow$ barrier strength.

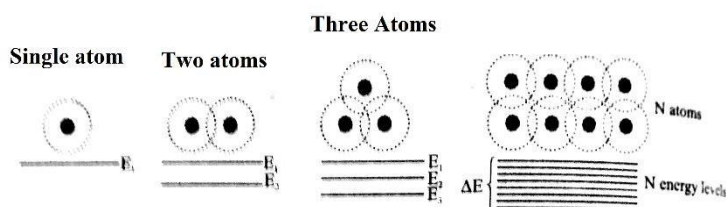
barrier)

Conclusions: 1. The motion of electrons in a periodic lattice is characterized by the allowed energy bands separated by forbidden regions. 2. As the value of αa increases the width of the allowed energy bands also increases and the width of the forbidden band decreases. 3. If the potential barrier strength P is large, the function described by the right-hand side of the equation crosses +1 and -1 region. Thus, the allowed bands become narrower and forbidden bands become wider. 4. If $P \rightarrow \infty$, the allowed band reduces to one single energy level corresponding to the discrete energy level of an isolated atom. when $P \rightarrow 0$, no energy levels exist. *The particle is completely free. Thus, by varying P from 0 to ∞ we find that the completely free electron becomes completely bound.*



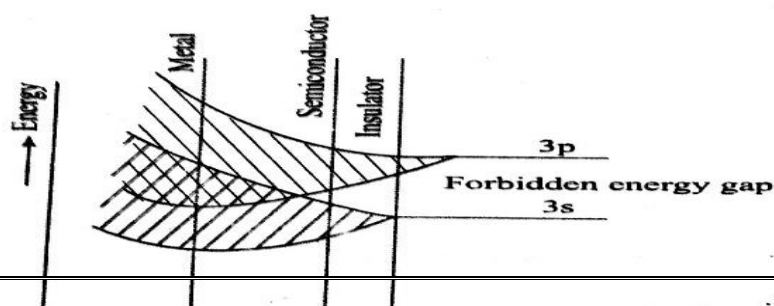


2. Explain origin of Energy band formation in solids(5M) (BTL 2)

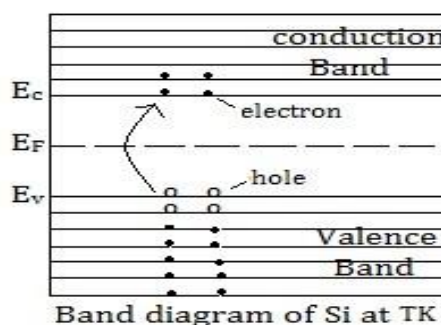
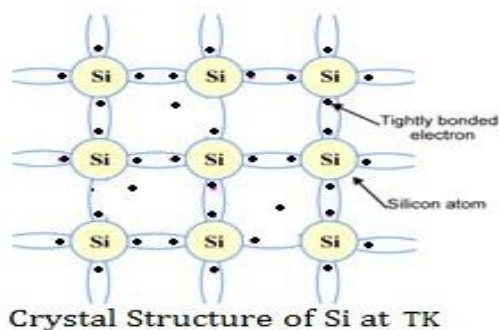


In isolated atom, the electrons are tightly bound and have discrete sharp energy level. But in the case of solid which contains 'N' number of atoms. The closeness of atoms results in the intermixing of electrons of neighboring atoms, for a solid of N atoms their exist N energy levels forms continuous bands. A set of closely spaced energy levels is called energy band. Let us consider sodium crystal, each sodium atom has eleven electrons as 's' and 'p' subshells can accommodate two and six electrons respectively. One electron is unfilled, the outermost '3s' electron is termed as valence electron and the band formed by valence electrons are known as "valence band" which is partially or completely filled, the next higher permitted band or the allowed band of energy above valence band is the conduction band which is partially or lowest unfilled energy band. Both the bands are separated by a region or gap termed as forbidden band.

Based on the equilibrium spacing we can classify the solids into conductors' insulators' and semiconductors.



4.Explain the concept of hole and discuss about carrier concentration in intrinsic semiconductors.
(BTL 2)



Intrinsic semiconductors are pure semiconductors. At '0' kelvin pure semiconductor act as insulator, as we increase the temperature to 'T' kelvin due to thermal excitation electron jump from valence band to the conduction band. Hence, conduction takes place. Ex: Silicon and Germanium.

Let us consider Silicon semiconductor, at '0'Kelvin valence band is full and conduction band is empty. As the temperature increases, electrons will come out by breaking their covalent bonds and they move freely inside the crystal. The emitted electrons participate in electrical conduction. As an electron come out from valence band a vacancy is created in valence band called **hole**.

Thus, at 'T' Kelvin, in an intrinsic semiconductor, if n 'covalent' bonds are broken per unit volume of the material, then there will be n electrons in the conduction band and same number of holes in the valence band. Usually the number of electrons present in the conduction band per unit volume of the semiconductor is called electron concentration (n). Similarly, the number of holes present in the valence band per unit volume of the semiconductor is called hole concentration (p). Both the free electrons and holes present in the material participate in electrical conduction. The free electrons and holes present per unit volume of the semiconductor is called **carrier concentration (n_i)**.

Derive carrier concentration in intrinsic semiconductors.

In intrinsic semiconductor, density of holes in valence band = density of electrons in conduction band.

$$n_i^2 = (n_e) (n_h)$$

In intrinsic semiconductor number of holes is equal to number of electrons

$$\therefore n_i^2 = np \text{ where } n_i \text{ is called intrinsic carrier concentration}$$

Electron concentration (n) is given by

$$n = 2 \left(\frac{2\pi m_e^* K T}{h^2} \right)^{\frac{3}{2}} \exp\left(\frac{E_F - E_c}{K T}\right) \text{ --- (1)}$$

Hole concentration (P) is given by

$$p = 2 \left(\frac{2\pi m_h^* K T}{h^2} \right)^{\frac{3}{2}} \exp\left(\frac{E_v - E_F}{K T}\right) \text{ --- (2)}$$

Multiply above two equation i.e $n \cdot p = n_i^2 = np$

$$\begin{aligned} n_i^2 &= 2 \left(\frac{2\pi m_e^* K T}{h^2} \right)^{\frac{3}{2}} \exp\left(\frac{E_F - E_c}{K T}\right) 2 \left(\frac{2\pi m_h^* K T}{h^2} \right)^{\frac{3}{2}} \exp\left(\frac{E_v - E_F}{K T}\right) \\ &= 4 \left(\frac{2\pi K T}{h^2} \right)^3 (m_e^* m_h^*)^{\frac{3}{2}} \exp\left(\frac{E_F - E_c + E_v - E_F}{K T}\right) \end{aligned}$$

5. Explain the phenomenon of Electrical conductivity in semiconductors (BTL 2)

We know that for a semiconducting material, electrical conductivity σ is given by

$$\sigma = (n e \mu_e + n e \mu_h)$$

Where μ_e and μ_h are the mobility of electron and hole respectively

Hence $\sigma = n i e (\mu_e + \mu_h)$ -----(1) Since $n = p = n_i$

$$\text{but } n_i = 2 \left(\frac{2\pi K T}{h^2} \right)^{\frac{3}{2}} (m_e^* m_h^*)^{\frac{3}{4}} \exp\left(\frac{-E_g}{2KT}\right)$$

Substitute above value in equation (1)

$$\sigma = 2 \left(\frac{2\pi K T}{h^2} \right)^{\frac{3}{2}} (m_e^* m_h^*)^{\frac{3}{4}} \exp\left(\frac{-E_g}{2KT}\right) e (\mu_e + \mu_h)$$

Thus conductivity depends on negative exponential of the forbidden energy gap between the valence and conduction band, and on the mobility s of both hole and electron

Hence electrical conductivity of an intrinsic semiconductor written as $\sigma = A \exp\left(\frac{-E_g}{2KT}\right)$ Take all constants as A

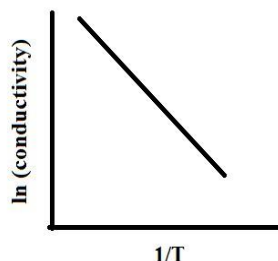
$$\sigma = A \exp\left(\frac{-E_g}{2KT}\right)$$

Where A is a constant

Taking logarithms on both sides

$$\ln \sigma = \ln A - \left(\frac{E_g}{2KT} \right)$$

Graph between $1/T$ and $\ln \sigma$ is shown in figure. From the graph we understand that conductivity increases with temperature



6.State and Explain Hall Effect? Determine the hall voltage? (BTL 2)

When a piece of conductor (metal or semiconductor) carrying current is placed in a transverse magnetic field, an electric field is produced inside the conductor in a direction normal to both the current and the magnetic field. This phenomenon is known as the **Hall effect** and the generated voltage is known as **Hall voltage**.

Let B be the magnetic field applied at right angles to the direction of current flow. If the material is N-type, and ' v ' is the velocity of electrons then the electrons experience a force ' \mathbf{Bev} ' due to magnetic field at right angles to both flow direction and B . This causes the electron current to be deflected causing a negative charge to accumulate on the face (1) of the slab as shown in figure. A potential difference is therefore established across the faces (1) and (2) causing a field called Hall electric field ' $\mathbf{E_H}$ '.

This field gives rise to a force ' eE_H ' on electrons in the opposite direction.

$$H \quad \text{----- (1)}$$

If J is the current density, then $J = nev \rightarrow v = J/ne$

Therefore eq(1) can be written as $E_H = \frac{1}{ne} BJ$

$$E_H = R_H BJ$$

R_H is the Hall coefficient.

For n-type semiconductors, Hall coefficient $R_H = \frac{-E_H}{BJ} = \frac{-1}{ne}$ where n is the density of

For p-type semiconductors, Hall coefficient $R_H = \frac{E_H}{BJ} = \frac{1}{pe}$ where p is the density of holes.

If ' w ' is the width of sample across which Hall voltage V_H is measured $E_H = \frac{V_H}{w}$

$$\frac{E_H}{BJ} = \frac{V_H}{wBJ} \Rightarrow V_H = R_H BJw$$

If ' t ' is the thickness of the sample, then its cross-section is wt and current density $J = \frac{I}{A} = \frac{I}{wt}$

$$E_H \frac{I}{wt} w = R_H B \frac{I}{t} \Rightarrow R_H = \frac{V_H t}{BI}$$

At equilibrium, $eE_H = Bev$

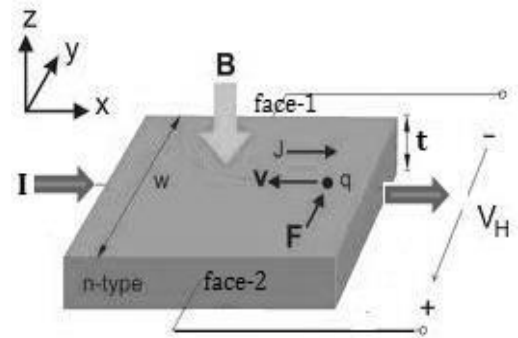
$$E = Bv$$

Where $R_H = \frac{1}{ne}$ electrons

Hence, $R_H =$

Hence $V_H = R_H B I$

' V_H ' will be opposite for N-type and P-type semiconductors.



7.Applications of Hall Effect (BTL 3)

- i) Determination of type of semiconductor

For an N-type semiconductor, the hall coefficient is negative whereas for a P-type it positive. Thus from the direction of Hall voltage developed we can find out the type of semiconductor

- ii) Calculation of carrier concentration

Once the Hall coefficient R_H is measured, the carrier concentration n can be obtained from

$$n = \frac{1}{eR_H}$$

- iii) Determination of mobility

$$\sigma$$

We know that conductivity $\sigma_n = ne\mu_e \Rightarrow \mu_e = \frac{\sigma_n}{ne} = -\sigma_n R_H$ iv)

Measurement of magnetic flux density

Using a semiconductor sample of known Hall coefficient, the magnetic flux density can be deduced from the formula $R_H = \frac{V_{BI}}{I H} \Rightarrow B = I^V R_H H^t$

8. What is Thermistor? Discuss classifications of thermistor based on temperature. (BTL 2)

We know that the resistance of a conductor increases with the increase in temperature whereas in semiconductor resistance decreases with the increase in temperature. It is further found that the variation in the resistance is more in semiconductors than in conductors. The component whose resistance is very sensitive to temperature variation is called thermistor.

Thermistors can be classified into two types:

- 1) Positive temperature coefficient (PTC) thermistor: -resistance increase with increase in temperature.
- 2) Negative temperature coefficient (NTC) thermistor: -resistance decrease with increase in temperature.

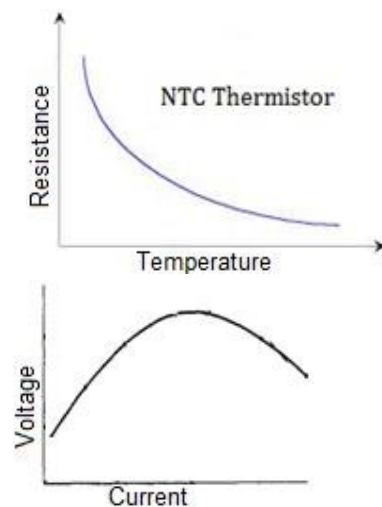
NTC thermistors are normally very small in size but are complex in construction and material composition. They come in variety of sizes and shapes like beads, washers, rods etc.

The resistance of a thermistor as a function of temperature is given by $R=A \exp(E/kT)$

Where A is constant, and E is the activation energy for the conduction process. The resistance of a thermistor falls off exponentially with temperature as shown in figure (1). It is observed that at low potential difference, a thermistor obeys ohm's law. At high currents it exhibits negative resistance due to self-heating as shown in figure.

If we plot a graph between current and time it can be observed that there is a time delay to reach the maximum current at a temperature as shown in fig. These characteristics help in introducing a time delay in an electronic circuit.

Uses: NTC Thermistor can be used as temperature sensors, temperature controllers, pressure meters and flow meters.



9.Explain I-V characteristics of PN junction diode. (BTL 2)

P-N junction diode is the most fundamental and the simplest electronics device. When, one side is made p-type by doping with n-type material, a p-n junction diode is formed. This is a two-terminal device. When the **P-N diode** is in unbiased condition that is no voltage is applied across it, electrons will diffuse through the junction to p-side and holes will diffuse through the junction to n-side and they combine with each other. Thus, the acceptor atom near the p-side and donor atom near n-side are left unutilized. An electric field is generated by these uncovered charges. This opposes further diffusion of carriers. So, no movement of region is known as space charge or depletion region. If, we apply forward bias to the **p-n junction diode**. That means if positive side of the battery is connected to the p – side, then the depletion region's width decreases and carriers flow across the junction. If the bias is reversed the depletion width increases and no charge can flow across the junction. Let's a voltage V is applied across a **p-n junction** and total current I, flows through the junction. It is given as. $I = I_s [\exp(eV/\eta K_B T) - 1]$ Here, I_s = reverse saturation current e = charge of electron η = emission coefficient K_B = Boltzmann constant T = temperature

The current voltage characteristics plot is given below. When, V is positive the junction is forward biased and when V is negative, the junction is reverse biased. When V is negative and less than V_{TH} , the current is very small. But when V exceeds V_{TH} , the current suddenly becomes very high. The voltage V_{TH} is known as threshold or cut in voltage.



**ISL ENGINEERING COLLEGE
CHANDRAYANGUTTA, HYDERABAD
DEPARTMENT OF HUMANITIES & SCIENCE**

[UNIT-III]
Ch. 2 Di-electric materials

①

- * Dielectric materials electrons are tightly bonded.
- * Dielectric materials are similar to Insulators
- * They are classified as passive dielectrics and Active dielectrics.
- * If they are used for charge storage then they are called as 'active dielectrics'.
- * When these materials are used to prevent the flow of electricity through them, then they are known as 'passive dielectrics'.
- * Dielectrics include some solids: glass, porcelain, liquids: pure water, gases: hydrogen, Nitrogen, etc.
- * A dielectric is termed as homogeneous, isotropic material.
- * When electric field is zero, the centre of mass of the positive and negative charges in a molecule of a dielectric coincide, it is known as non-polar dielectrics and if the positive or negative charges does not coincide, it is termed as polar dielectrics.

Dipole: A pair of equal and opposite charges separated by a small distance constitutes an electric dipole.

Dipole moment: The product of magnitude of one of the charges 'q' and the distance of their separation 'x'.



BTL 1

* Polarization: When a dielectric material is placed in an external electric field, it becomes polarized. The polarization 'P' is defined as the dipole moment per unit volume.

$$P = \frac{p}{\Delta V}$$

→ If the number of molecules per unit volume is 'N' and if each has a moment 'p', then

$$\text{Polarization } [P = Np]$$

Hence polarization in dielectrics is known as "Dielectric polarization".

* Dielectric constant (or) relative permittivity: ϵ_r

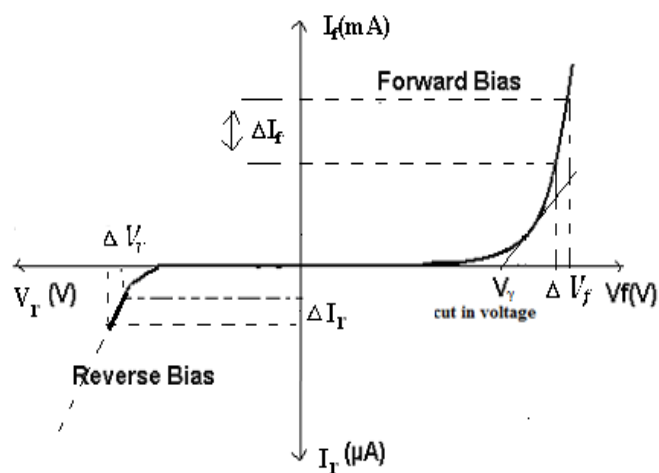
It is the measure of the degree to which a medium can sustain the flow of charge. Mathematically, it is defined as the ratio of the electric displacement 'D' to the electric field intensity 'E'. $\epsilon = \frac{D}{E} = \epsilon_r \epsilon_0$ where ϵ_r is the relative permittivity of the medium & ϵ_0 is the permittivity of free space.

$$\epsilon_r = 1, \quad \epsilon = \epsilon_0$$

* Polarizability: It is the induced dipole moment is proportional to the local field E_{local} .

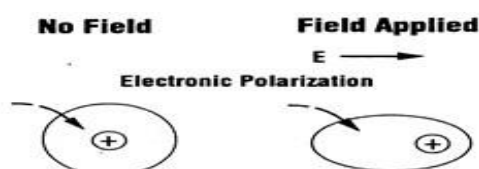
$$[P = \alpha E_{\text{local}}] \text{ where } \alpha \text{ is known as electrical}$$

polarizability of the atom. The total polarization of the dielectric containing 'N' atoms is given by $[P = N\alpha E_{\text{local}}]$



Chapter 2. Dielectric materials

1. Explain different types of Dielectric polarization (BTL 2)



Electronic Polarization

When external electric field is applied to the dielectric material, polarization occurs and displacement of the positively charged nucleus, negatively charged electron cloud in opposite direction takes place. Dipole moment is induced within each atom. The extent of this shift is proportional to the field strength. This type of polarization is independent of temperature. Electronic polarization is rapid and occurs at all frequency range. Ex: Diamond and phosphorus etc.,



Ionic Polarization

The ionic polarization is due to the displacement of cations and anions in opposite directions. This occurs in ionic solids. This polarization is independent of temperature. It occurs at infra-red frequency range and are slower than electronic polarization. Ex: NaCl, KCl

Orientation Polarization

When an external field is applied to polar dielectrics, they tend to align themselves in the direction of external applied field. The polarization due to such alignment is called Orientational polarization.

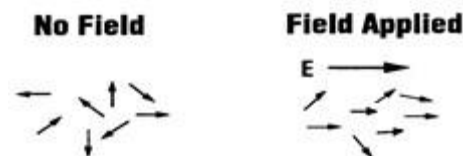


Fig: Orientational Polarization

The Orientational polarization is strongly temperature dependent. With increase of temperature, the thermal energy tends to randomize the alignment. It occurs at electrical frequency which is smaller than ionic polarization frequency Ex: Ferro Electric materials


(3)

Mechanism of Polarization BTL 1


When dielectric material is subjected to external electric field, polarization takes place by various mechanisms

(i) Electronic polarization (ii) Ionic polarization
(iii) orientation polarization (iv) space charge polarization

(i) Electronic polarization: When external electric field is applied to the dielectric material, polarisation occurs and displacement of the positively charged nucleus, negatively charged electron cloud in opposite direction takes place.

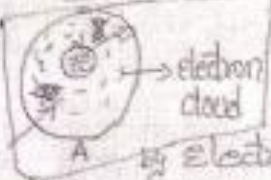


$E=0$



$E \neq 0$

Expression for electronic polarizability BTL 1



A

Let us consider atom 'A', 'r' be the radius whose atomic number is 'Z', the nucleus of charge is 'Ze' and it is surrounded by electron cloud. When external electric field is applied to a dielectric material, the molecule inside the material passes local electric field due to which positive charged nucleus and negative electron cloud displaces and the separation continues till the coulombic force of attraction balances force due to local electric field.

At equilibrium

$$F_{\text{Coulomb}} = F_{\text{local (E.P.)}}$$

$$F_{\text{Coulomb}} = q \cdot E_{\text{local}}$$

$$\left\{ \begin{array}{l} E = \text{Electric Field} \\ \text{Coulomb's Law} \end{array} \right.$$

(4)

If $q = ze$ (positive charge)

$$F_{\text{coulomb}} = (ze) E_{\text{local}} \quad (1)$$

$$F_{\text{coulomb}} = \frac{1}{4\pi\epsilon_0} \frac{q'q}{d^2} \quad (2) \quad \text{"q'" is the effective negative charge}$$

"q'" effective negative charge enclosed $= \frac{4\pi d^3 \rho}{3}$

$$q' = \frac{4\pi d^3}{3} \left(\frac{ze}{\frac{4\pi d^3}{3}} \right) \quad \left[\rho = \frac{ze}{\frac{4\pi d^3}{3}} \right] \quad \left[\rho \rightarrow \text{density} \right]$$

$$q' = ze \left(\frac{d^3}{x^3} \right) \quad \text{Substituting } q' \text{ in equation (2)}$$

$$F_{\text{coulomb}} = \frac{1}{4\pi\epsilon_0} \left(\frac{ze}{d^2} \right) \left(ze \right) \left(\frac{d^3}{x^3} \right) = \frac{(ze^2) d}{4\pi\epsilon_0 (x^3)} \quad (3)$$

comparing equation (1) & (3)

$$\frac{(ze)^2 d}{4\pi\epsilon_0 x^3} = (ze) E_{\text{local}} \Rightarrow \frac{(ze) d}{4\pi\epsilon_0 x^3} = E_{\text{local}}$$

$$(ze) d = 4\pi\epsilon_0 x^3 (E_{\text{local}}) \quad (4) \quad \therefore \text{The induced dipole moment}$$

Also polarisability
 $P = N \alpha_e E_{\text{local}}$
 $\alpha_e = 4\pi\epsilon_0 x^3$

$\therefore \alpha_e$ is the electronic polarisability

$$P_e = N (4\pi\epsilon_0 x^3) E_{\text{local}} \quad \text{e.g., Diamond, phosphorus etc}$$

Ionic polarisation when an external field is applied

$\begin{array}{ccc} \text{---} \text{O} & \text{---} \text{O} & \text{---} \text{O} \\ E=0 & E \neq 0 & \end{array}$

to ionic solid (dielectric) displacement of cations and anions takes place in opposite direction

Example: NaCl, KCl [sodium chloride, potassium chloride]

Space- charge Polarization

Space charge polarization occurs due to accumulation of charges at the electrodes or at the interfaces in multiphase dielectrics. As shown in figure, the ions diffuse over appreciable distance in response to the applied field. This gives rise to redistribution of charges in dielectric medium. It occurs at low frequency range (power frequency range). It is found in ferrites and semiconductors.

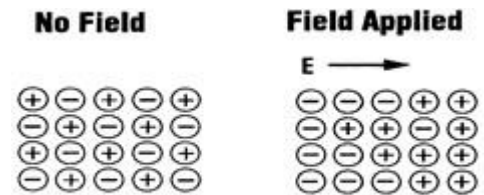
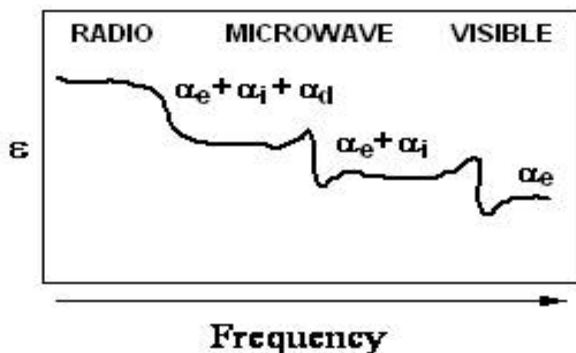


Fig: Space Charge Polarization

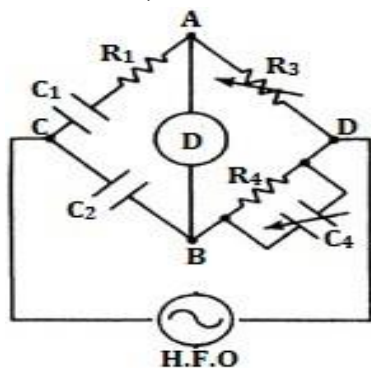


2.Determine dielectric constant by schering bridge method. (BTL 2)

Dielectric constant: it is a measure of the degree to which a medium can resist the flow of charge.

It is also defined as

$\epsilon = D/E$ I.e It is the ratio of Electric Displacement D to Electric field intensity.



C1 is the capacitor whose capacitance is to be determined

R1 is a series resistance, c2 is the standard capacitor; R3 is non- inductive variable resistance; R4 is non inductive resistance; C4 is variable capacitor; D is A.C. Null detector and H.F.O is high frequency

Oscillator. Now, in order to obtain C_1 value Detector current becomes zero by varying C_4 and R_3 without inserting dielectric inside C_1 .

$$\frac{\frac{1}{j\omega C_1} + R_1}{R_3} = \frac{\frac{1}{j\omega C_2}}{\frac{R_4}{1 + j\omega C_4 R_4}}$$

$$\left[R_1 + \frac{1}{j\omega C_1} \right] R_4 = \frac{R_3(1 + j\omega C_4 R_4)}{j\omega C_2}$$

$$R_1 R_4 + \frac{R_4}{j\omega C_1} = \frac{R_3}{j\omega C_2} + \frac{R_3 R_4 C_4}{C_2}$$

Equating the real and imaginary parts, we get

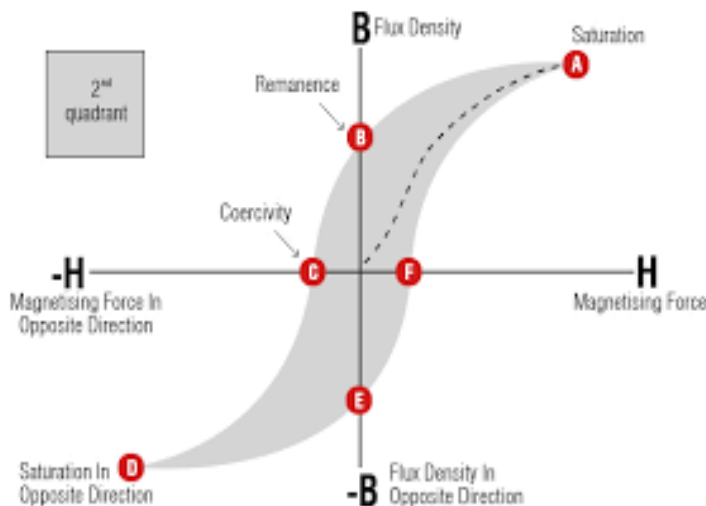
$$R_1 = \frac{R_3 C_4}{C_2} \quad \text{and} \quad C_1 = \frac{R_4 C_2}{R_3}$$

Since R_4 and C_2 are fixed, the resistance R_3 is calibrated to read the capacitance C_1 directly.

- (ii) The dielectric specimen should be in the size of C_1 (in its area) and inserted between the plates C_1 . Now once again the bridge is balanced. Now the reading in R_3 will give the value of new capacitance C_1'

Then the dielectric constant can be calculated using the formula $\epsilon_r = \frac{C}{C_0} = \frac{C_1'}{C_1}$

3. Discuss ferroelectricity in dielectrics. (BTL 2)



Ferroelectricity refers to the creation of enormous value of induced dipole moment in a weak electric field as well as existence of electric polarization even in the absence of applied electric field. Ferroelectricity is a result of dielectric hysteresis.

When a ferroelectric material is subjected to electric field, the polarization P versus electric field E describes a closed loop called as hysteresis loop as shown figure. Let initially, the material has polarization equal to zero. When the electric field is applied, the polarization increases along the path OA. After the point A, the polarization will not increase even if E is increased. This polarization is called saturation polarization P_s .

When E is reduced gradually such that $E=0$, the curve traces the path AB. It is observed that certain amount of polarization called remnant polarization P_r is still present. This is the polarization that exists in the absence of external electric field. Therefore, this is called spontaneous polarization.

In order to reduce the polarization to zero, a field in reverse direction must be applied. This is denoted by E_c called as coercive field. Further increase of field brings the material to saturation state. When the field is brought to zero and increased in the positive direction, a curve FGA is traced. Now, the hysteresis cycle is completed. The area bounded within the curve represents the loss of electrical energy per cycle.

4. Write a short note on Barium titanate. (BTL 2)

The structural changes in Barium titanate (BaTiO_3) crystal due to lattice variation give rise to Ferroelectricity. Above Curie temperature (approx. 120°C), BaTiO_3 has a cubic crystal structure with Barium ions at the corners, the titanium ions exactly at the body center, and Oxygen ions are at the face centers. At these temperatures, there is no spontaneous dipole moment.

When the crystal is cooled below 120°C , one axis (axis C) stretches and the other axes shrink and turn into a tetragonal crystal structure. In this case, polarization occurs as a result of the unit shift of axially elongated Ti- ion crystal. This polarization occurs without applying an external electric field or pressure and is known as "spontaneous polarization." This characteristic is called "ferroelectricity". The displacements of titanium ions create electric dipoles and all the dipoles of the adjacent unit cells get aligned in the same direction.

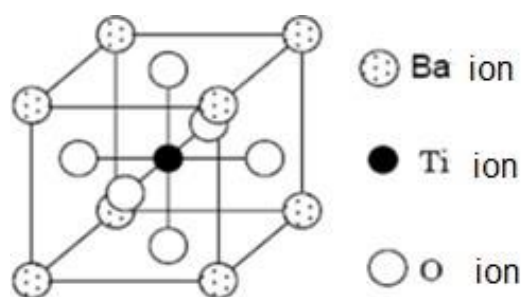
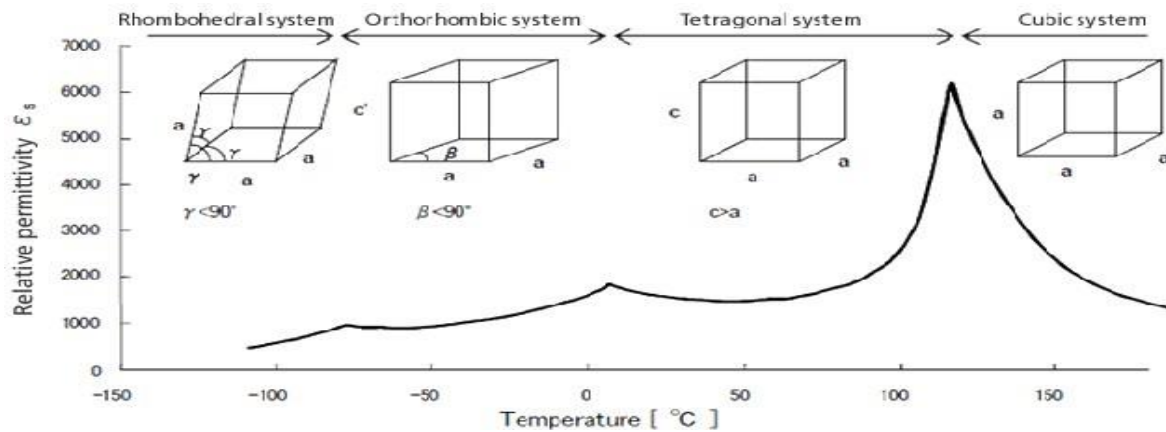


Fig: Unit cell for BaTiO_3 above 120°C



5. Write few applications of ferroelectric materials (BTL 3)

- Oscillators and filters
- Light deflectors, modulators and displays
- They possess very high value of D.C. Hence, they are used in the manufacture of small sized and large capacitance capacitors.
- They are used to detect infra-red radiations.
- They are used as memory devices in computers.

Unit-III WAVE MECHANICS

1. Derive De-Broglie's equation BTL 1

According to De-Broglie every moving particle is associated with wave. The dual Nature of light possessing both wave and particle properties was explained by combining Planck's expression for the energy of photon with Einstein's mass energy relation to give

$$\begin{aligned}
 E &= h\nu \quad \text{--- (1)} \\
 E &= mc^2 \quad \text{--- (2)} \\
 \text{Comparing (1) \& (2)} \\
 h\nu &= mc^2 \\
 \because \nu &= \frac{c}{\lambda} \\
 \frac{hc}{\lambda} &= mc^2 \Rightarrow \lambda = \frac{h}{mc} \quad \text{--- (3)}
 \end{aligned}$$

where λ is the wavelength of photon

$$\text{Eq (3)} \quad \lambda = \frac{h}{mv} = \frac{h}{p}$$

If particle moves with velocity 'v' then

From above equation if particle velocity is less, then wavelength of wave is more. It was by analogy with this equation associating momentum with a photon that de Broglie expressed the concept of matter wave, according to which a material particle of mass 'm' moving with a velocity 'v' should have an associated wavelength, called the de-Broglie wavelength.

2. Write different forms of De-Broglie's Wavelength BTL 1

(1) De-Broglie's wave equation is given by --- (1) $\lambda = \frac{h}{mv} = \frac{h}{p}$

If kinetic Energy of particle is --- (2) $E = \frac{1}{2}mv^2$, substitute Eq (2) in Eq (1)

$$\begin{aligned}
 E &= \frac{p^2}{2m} \\
 \Rightarrow p &= \sqrt{2mE} \\
 \lambda &= \frac{h}{\sqrt{2mE}} \quad \text{(Where E is kinetic Energy)}
 \end{aligned}$$

(2) The wavelength associated with a moving particle is independent of any charge associated with it. If the velocity 'v' is given to an electron by accelerating it through a potential difference 'V' then the work done on the electron is eV . This work done is converted into the kinetic energy of the electron, then

$$\frac{1}{2}$$

$$eV = 1.2 \times 10^{-18} \text{ J} = 2.07 \times 10^{-18} \text{ J}$$

$$\sqrt{2meV}$$

Substituting this value in the De Broglie equation we have

$$\frac{h}{\sqrt{2meV}}$$

Charge of electron is

$1.6 \times 10^{-19} \text{ C/s}$ and Mass of electron is $9.1 \times 10^{-31} \text{ Kg}$ substitute in above equations

$$\frac{12.27}{\sqrt{V}}$$

3. What are the properties of de Broglie's waves or Matter Waves? BTL 2

- (1) Lighter is the particle, greater is the wavelength associated with it.
- (2) Smaller is the velocity of the particle greater is the wavelength associated with it.
- (3) When $v = 0$ then i.e., wave becomes indeterminate and if $v = \infty$ then $\lambda = 0$. This shows that matter waves are generated by the motion of particles. These waves are produced whether the particles are charged particles or they are uncharged. This fact reveals that these waves are not electromagnetic waves but they are a new kind of waves.
- (4) The velocity of matter waves depends on the velocity of material particle i.e. it is not a constant while the velocity of electromagnetic wave is constant.
- (5) The wave nature of matter introduces an uncertainty in the location of the position of the particle because a wave cannot be said exactly at this point or exactly at that point. However, where the wave is large there is good chance of finding the particle while, where the wave is small there is very small chance of finding the particle.

4. Derive Schrödinger time independent equation BTL 1

Let us consider a group of waves associated with a moving particle. Let ψ represent the displacement of these waves at any time 't'. Let us consider that the wave motion be represent by classical wave equation.

$$\nabla^2 \psi + \frac{2mE}{\hbar^2} \psi = 0 \quad (1)$$

Where v is the velocity. The solution of the above equation is given by

$$\psi = \psi_0 e^{-i\omega t} \quad \text{--- (2)}$$

Differentiate above equation with respect to 't'

$$\frac{\partial \psi}{\partial t} = \psi_0 (-i\omega) e^{-i\omega t} \Rightarrow \frac{\partial \psi}{\partial t} = \psi_0 e^{-i\omega t} (-i\omega)$$

$$\frac{\partial \psi}{\partial t} = \psi (-i\omega) \Rightarrow \frac{\partial^2 \psi}{\partial t^2} = -\omega^2 \psi$$

Substitute above value in equation (1) then $\nabla^2 \psi = \frac{1}{v^2} (-\omega^2 \psi)$

$$\nabla^2 \psi = \frac{1}{v^2} (-\omega^2 \psi)$$

We know that $\omega = 2\pi f = 2\pi \left(\frac{v}{\lambda}\right) \Rightarrow \frac{\omega}{v} = \frac{2\pi}{\lambda}$

$$\Rightarrow \frac{\omega^2}{v^2} = \frac{4\pi^2}{\lambda^2}$$

The wave equation is given by $\nabla^2 \psi = -\frac{4\pi^2}{\lambda^2} \psi$

We can substitute the wavelength of the wave accompanying the particle in terms of the particle like property i.e. $\lambda = \frac{h}{mv}$ Then $\nabla^2 \psi = -\frac{4\pi^2}{\lambda^2} \psi$

$$\nabla^2 \psi = -\frac{4\pi^2 m^2 v^2}{h^2} \psi \rightarrow (3)$$

If E and V are the total energy and the potential energy of the particle, respectively, then

$$E = V + \frac{1}{2}mv^2 \Rightarrow E - V = \frac{1}{2}mv^2$$

Multiplying 'm' on both sides

$$m(E - V) = \frac{1}{2}m^2v^2 \Rightarrow 2m(E - V) = \frac{1}{2}m^2v^2$$

Substitute the $\frac{1}{2}m^2v^2$ value in eq $\rightarrow (3)$

The wave equation is given by or

$$\nabla^2 \psi + \frac{4\pi^2}{h^2} [2m(E - V)] \psi = 0$$

$$\nabla^2 \psi + \frac{8\pi^2 m}{h^2} (E - V) \psi = 0$$

This equation is known as Schrodinger time independent wave equation.

5. Derive Schrödinger time dependent equation BTL 1

Let us consider a group of waves associated with a moving particle. Let ψ represent the displacement of these waves at any time 't'. Let us consider that the wave motion be represent by classical wave equation.

$$\frac{1}{v^2} \frac{\partial^2 \psi}{\partial t^2} = \nabla^2 \psi \quad \text{--- (1)}$$

Where 'v' is the velocity. The solution of the above equation is given by

$$\psi = \psi_0 e^{-i\omega t} \quad \text{--- (2)}$$

Differentiate above equation with respect to 't' --- then

$$\begin{aligned} \frac{\partial \psi}{\partial t} &= \psi_0 e^{-i\omega t} (-i\omega) \Rightarrow \omega = 2\pi\nu \Rightarrow E = h\nu \\ \nu &= \frac{E}{h} \Rightarrow \omega = 2\pi \left(\frac{E}{h} \right) \Rightarrow \omega = \frac{E}{\hbar} \\ &\quad \left[\because \hbar = \frac{h}{2\pi} \right] \end{aligned}$$

~~substitute~~ substitute in above equation we get

$$\begin{aligned} \frac{\partial \psi}{\partial t} &= -i\psi\omega \\ \text{Multiplying 'i' on both sides} \\ \Rightarrow i \frac{\partial \psi}{\partial t} &= -i^2 \psi \omega \end{aligned}$$

$$\Rightarrow i \frac{\partial \psi}{\partial t} = \frac{E}{\hbar} \psi$$

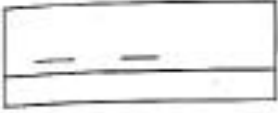
$$E\psi = i\hbar \frac{\partial \psi}{\partial t}$$

Substituting this value in time independent wave equation i.e.

$$\nabla^2 \psi + \frac{2m}{\hbar^2} \left[i\hbar \frac{\partial \psi}{\partial t} - V\psi \right] = 0$$

$$\left[\frac{\hbar^2 \nabla^2 \psi}{2m} + V\psi \right] = i\hbar \frac{\partial \psi}{\partial t}$$

$E\psi = V\psi \rightarrow$ S.T.D.E



Above equation is called as Schrödinger time dependent wave equation. The above equation

can be written as $\frac{\hbar^2 \nabla^2 \psi}{2m} + V\psi = E\psi$ where $\frac{\hbar^2 \nabla^2}{2m} + V$ as a Hamiltonian Operator.

6. Explain Physical significance of wave function ψ BTL 2

The wave function associated with a physical system contains all relevant information about the system and its future behavior and thus describes it completely. It is natural to assume that the wave function be large where the particle is most likely to be and small elsewhere.

If ψ is the amplitude of matter waves at any point in space, then the particle density at that point may be taken as proportional to ψ^2 . Thus is a measure of particle density. When this is multiplied by the charge of the particle, the charge density is obtained. In this way, ψ is a measure of charge density.

According to Max Born ψ^2 gives the probability of finding the particle in the state. ψ is a measure of probability density.

The function $\psi(r, t)$ is sometimes called probability amplitude of the particle at position r at time t . The total probability of finding the particle in the region is of course, unity, i.e. the particle is certainly to be found somewhere in space $\int \psi^2 dV = 1$.

properties of ψ

1. must be finite for all values of x, y, z of the region.
2. must be single valued i.e. for each set of values of x, y, z i.e. must be have one value only
3. must be continuous in all region except where potential energy is infinite
4. is analytical i.e. it possesses continuous first order derivative
5. Vanishes at the boundaries.

7. Apply Schrodinger time independent wave equation to particle in Potential Box BTL 1

Let us consider a square potential well with infinitely high sides, as indicated below fig... If particle in potential well the potential energy is zero. If particle is moving then potential energy increases.

According to Schrodinger time independent wave equation is given by

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2} [E - V] \psi = 0$$



Potential energy is zero if particle 'x' lies in between 0 to L i.e. $V(x) = 0$ for $0 < x < L$

If potential energy is equal to zero then S. E equation becomes

$$\frac{d^2\psi}{dx^2} + \frac{2mE}{\hbar^2} \psi = 0 \quad (1) \Rightarrow K^2 = \frac{2mE}{\hbar^2} \Rightarrow \frac{d^2\psi}{dx^2} + K^2 \psi = 0 \Rightarrow (D^2 + K^2) \psi = 0 \quad (1)$$

The solution of above differential equation is

$$\psi = A e^{ikx} + B e^{-ikx} \quad (2)$$

Applying the boundary conditions

① If $\psi = 0$; $x = 0$ equation (2) becomes $0 = A + B \Rightarrow \boxed{B = -A}$

Now eq. (2) $\psi = A e^{ikx} - A e^{-ikx} \Rightarrow \psi = A [e^{ikx} - e^{-ikx}]$

$\times \frac{2i}{2i} \Rightarrow$ we get $\psi = \frac{2iA}{2i} [e^{ikx} - e^{-ikx}]$

$\therefore \sin kx = \frac{e^{ikx} - e^{-ikx}}{2i} \Rightarrow \therefore \psi = 2iA \sin kx$

If $2iA = N \Rightarrow \boxed{\psi = N \sin kx} \quad (3)$

② If $\psi = 0$; $x = L$ equation (3) becomes

$0 = N \sin kL \Rightarrow kL = n\pi \Rightarrow k = \frac{n\pi}{L}$

$\Rightarrow \boxed{\psi_n(x) = N \sin\left(\frac{n\pi x}{L}\right)}$

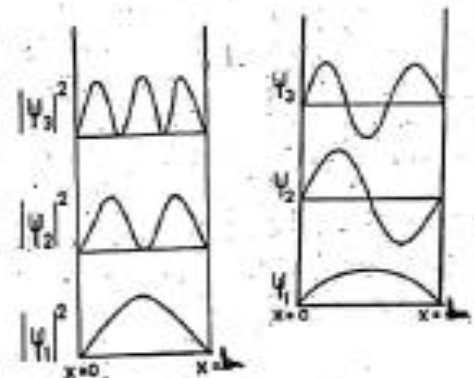
$$\begin{aligned}
 \therefore k^2 &= \frac{2mE}{\hbar^2} \Rightarrow k^2 = \frac{2mE}{\left(\frac{h}{2\pi}\right)^2} \Rightarrow k^2 = \frac{8\pi^2 m E}{h^2} \Rightarrow \left(\frac{n\pi}{L}\right)^2 = \frac{8\pi^2 m E}{h^2} \\
 \left[\because \hbar = \frac{h}{2\pi} \right] \\
 \text{Now } E_n &= \frac{n^2 h^2}{8mL^2}
 \end{aligned}$$

The integer 'n' introduced above is called a quantum number. The E values are called energy levels. The particle that is described by the wave function with a certain n values is said to be in quantum state 'n'. For n=1 the state is called ground state. For 2, 3, —etc. are known as excited states. The general form of wavefunction may be written as

$$\psi(x) = N \sin\left(\frac{n\pi x}{L}\right)$$

Evaluating 'N' Value

$n \in \{1, 2, 3, \dots\}$



we should normalize above function, normalize condition is

$$\begin{aligned}
 N &= \int_0^L |\psi|^2 dx = 1 \Rightarrow \psi(x) = N \sin\left(\frac{n\pi x}{L}\right) \Rightarrow \psi = N^2 \int_0^L \sin^2\left(\frac{n\pi x}{L}\right) dx = 1 \\
 \frac{N^2}{2} \int_0^L \left[1 - \cos\left(\frac{2n\pi x}{L}\right)\right] dx &= 1 \Rightarrow \frac{N^2}{2} \left[\int_0^L 1 dx - \int_0^L \cos\left(\frac{2n\pi x}{L}\right) dx \right] = 1 \\
 \Rightarrow \text{If odd limits for even function, then its function} &\rightarrow 0 \\
 \Rightarrow \frac{N^2 L}{2} = 1 \Rightarrow N^2 = \frac{2}{L} \Rightarrow N &= \sqrt{\frac{2}{L}}
 \end{aligned}$$

Hence the normalized wavefunctions will have the form

$$\psi_n = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi x}{L}\right)$$

Total Energy of the particle [30]

$$E_n = \frac{h^2}{8mL^2} (n_x^2 + n_y^2 + n_z^2)$$

$$\therefore \text{Eigen Function } \psi_{n_x, n_y, n_z} = \sqrt{\frac{2}{L}} \sin\left(\frac{n_x \pi x}{L}\right) \times \sqrt{\frac{2}{L}} \sin\left(\frac{n_y \pi y}{L}\right) \times \sqrt{\frac{2}{L}} \sin\left(\frac{n_z \pi z}{L}\right)$$

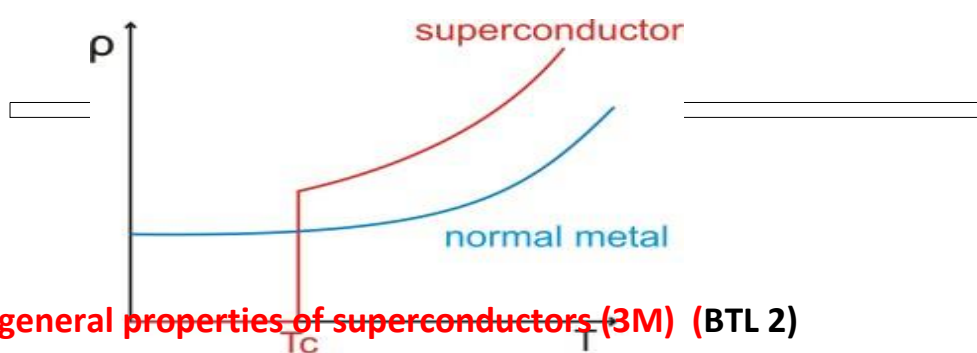
The energy level and wave function as shown in the fig.... The Probability of finding the particles more at maximum amplitude.

Unit-IV

Superconductivity

1. Explain the phenomenon of superconductivity (2M) (BTL 2)

Before the discovery of superconductivity, it was observed that the electrical resistance of a conductor turns out to be zero only at absolute zero. In some materials the electrical resistance becomes zero, when they are cooled to very low temperatures. For example, the electrical resistance of pure mercury suddenly drops to zero, when it is cooled below 4.2 kelvin. This phenomenon was first discovered by H.K. Onnes in 1911. This *phenomenon of losing the resistivity absolutely, when cooled to sufficiently low temperature is called **superconductivity***. The material which shows this behavior is called **superconductor**. The temperature at which a normal conductor loses its resistivity (ρ) and becomes a superconductor is known as **transition** or **critical temperature T_c** .



2. Write general properties of superconductors (3M) (BTL 2)

1. Super conductor can conduct electric current in the absence of an applied voltage.
2. By applying high pressure, it is possible to bring superconductivity transition temperature to room temperature. ($T_c \propto P$)
3. Superconductivity is found to occur in metallic elements in which the number of valence electrons lies between 2 and 8.
4. Superconducting elements, in general lie in the inner columns of the periodic table.

5. Transition metals having odd number of valence electrons are favorable to exhibit superconductivity while metals having even number of valence electrons are unfavorable.
6. Materials having high normal resistivity exhibit superconductivity.

7. The current in a superconducting ring persists for a very long time.

8. Transition temperature is different for different specimen having different isotopic mass.

$$T_c \propto M^{-1/2}$$

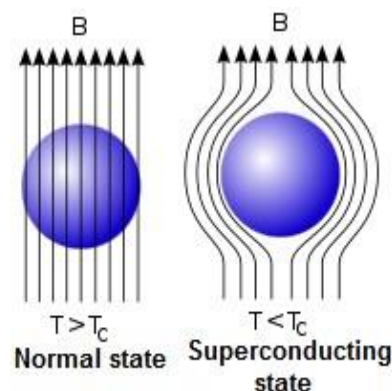
9. In superconducting state there are small changes in thermal conductivity and the volume of the material.

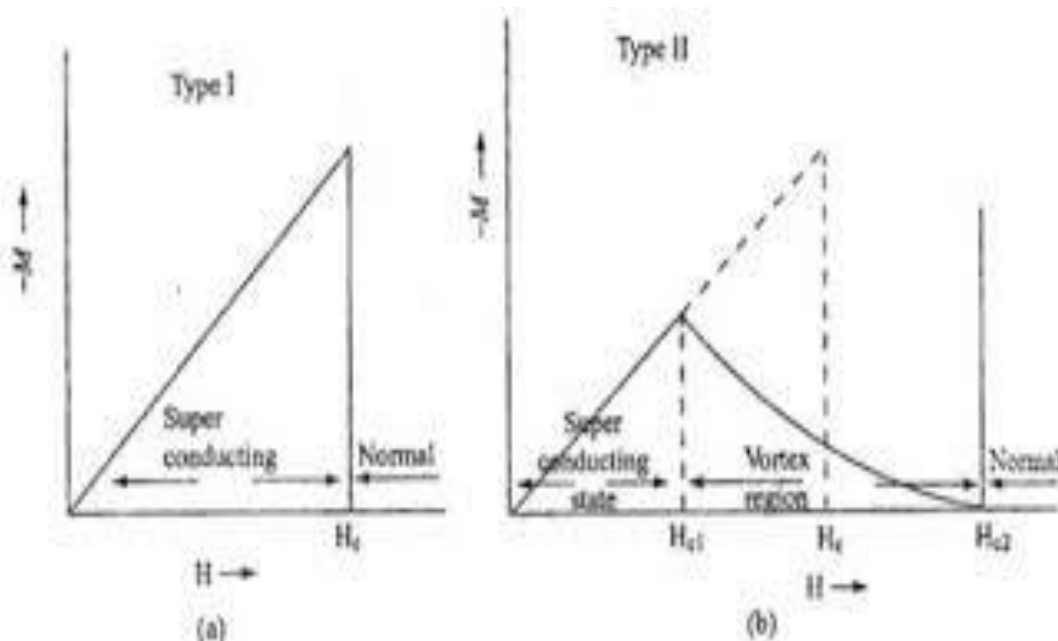
10. When the strength of the magnetic field applied reaches a critical value H_c the superconductivity disappears. The dependence of the critical field upon the temperature is given by

$$H_c(T) = H_c(0) \left[1 - \left(\frac{T}{T_c} \right)^2 \right]$$

3. What is Meissner effect (3M) (BTL 2)

When a superconducting material is placed in a weak magnetic field of flux density B , the magnetic lines of force penetrate through the material as shown in figure(a). When the material is cooled below its transition temperature ($T \leq T_c$), the magnetic lines of forces are expelled as shown in figure(b). We know that a diamagnetic material has the tendency to expel the magnetic lines of forces. Since *the superconductor also expels the magnetic lines of forces it behaves as a perfect diamagnet*. This is called as Meissner effect.





Soft super conductors (Type I -superconductor)	Hard super conductors (Type II - Superconductor)
1.They exhibit complete meissner effect	1.They do not show complete Meissner effect.
2. They Possess only one critical field.	2.They possess two critical fields.
3. They are not used for commercial purpose	3.They are used for commercial purpose.
4. Due to low value of critical field makes these materials un suitable to use in high field superconducting magnets.	4.Due to high value of critical field makes these materials suitable to use in high field superconducting magnets .
5. The maximum critical field is 0.1 Wb/m^2 .	5.The maximum critical field is 30 Wb/m^2 .

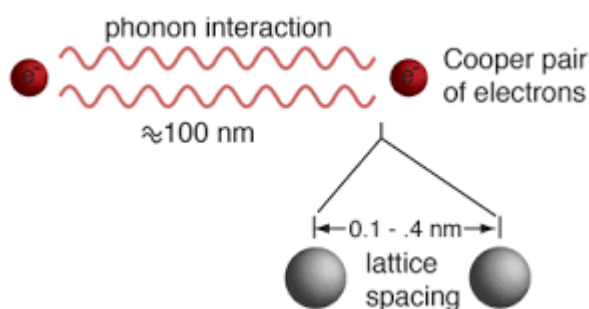
6. The critical field H_c is relatively low	6. The value of H_{c2} is very large.
7.Examples: Al, Zn, Ga, etc.	7. Examples: Lead-Indium alloy, etc.

5. Discuss BCS theory of superconductivity (BTL 2)

In 1957, Bardeen, Cooper and Schrieffer Proposed the theory to explain the phenomenon of superconductivity, which is known as BCS theory.

Super conductivity is a phenomenon arise due to electron – phonon- electron interaction which are Cooper pair. Phonons are quantum lattice vibrations of the positive ions in a crystal.

A pair of electrons relatively far apart but interact with each other through lattice vibration is known as “cooper pair”.



An electron in a solid exerts an attractive force on an adjacent ion and disturb the lattice. If a second electron interact with this disturb lattice it experiences an attractive force. At low temperature this attractive force dominant than the repulsive force. Energy of the cooper pair of electrons is less than the energy of pair of electrons in free state.

6. Write a short note on High temperature superconductors. (BTL 2)

Super conductors which has transition temperature more than 10K is known as high temperature superconductors. Example: ceramics and aluminum oxides etc., Generally, high temperature superconductors are anisotropic materials. New oxide superconductors have been discovered whose transition temperature is greater than 90K. It has been realized that role of oxygen is essential for high transition temperature oxide

superconductors. The high T_c superconductors developed so far belong to five chemical systems having the following general formulae.

1. $\text{BaPb}_{1-x}\text{Bi}_x\text{O}_3$
2. $\text{La}_{2-x}\text{M}_x\text{CuO}_{4-x}$ ($\text{M} = \text{Ba}, \text{Sr}$)
3. $\text{Ba}_2\text{MCu}_3\text{O}_{7-x}$ ($\text{M} = \text{Y}$ or rare earth metals such as Gd, Eu , etc.)
4. $\text{Ba}_{2-x}\text{La}_{1+x}\text{Cu}_3\text{O}$
5. $\text{Bi}_2\text{CaSr}_2\text{Cu}_2\text{O}$

It is peculiar to state the mechanism of high Temperature superconductivity. It has been realized that the role of oxygen is essential for high T_c oxide superconductors. The unit cell of high T superconductors has complicated structure. If the cell contains one atom of rare earth metal, two barium atoms, three copper atoms and seven oxygen atoms, then such compounds are named 1-2-3 superconductors.

7. Explain the applications of superconductors (BTL 3)

Superconductors are used in the following applications:

- Nuclear magnetic resonance apparatus consisting of super conducting materials which can be used in clinical medicine to diagnose the disease rapidly.
- Maglev (magnetic levitation) trains which works as the superconductor repels magnetic field due to which magnet will float above a superconductor – this virtually eliminates the friction between the train and the track.
- Wiring with super conductors can speed the passage of electrical signals in computers.
- SQUIDS (Superconducting Quantum Interference Devices) are used to detect even the weakest magnetic field. They are used in mine detection equipment to help in the removal of land mines.
- Super conducting elements are used to build fast and large-scale computer with a small volume and power consumption is less than a watt.

NUMERICAL PROBLEMS

1. Superconducting tin has a critical temperature of 3.7K at zero magnetic field and a critical field of 0.0306 Tesla at 0K. find the critical field at 2K. Solution:

Critical Field $H_c(T) = H_c(0) \left[1 - \frac{T^2}{T_c^2} \right] = 0.0306 \left[1 - \frac{2^2}{3.7^2} \right] = 0.02166 \quad \text{Tesla}$

2. Calculate the critical current for a wire of lead having a diameter of 1mm at 4.2K. Critical temperature for leads is 7.18K and $H_c(0) = 6.4 \times 10^4 \text{ A/m}$ Solution:

Critical Field $H_c(T) = H_c(0) \left[1 - \frac{T^2}{T_c^2} \right] = 6.4 \times 10^4 \left[1 - \frac{4.2^2}{7.18^2} \right] = 4.2 \times 10^4 \quad \text{A/m}$

Critical Current $I_c = 2\pi r H_c = 2 \times 3.14 \times 0.5 \times 10^{-3} \times 4.2 \times 10^4 = 134.26 \text{ A}$

3. The critical temperature for a metal with isotopic mass 199.5 is 4.185K. Calculate the isotopic mass if the critical temperature falls to 4.133K.

Solution:

We know that isotopic effect is given by $T_c M^\alpha = \text{constant}$ Hence,

$$T_{c1} M_1^\alpha = T_{c2} M_2^\alpha$$

4. The critical temperature for Hg with isotopic mass 199.5 is 4.184K. Calculate the critical temperature when its isotopic mass changes to 203.4K.

Solution:

We know that isotopic effect is given by $T_c M^\alpha = \text{constant}$ Hence,

$$4.1435 \text{ K}$$

Questions from previous papers

1. Write a note on Type I and Type II superconductors. [June 2011, 4 marks]
2. Write a note on High temperature superconductors. [Jan 2012, 5 marks]
3. Distinguish between type I and type II superconductors [June 2012, 2 marks]
4. What is superconductivity? Explain the general properties of superconductors. [Jan 2013, 5 marks]
5. What are type II superconductors? Explain their importance [June-2013, 3marks]
6. What is superconductivity? Describe the preparation of high T_c superconductors [June-2013, 4marks]
7. The superconducting transition temperature of a metal is 7.26K. The critical field at 0 K is $64 \times 10^3 \text{ A/m}$. Calculate the critical field at 5K. [Jan 2013, 3 marks]

Unit-IV

Magnetic Materials

1. Discuss classification of magnetic materials (5M). (BTL 2.)

Diamagnetic materials: The materials which when placed in a magnetic field acquire feeble magnetism opposite to the direction of the magnetic field are known as diamagnetic materials.

Bismuth (Bi), Zinc (Zn), Copper (Cu), Silver (Ag), Gold(Au), Salt(NaCl), Water(H₂O), Mercury(Hg), Hydrogen(H₂) are the examples of diamagnetic materials.

Properties:

1. When a bar of diamagnetic material is placed in a magnetic field, it tries to repel the lines of force away from it as shown in figure. This shows the magnetic induction B in it is less than the applied field H. So the permeability (μ) is less than one.
2. When a bar of diamagnetic material is suspended freely between two magnetic poles, the axis of the bar becomes perpendicular to magnetic field.
3. The magnetic susceptibility χ is negative and is independent of temperature.

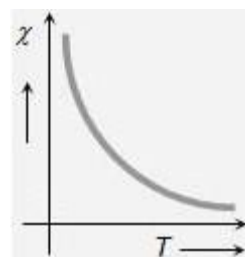
Paramagnetic materials: The materials which when placed in a magnetic field, acquire feeble magnetism in the direction of magnetic field are known as paramagnetic materials.

Examples: Aluminium (Al), Platinum (Pt), Manganese (Mn), copper chloride (CuCl₂), Oxygen (O₂)

Properties:

1. When a bar of paramagnetic material is placed in a magnetic field, it tries to attract the lines of force towards it as shown in figure. This shows the magnetic induction B in it is greater than the applied field H. so, the permeability is greater than one.
2. When a bar of paramagnetic material is suspended freely between two magnetic poles, its axis becomes parallel to magnetic field as shown in figure. Moreover, the poles produced at the ends of the bar are opposite to nearer magnetic poles.

- The molecules of paramagnetic material possess permanent magnetic dipole moments. In the absence of external magnetic field, the dipoles are randomly oriented. Hence, the net magnetic moment is zero. In the presence of magnetic field, the dipoles tend to align along the field direction. This leads to magnetization in the direction of field. However, this tendency is opposed by thermal agitation. Therefore, only partial alignment takes place.
- The paramagnetic susceptibility is positive and depends greatly on temperature as per Curie's law $\chi \propto \frac{1}{T}$, where C is Curie constant.



Ferromagnetic materials:

The materials which when placed in a magnetic field become strongly magnetized in the direction of field are known as ferromagnetic materials.

Examples: Iron (Fe), Nickel (Ni), Cobalt (Co), Magnetite (Fe_3O_4), etc Properties:

- When a ferromagnetic material is placed inside a magnetic field, it attracts the magnetic lines of forces very strongly as shown in fig.
- They acquire relatively high magnetization in a weak field. Further even in the absence of applied field, the magnetic moments are enormous. This is called **spontaneous magnetization**.
- The magnitude of susceptibility is very large and positive.
- The susceptibility of a ferromagnetic substance decreases steadily with the rise of temperature in accordance with Curie-Weiss Law.
 $\chi = \frac{C}{T - T_c}$, where C is Curie constant and T_c is Curie's temperature.
- Above certain temperature, called Curie temperature, ferromagnetic material changes to paramagnetic.

2. Weiss molecular field theory of ferromagnetism (5M) (BTL 2.)

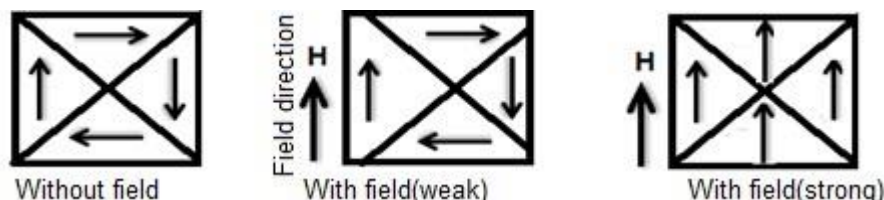
3. Weiss domain theory of ferromagnetism (BTL 2)

According to Weiss, a virgin specimen of ferromagnetic material consists of several small regions called **domains**. These domains have spontaneous magnetization due to the parallel alignment of spin magnetic moments in each domain. But the direction of spontaneous magnetization varies from

domain to domain and are oriented in such a way that the net magnetization of the specimen is zero as shown in figure(1).

When the magnetic field is applied, the magnetization occurs in the specimen by two ways. (i)

By the motion of domain walls and (ii) By rotation of domain walls



The motion of domain walls takes place in weak magnetic field. The volume of domains oriented in the direction of magnetic field increases at the cost of those that are unfavorably oriented as shown in figure(2). magnetization, **theory:**

The **Magnetic Hysteresis** loop above, shows the behaviour of a ferromagnetic core graphically as the relationship between B and H is non-linear. Starting with an unmagnetised core both B and H will be at zero, point 0 on the magnetisation curve.

If the magnetisation current, i is increased in a positive direction to some value the magnetic field strength H increases linearly with i and the flux density B will also increase as shown by the curve from point 0 to point a as it heads towards saturation.

Now if the magnetising current in the coil is reduced to zero, the magnetic field circulating around the core also reduces to zero. However, the coils magnetic flux will not reach zero due to the residual magnetism present within the core and this is shown on the curve from point a to point b.

To reduce the flux density at point b to zero we need to reverse the current flowing through the coil. The magnetising force which must be applied to null the residual flux density is called a “Coercive Force”. This coercive force reverses the magnetic field re-arranging the molecular magnets until the core becomes unmagnetised at point c.

An increase in this reverse current causes the core to be magnetised in the opposite direction and increasing this magnetisation current further will cause the core to reach its saturation point but in the opposite direction, point d on the curve.

This point is symmetrical to point b. If the magnetising current is reduced again to zero the residual magnetism present in the core will be equal to the previous value but in reverse at point e.

Again reversing the magnetising current flowing through the coil this time into a positive direction will cause the magnetic flux to reach zero, point **f** on the curve and as before increasing the magnetisation current further in a positive direction will cause the core to reach saturation at point **a**.

Then the B-H curve follows the path of **a-b-c-d-e-f-a** as the magnetising current flowing through the coil alternates between a positive and negative value such as the cycle of an AC voltage. This path is called a **Magnetic Hysteresis Loop**.

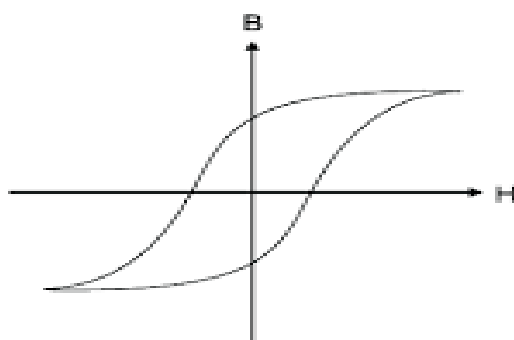
Hysteresis curve based on Domain theory.

When a field is applied, domains where the magnetization is parallel or at a small angle with the field grow at the expense of those where the magnetization is antiparallel so that the boundary between domains is displaced.

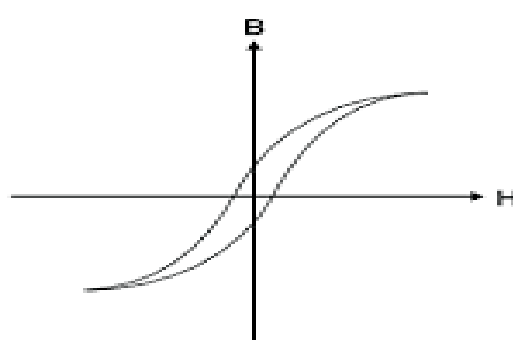
Initially OA the magnetization of the substance as whole proceeds by small reversible boundary displacement but the steeper part AB of the magnetization curve is due to larger, irreversible displacements. Above the knee of the curve BS magnetization proceeds by rotation of the direction of magnetization of whole domains and such a process is rather difficult and the increase in magnetization is relatively slow.

When the applied field is reduced, there is a little change in the domain structure so that the magnetic induction or magnetization remains quite high, until high reverse fields are applied. Further even when the external field is zero, there is a residual magnetization in the specimen and that can be destroyed by applying a high reverse field. Thus the reversible and irreversible domain wall movements give rise to hysteresis in the ferromagnetic materials.

Distinguish between hard and soft magnetic materials. (BTL 2)



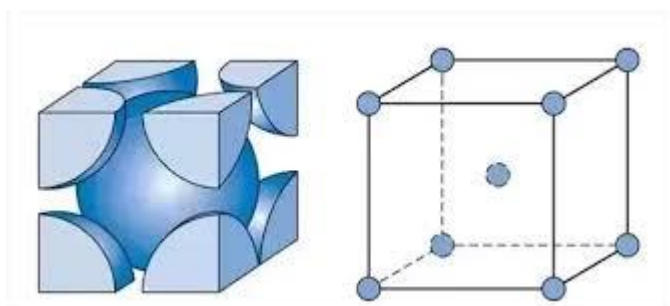
Hard Magnetic Materials



Soft Magnetic Materials

Hard magnetic materials	Soft magnetic materials
1.They have Large hysteresis loss due to large hysteresis loop area.	1.They have small hysteresis loss due to small hysteresis loop area.
2. They cannot be easily magnetised and demagnetised.	2.They can be easily magnetised and demagnetised.
3. The coercivity and retentivity are large	3.The coercivity and retentivity are small.
4. These are used to produced permanent magnets in voltage regulator,magnetic separators.	4.They are used in switching circuits, shift resistors.
5. They have small values for permeability and susceptibility.	5.They have large values of permeability and susceptibility.

Write short notes on ferrites.



Let us consider a crystal which contains A – type lattice and B- type lattice. If the antiparallel magnetic moments of two sublattices are not completely compensated, such materials are termed as ferrimagnetic materials. They exhibit spontaneous magnetization below the ferrimagnetic neel temperature. The natural ferrite is the iron ore magnetite

X – ray crystallography reveals that ferrite oxygens have fcc structure with tetrahedral and octahedral interstitial spaces. The tetrahedral space is surrounded by four oxygens and octahedral space is surrounded by six oxygens which is denoted as A -sites and B- sites respectively. The arrangements of cations in these spaces shows the magnetic properties of these materials

Unit V

Optical fiber and lasers

What is Ray Transmission Theory ? (BTL 2)

Before studying how the light propagates through the fiber, laws governing the nature of light must be studied. These were called as **laws of optics (Ray theory)**. There is a conception that light always travels at the same speed. This fact is simply not true. The speed of light depends upon the material or medium through which it is moving. In free space light travels at its maximum possible speed i.e. 3×10^8 m/s or 186×10^3 miles/sec. When light travels through a material it exhibits certain behavior explained by laws of reflection, refraction. □

Reflection

□ The law of reflection states that, when a light ray is incident upon a reflective surface at some incident angle ϕ_1 from imaginary perpendicular normal, the ray will be reflected from the surface at some angle ϕ_2 from normal which is equal to the angle of incidence. □

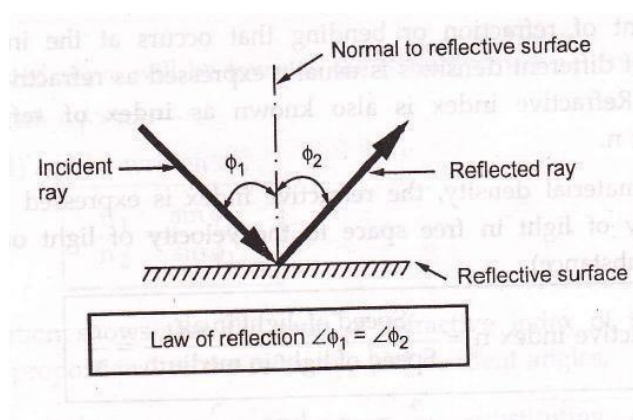


Fig. 1.6.2
reflection.

shows law of

Refraction

Refraction occurs when light ray passes from one medium to another i.e. the light ray changes its direction at interface. Refraction occurs whenever density of medium changes. E.g. refraction occurs at air and water interface, the straw in a glass of water will appear as it is bent. □

The refraction can also observed at air and glass interface.

- When wave passes through less dense medium to more dense medium, the wave is refracted (bent) towards the normal. Fig. 1.6.3 shows the refraction phenomena. □

□

- The refraction (bending) takes place because light travels at different speed in different mediums. The speed of light in free space is higher than in water or glass. □

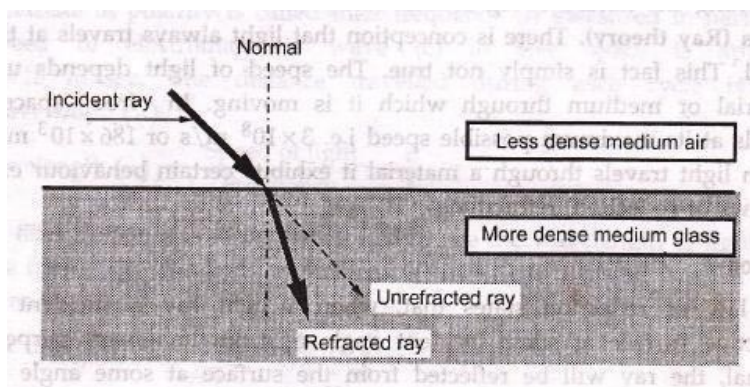


Fig.1.6.3

Refraction

Refractive Index (BTL 2)

□

- The amount of refraction or bending that occurs at the interface of two materials of different densities is usually expressed as refractive index of two materials. Refractive index is also known as **index of refraction** and is denoted by n . □

□

- Based on material density, the refractive index is expressed as the ratio of the velocity of light in free space to the velocity of light of the dielectric material

(substance). □

$$\text{Refractive index } n = \frac{\text{Speed of light in air}}{\text{Speed of light in medium}} = \frac{c}{v}$$

The refractive index for vacuum and air is 1.0 for water it is 1.3 and for glass refractive index is 1.5.

Snell's Law

- Snell's law states how light ray reacts when it meets the interface of two media having different indexes of refraction. □
- Let the two medias have refractive indexes n_1 and n_2 where $n_1 > n_2$. □

□₁ and □₂ be the angles of incidence and angle of refraction respectively.

Then according to Snell's law, a relationship exists between the refractive index of both materials given by

$$n_1 \sin \theta_1 = n_2 \sin \theta_2 \quad \dots (1.6.1)$$

- A refractive index model for Snell's law is shown in Fig. 1.6.4.
- The refracted wave will be towards the normal when $n_1 < n_2$ and will away from it when $n_1 > n_2$.

Equation (1.6.1) can be written as,

$$\frac{n_1}{n_2} = \frac{\sin \theta_2}{\sin \theta_1}$$

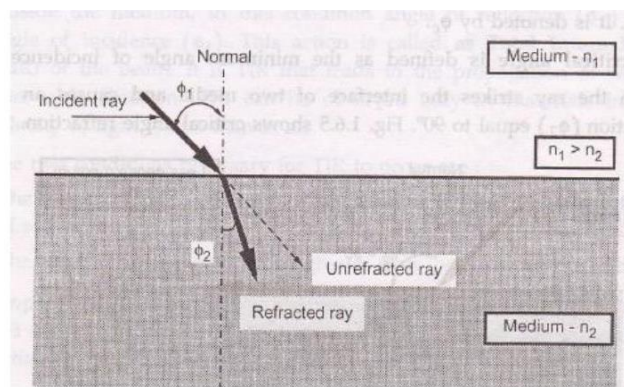


Fig 1.6.4 Refractive model for Snells Law

This equation shows that the ratio of refractive index of two mediums is inversely proportional to the refractive and incident angles.

As refractive index $n_1 = \frac{c}{v_1}$ $n_2 = \frac{c}{v_2}$

substituting these values in equation (1.6.2)

$$\frac{c/v_1}{c/v_2} = \frac{\sin \theta_2}{\sin \theta_1}$$

$$\frac{v_2}{v_1} = \frac{\sin \theta_2}{\sin \theta_1}$$

Critical Angle (BTL 1)

- When the angle of incidence (Φ_1) is progressively increased, there will be progressive increase of refractive angle (Φ_2). At some condition (Φ_1) the refractive angle (Φ_2) becomes 90° to the normal. When this happens the refracted light ray travels along the interface. The angle of incidence (Φ_1) at the point at which the refractive angle (Φ_2) becomes 90° is called the critical angle. It is denoted by Φ_c .
- The **critical angle** is defined as the minimum angle of incidence (Φ_1) at which the ray strikes the interface of two media and causes an angle of refraction (Φ_2) equal to 90° . Fig 1.6.5 shows critical angle refraction.

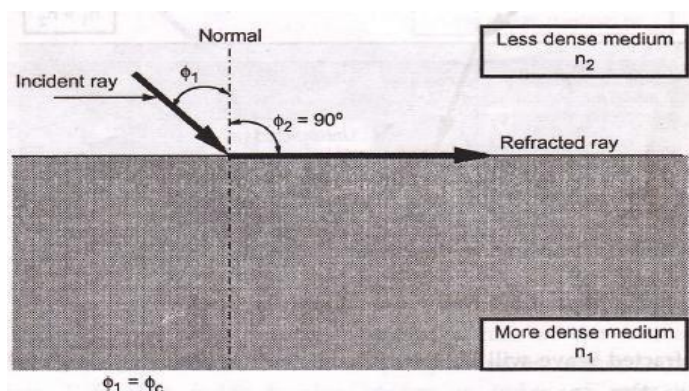


Fig.1.6.5 Critical

Angle

Hence at critical angle $\Phi_1 = \Phi_c$ and $\Phi_2 = 90^\circ$

Using Snell's law : $n_1 \sin \Phi_1 = n_2 \sin \Phi_2$

$$\sin \phi_c = \frac{n_2}{n_1} \sin 90^\circ$$

\therefore

$$\sin 90^\circ = 1$$

There $\sin \phi_c = \frac{n_2}{n_1}$

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

(1.6 .3)

...

- The actual value of critical angle is dependent upon combination of materials present on each side of boundary.

Total Internal Reflection (TIR)(BTL 1)

When the incident angle is increased beyond the critical angle, the light ray does not pass through the interface into the other medium. This gives the effect of mirror exists at the interface with no possibility of light escaping outside the medium. In this condition angle of reflection (Φ_2) is equal to angle of incidence (Φ_1). This action is called as **Total Internal Reflection (TIR)** of the beam. It is TIR that leads to the propagation of waves within fiber-cable medium. TIR can be observed only in materials in which the velocity of light is less than in air.

The refractive index of first medium must be greater than the refractive index of second one.

1. The angle of incidence must be greater than (or equal to) the critical angle.

Example 1.6.1 : A light ray is incident from medium-1 to medium-2. If the refractive indices of medium-1 and medium-2 are 1.5 and 1.36 respectively then determine the angle of refraction for an angle of incidence of 30° .

Solution : Medium-1 $n_1 = 1.5$

Medium-2 $n_2 = 1.36$

Angle of incidence $\phi_1 = 30^\circ$.

Angle of incident $\phi_2 = ?$

$$\text{Snell's law : } n_1 \sin \phi_1 = n_2 \sin \phi_2$$

$$1.5 \sin 30^\circ = 1.36 \sin \phi_2$$

$$\sin \phi_2 = \frac{1.5}{1.36} \sin 30^\circ$$

$$\sin \phi_2 = 0.55147$$

\therefore

$$\phi_2 = 33.46^\circ$$

Angle of refraction 33.46° from normal.

... Ans.

Example 1.6.2 : A light ray is incident from glass to air. Calculate the critical angle (ϕ_c).

Solution : Refractive index of glass $n_1 = 1.50$

Refractive index of air $n_2 = 1.00$

$$\text{Snell's law : } n_1 \sin \phi_1 = n_2 \sin \phi_2$$

$$\sin \phi_1 = \frac{n_2}{n_1} \sin \phi_2$$

\therefore

$$\sin \phi_1 = \frac{n_2}{n_1} \sin 90^\circ$$

Example 1.6.3 : Calculate the NA, acceptance angle and critical angle of the

fiber having n_1 (Core refractive index) = 1.50 and refractive index of cladding = 1.45.

Solution : $n_1 = 1.50$, $n_2 = 1.45$

$$\Delta = \frac{(n_1 - n_2)}{(n_1)} = \frac{1.50 - 1.45}{1.50} = 0.033$$

$$\text{Numerical aperture, } NA = n_1 \sqrt{2\Delta}$$

$$NA = 1.50 \sqrt{2 \times 0.033}$$

$$NA = 0.387$$

$$\text{Acceptance angle } \phi_0 = \sin^{-1} NA \quad \phi_0 = \sin^{-1} 0.387$$

$$\text{Critical angle } \phi_c = \sin^{-1} \frac{n_2}{n_1} \quad \phi_c = \sin^{-1} \frac{1.45}{1.50}$$

$$\phi_0 = 22.78^\circ$$

Optical Fiber as Waveguide (BTL 2)

- An optical fiber is a cylindrical dielectric waveguide capable of conveying electromagnetic waves at optical frequencies. The electromagnetic energy is in the form of the light and propagates along the axis of the fiber. The structural of the fiber determines the transmission characteristics. □

□

- The propagation of light along the waveguide is decided by the modes of the waveguides, here mode means path. Each mode has distinct pattern of electric and magnetic field distributions along the fiber length. Only few modes can satisfy the homogeneous wave □

equation in the fiber also the boundary condition a waveguide surfaces. When there is only one path for light to follow then it is called as single mode propagation. When there is more than one path then it is called as multimode propagation. □

Single fiber structure

- A single fiber structure is shown in Fig. 1.6.6. It consists of a solid dielectric cylinder with radius 'a'. This cylinder is called as **core** of

fiber. The core is surrounded by dielectric, called **cladding**. The index of refraction of core (glass fiber) is slightly greater than the index of refraction of cladding. □

If refractive index of core (glass fiber) = n_1
and refractive index of cladding = n_2
then $n_1 > n_2$.

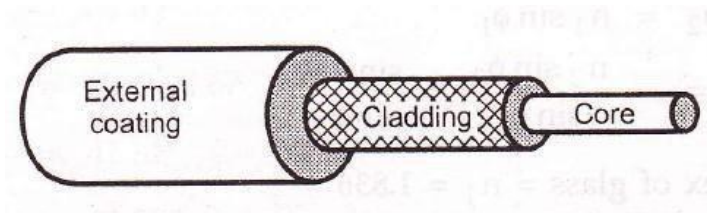


Fig.1.6.6.
Single

optical Fibre Structure

Propagation in Optical Fiber. (BTL 2)

- To understand the general nature of light wave propagation in optical fiber. We first consider the construction of optical fiber. The innermost is the glass core of very thin diameter with a slight lower refractive index n_2 . The light wave can propagate along such a optical fiber. A single mode propagation is

illustrated in Fig. 1.6.7 along with standard

size of fiber. □

Single mode fibers are capable of carrying only one signal of a specific wavelength. □

□

□

- In multimode propagation the light propagates along the fiber in zigzag fashion, provided it can undergo total internal reflection (TIR) at the core cladding boundaries. □
- Total internal reflection at the fiber wall can occur only if two conditions are satisfied. □

Condition 1:

The index of refraction of glass fiber must be slightly greater than the index of refraction of material surrounding the fiber (cladding).

If refractive index of glass fiber = n_1
and refractive index of cladding = n_2
then $n_1 > n_2$.

Condition 2 :

The angle of incidence (θ_1) of light ray must be greater than critical angle (θ_c).

- A light beam is focused at one end of cable. The light enters the fibers at different angles.
 \square Fig. 1.6.8 shows the conditions exist at the launching end of optic fiber. The light source is surrounded by air and the refractive index of air is $n_0 = 1$. Let the incident ray makes an angle θ_0 with fiber axis. The ray enters into glass fiber at point P making refracted angle θ_1 to the fiber axis, the ray is then propagated diagonally down the core and reflect from the core wall at point Q. When the light ray reflects off the inner surface, the angle of incidence is equal to the angle of reflection, which is greater than critical angle.
 \square
- In order for a ray of light to propagate down the cable, it must strike the core cladding interface at an angle that is greater than critical angle (θ_c).
 \square

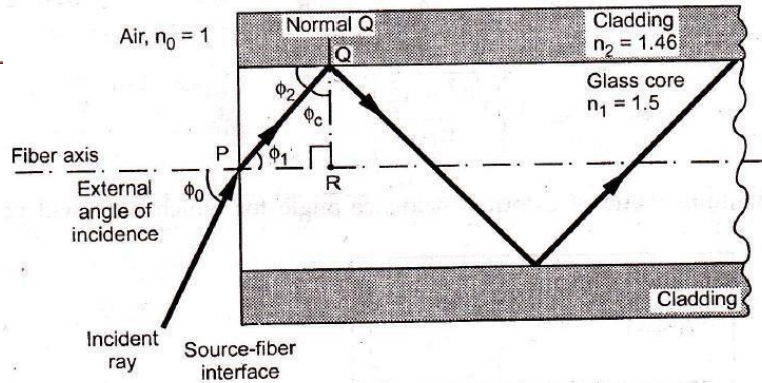


Fig. 1.6.8 Ray propagation by TIR

Derive acceptance Angle ? (BTL 1)

Applying Snell's law to external incidence angle.

$$n_0 \sin \Phi_0 = n_1 \sin \Phi_1$$

But $\Phi_1 = (90 - \Phi_c)$

$$\sin \Phi_1 = \sin (90 - \Phi_c) = \cos \Phi_c$$

Substituting $\sin \Phi_1$ in above equation.

$$n_0 \sin \Phi_0 = n_1 \cos \Phi_c$$

$$\sin \Phi_c = \frac{n_1}{n_0} \cos \Phi_c$$

Applying Pythagorean theorem to ΔPQR .

The maximum value of external incidence angle for which light will propagate in the fiber.

$$\phi_{0(\max)} = \sin^{-1} \left[\frac{\sqrt{n_1^2 - n_2^2}}{n_0} \right]$$

When the light rays enters the fibers from an air medium $n_0 = 1$. Then above equation reduces to,

$$\phi_{0(\max)} = \sin^{-1} \left(\sqrt{n_1^2 - n_2^2} \right)$$

The angle ϕ_0 is called as

acceptance angle and $\phi_{0(\max)}$ defines the maximum angle in which the light ray may incident on fiber to propagate down the fiber.

What is Acceptance Cone? (BTL 2)

- Rotating the acceptance angle $\phi_{0(\max)}$ around the fiber axis, a cone shaped pattern is obtained, it is called as **acceptance cone** of the fiber input. Fig 1.6.10 shows formation of acceptance cone of a fiber cable.

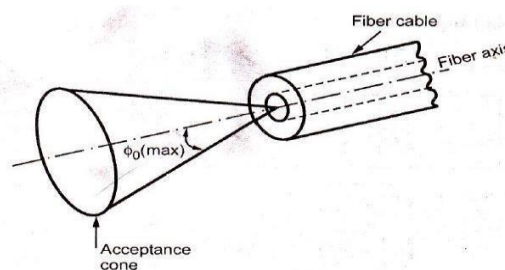


FIG: 1
acceptance cone of a

shows formation of
fiber cable.

- The Cone of acceptance is the angle within which the light is accepted into the core and can travel along the fiber. The launching of light wave becomes easier for large acceptance come.□
- The angle is measured from the axis of the positive cone so the total angle of convergence is actually twice the stated value.

Derive Numerical Aperture (NA) (BTL 1)

- The **numerical aperture** (NA) of a fiber is a figure of merit which represents its light gathering capability. Larger the numerical aperture, the greater the amount of light accepted by fiber. The acceptance angle also determines how much light can be enter the fiber and hence there is relation between the numerical aperture and the cone of acceptance.

$$\text{Numerical aperture (NA)} = \sin \theta_{0(\max)}$$

$$\text{NA} = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$$

For air no = 1

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

$$\text{NA} = \sqrt{n_{\text{core}}^2 - n_{\text{cladding}}^2}$$

...

$$\text{Hence acceptance angle} = \sin^{-1} \text{NA}$$

By the formula of NA note that the numerical aperture is effectively dependent only on refractive indices of core and cladding material. NA is not a function of fiber dimension.

- The index difference (Δ) and the numerical aperture (NA) are related to the

core and cladding indices:

$$\Delta = \frac{(n_1 - n_2)}{n_1}$$

$$\Delta = \frac{\text{NA}^2}{2n_1^2}$$

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

Example 1.6.5 : Calculate the numerical aperture and acceptance angle for a fiber cable of which $n_{\text{core}} = 1.5$ and $n_{\text{cladding}} = 1.48$. The launching takes place from air.

Solution :

$$NA = (n_1^2 - n_2^2)^{1/2}$$

$$NA = \sqrt{n_{\text{core}}^2 - n_{\text{cladding}}^2}$$

$$NA = n_1 (2\Delta)^{1/2}$$

$$NA = \sqrt{1.5^2 - 1.48^2}$$

Acceptance angle –

$$\sin^{-1} \sqrt{n_{\text{core}}^2 - n_{\text{cladding}}^2} = \sin^{-1} NA$$

$$\text{Acceptance angle} = \sin^{-1} 0.244$$

$$= 14.12^\circ$$

Explain different types of Rays. (BTL 2)

- If the rays are launched within core of acceptance can be successfully propagated along the fiber. But the exact path of the ray is determined by the

position and angle of ray at which it strikes the core.

There exists three different types of rays.

i) Skew rays

ii) Meridional rays

iii) Axial rays.

- **The skew rays** does not pass through the center, as show in Fig. 1.6.11 (a). The skew rays reflects off from the core cladding boundaries and again bounces around the outside of the core. It takes somewhat similar shape of spiral or helical path. □

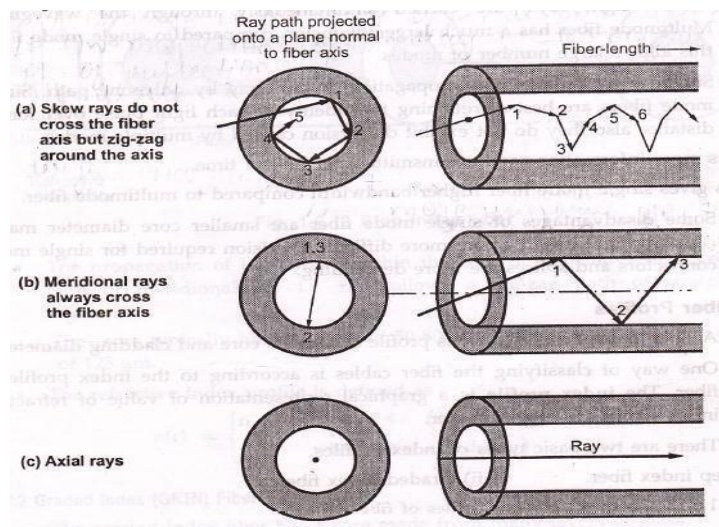


Fig:2

Different Ray
Propagation

- The **meridional** ray enters the core and passes through its axis. When the core surface is parallel, it will always be reflected to pass through the enter. The meridional ray is shown in fig.
- The **axial ray** travels along the axis of the fiber and stays at the axis all the time.

Different modes of Fiber.(BTL 2)

- Fiber cables can also be classified as per their mode. Light rays propagate as an electromagnetic wave along the fiber. The two components, the electric field and the magnetic field form patterns

across the fiber. These patterns are called **modes** of transmission. The **mode** of a fiber refers to the number of paths for the light rays within the cable. According to modes optic fibers can

□ be classified into two types.

i) Single mode fiber ii) Multimode fiber.

- Multimode fiber was the first fiber type to be manufactured and commercialized. The term multimode simply refers to the fact that numerous modes (light rays) are carried simultaneously through the waveguide. Multimode fiber has a much larger diameter, compared to single mode fiber, this allows large number of modes.
- Single mode fiber allows propagation to light ray by only one path. Single mode fibers are best at retaining the fidelity of each light pulse over longer distance also they do not exhibit dispersion caused by multiple modes.

Thus more information can be transmitted per unit of time.

This gives single mode fiber higher bandwidth compared to multimode fiber.

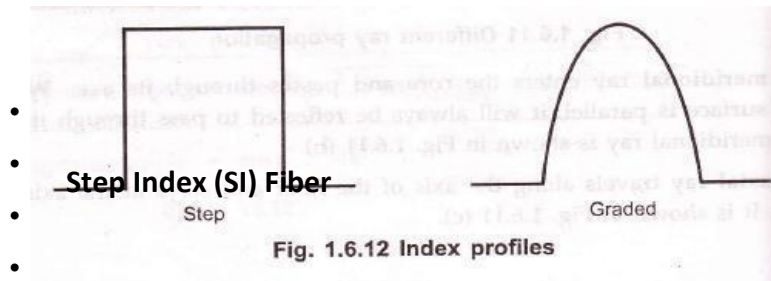
- Some disadvantages of single mode fiber are smaller core diameter makes coupling light into the core more difficult. Precision required for single mode connectors and splices are more demanding.

Explain Fiber Profiles (BTL 2)

- A fiber is characterized by its profile and by its core and cladding diameters.
- One way of classifying the fiber cables is according to the index profile at fiber. The **index profile** is a graphical representation of value of refractive index across the core diameter.
- There are two basic types of index profiles.

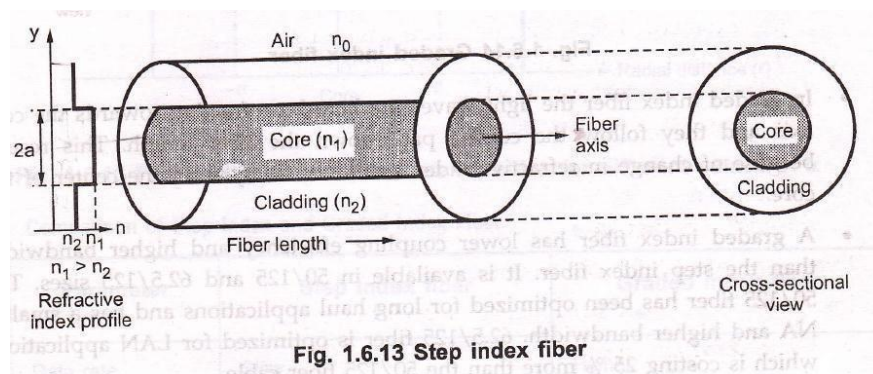
i) Step index fiber. ii) Graded index fiber.

Fig. shows the index profiles of fibers.



- The step index (SI) fiber is a cylindrical waveguide core with central or inner core has a uniform refractive index of n_1 and the core is surrounded by outer cladding with uniform refractive index of n_2 . The cladding refractive index

(n_2) is less than the core refractive index (n_1). But there is an abrupt change in the refractive index at the core cladding interface. Refractive index profile of step indexed optical fiber is shown in Fig. 1.6.13. The refractive index is plotted on horizontal axis and radial distance from the core is plotted on vertical axis.□



- The propagation of light wave within the core of step index fiber takes the path of meridional ray i.e. ray follows a zig-zag path of straight line segments. □

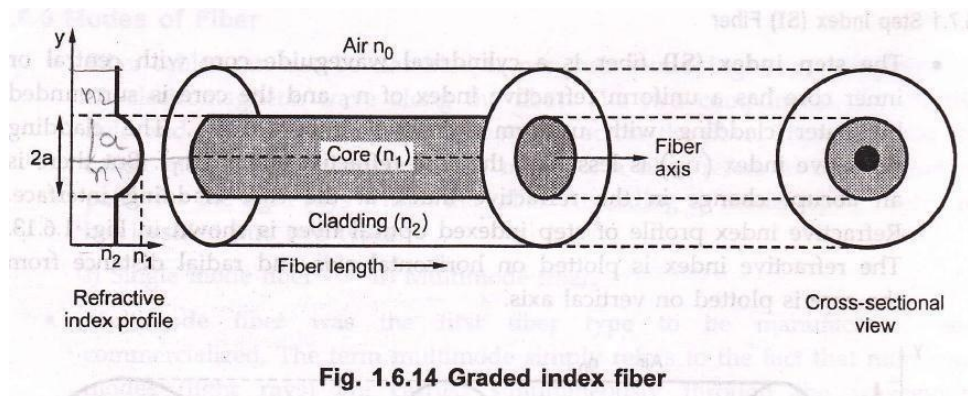
The core typically has diameter of 50-80 μm and the cladding has a diameter of 125 μm .

- The refractive index profile is defined as –

$$n(r) = \begin{cases} n_1 & \text{when } r < a \text{ (core)} \\ n_2 & \text{when } r \geq a \text{ (cladding)} \end{cases}$$

Graded Index (GRIN) Fiber (BTL 2)

- The graded index fiber has a core made from many layers of glass. □
- In the **graded index (GRIN)** fiber the refractive index is not uniform within the core, it is highest at the center and decreases smoothly and continuously with distance towards the cladding. The refractive index profile across the core takes the parabolic nature. Fig. 1.6.14 shows refractive index profile of graded index fiber.



- In graded index fiber the light waves are bent by refraction towards the core axis and they follow the curved path down the fiber length. This results because of change in refractive index as moved away from the center of the core.
- A graded index fiber has lower coupling efficiency and higher bandwidth than the step index fiber. It is available in 50/125 and 62.5/125 sizes. The 50/125 fiber has been optimized for long haul

applications and has a smaller NA and higher bandwidth. 62.5/125 fiber is optimized for LAN applications

which is costing 25% more than the 50/125 fiber cable.

- The refractive index variation in the core is given by relationship

where,

$$n(r) = \begin{cases} n_1 \left(1 - 2\Delta \left(\frac{r}{a} \right)^\alpha \right) & \text{when } r < a \text{ (core)} \\ n_1 (1 - 2\Delta)^{\frac{1}{\alpha}} \approx n_2 & \text{when } r \geq a \text{ (cladding)} \end{cases}$$

r = Radial distance

from
fiber axis

a = Core radius n_1 =

Refractive index of core

n_2 = Refractive index of

cladding

α = Shape of index profile.

- Profile parameter α determines the characteristic refractive index profile of fiber core. The range of refractive index as variation of α is shown in Fig.

1.6.15

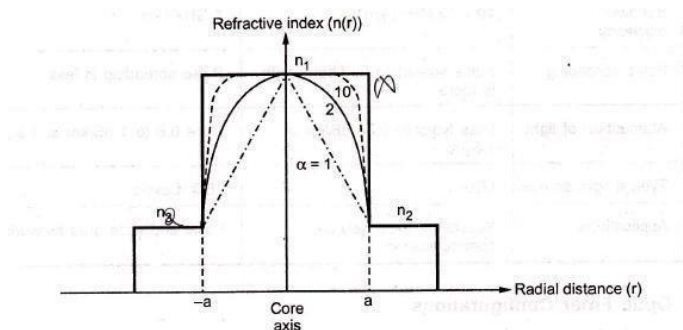


Fig. 1.6.15 Possible fiber refractive index profiles for different values of α

Comparison of Step Index and Graded Index Fiber (BTL 2)

Sr. No.	Parameter	Step index fiber	Graded index fiber
1.	Data rate	Slow.	Higher
2.	Coupling efficiency	Coupling efficiency with fiber is higher.	Lower coupling efficiency.
3.	Ray path	By total internal reflection.	Light travelled oscillatory fashion.
4.	Index variation		
5.	Numerical aperture	NA remains same.	Changes continuously distance from fiber axis.
6.	Material used	Normally plastic or glass is preferred.	Only glass is preferred.
7.	Bandwidth efficiency	10 – 20 MHz/km	1 GHz/km
8.	Pulse spreading	Pulse spreading by fiber length is more.	Pulse spreading is less
9.	Attenuation of light	Less typically 0.34 dB/km at 1.3 μm .	More 0.6 to 1 dB/km at 1.3 μm .
10	Typical light source	LED.	LED, Lasers.

	Applications	Subscriber local network communication.	networks.
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Different types of Optic Fiber Configurations.(BTL 2)

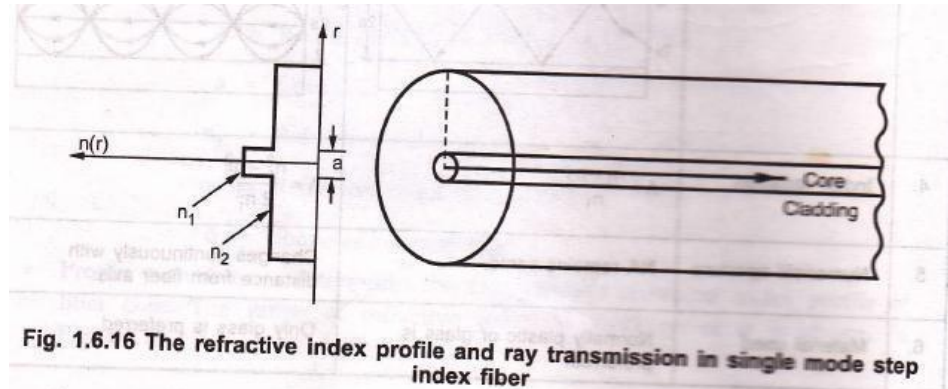
Depending on the refractive index profile of fiber and modes of fiber there exist three types of optical fiber configurations. These optic-fiber configurations are

- i) Single mode step index fiber.
- ii) Multimode step index fiber.
- iii) Multimode graded index fiber.

Single mode Step index Fiber (BTL 2)

- In single mode step index fiber has a central core that is sufficiently small so that there is essentially only one path for light ray through the cable. The light ray is propagated in the fiber through reflection. Typical core sizes are 2 to 15 μm . Single mode fiber is also known as fundamental or monomode fiber.

Fig. 1.6.16 shows single mode fiber.



- Single mode fiber will permit only one mode to propagate and does not suffer from mode delay differences. These are primarily developed for the 1300 nm window but they can be also be used effectively with time division multiplex (TDM) and wavelength division multiplex (WDM) systems operating in 1550 nm wavelength region.
- The core fiber of a single mode fiber is very narrow compared to the wavelength of light being used. Therefore, only a single path exists through the cable core through which light can travel. Usually, 20 percent of the light
in a single mode cable

travels down the cladding and the effective diameter of the cable is a blend of single mode core and degree to which the cladding carries light. This is referred to as the 'mode field diameter', which is larger than physical diameter of the core depending on the refractive indices of the core and cladding.

- The disadvantage of this type of cable is that because of extremely small size interconnection of cables and interfacing with source is difficult. Another disadvantage of single mode fibers is that as the refractive index of glass decreases with optical wavelength, the light velocity will also be wavelength dependent. Thus the light from an optical transmitter will have definite spectral width.

Multimode step Index Fiber

- **Multimode step index fiber** is more widely used type. It is easy to manufacture. Its core diameter is 50 to 1000 μm i.e. large aperture and allows more light to enter the cable. The light rays are propagated down the core in zig-zag manner. There are many many paths that a light ray may follow during the propagation.□
- The light ray is propagated using the principle of total internal reflection (TIR). Since the core index of refraction is higher than the cladding index of

refraction, the light enters at less than critical angle is guided along the fiber.

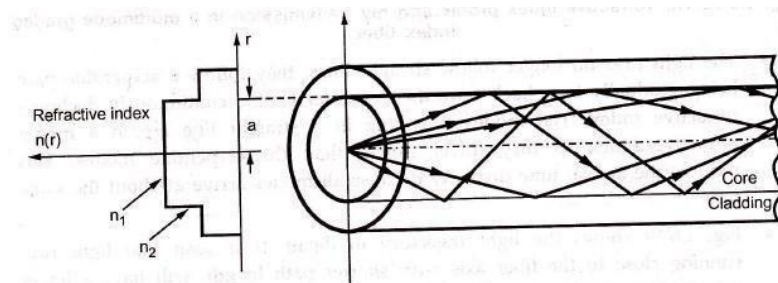


Fig. 1.6.17 TIR in multimode step index fiber

- Light rays passing through the fiber are continuously reflected off the glass cladding towards the center of the core at different angles and lengths, limiting overall bandwidth.
- The disadvantage of multimode step index fibers is that the different optical lengths caused by various angles at which light is propagated relative to the core, causes the

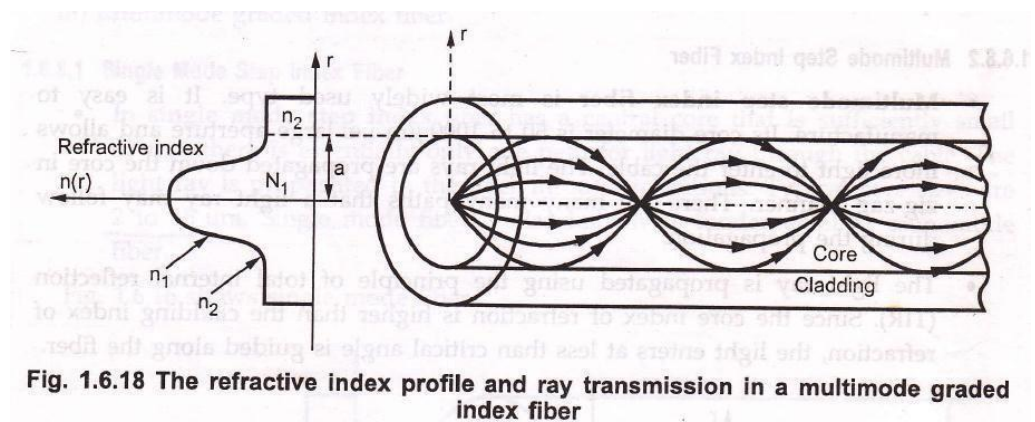
transmission bandwidth to be small. Because of these limitations, multimode step index fiber is typically only used in applications requiring distances of less than 1 km.

Multimode Graded Index Fiber

The core size of **multimode graded index fiber** cable is varying from 50 to 100 μm range. The light ray is propagated through the refraction. The light ray enters the fiber at

many different angles. As the light propagates across the core toward the center it is intersecting a less dense to more dense medium. Therefore the light rays are being constantly being refracted and ray is bending continuously. This cable is mostly used for long distance communication.

Fig 1.6.18 shows multimode graded index fiber.



- The light rays no longer follow straight lines, they follow a serpentine path being gradually bent back towards the center by the continuously declining refractive index. The modes travelling in a straight line are in a higher refractive index so they travel slower than the serpentine modes. This reduces the arrival time disparity because all modes arrive at about the same time.

□

- Fig 1.6.19 shows the light trajectory in detail. It is seen that light rays running close to the fiber axis with shorter path length, will have a lower velocity

because they pass through a region with a high refractive index.

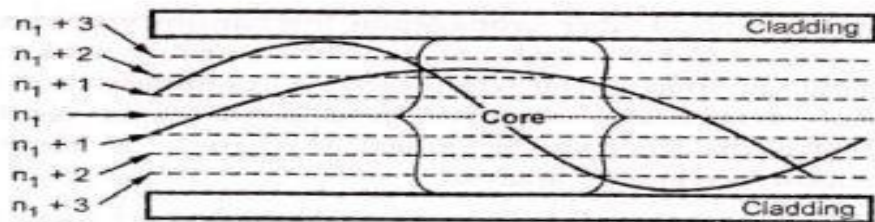


Fig. 1.6.19 Light trajectories in a graded index fiber

Rays on
core edges

offers reduced refractive index, hence travel more faster than axial rays and cause the light components to take same amount of time to travel the length of fiber, thus minimizing dispersion losses. Each path at a

different angle is termed as

‘transmission mode’ and the NA of graded index fiber is defined as the maximum value of acceptance angle at the fiber axis.

Typical attenuation coefficients of graded index fibers at 850 nm are 2.5 to 3 dB/km, while at 1300 nm they are 1.0 to 1.5 dB/km.

The main advantages of graded index fiber are:1.

Reduced refractive index at the center of core.

2. Comparatively cheap to produce

2.1 Attenuation

- Attenuation is a measure of decay of signal strength or loss of light power that occurs as light pulses propagate through the length of the fiber.
- In optical fibers the attenuation is mainly caused by two physical factors absorption and scattering losses. Absorption is because of fiber material and scattering due to structural imperfection within the fiber. Nearly 90 % of total attenuation is caused by Rayleigh scattering only. Micro bending of optical fiber also contributes to the attenuation of signal.

- The rate at which light is absorbed is dependent on the wavelength of the light and the characteristics of glass. Glass is a silicon compound, by adding different additional chemicals to the basic silicon dioxide the optical properties of the glass can be changed.
- The Rayleigh scattering is wavelength dependent and reduces rapidly as the wavelength of the incident radiation increases.
- The attenuation of fiber is governed by the materials from which it is fabricated, the manufacturing process and the refractive index profile chosen. Attenuation loss is measured in dB/km.

Derive Attenuation Units (BTL 1)

- As attenuation leads to a loss of power along the fiber, the output power is significantly less than the couples power. Let the couples optical power is $p(0)$ i.e. at origin ($z = 0$).

Then the power at distance z is given by,

$$P(z) = P(0)e^{-\alpha_p z} \quad \dots (2.1.1)$$

where, α_p is fiber attenuation constant (per km).

$$\alpha_p = \frac{1}{z} \ln \left[\frac{P(0)}{P(z)} \right]$$

$$\alpha_{dB/km} = 10 \cdot \frac{1}{z} \log \left[\frac{P(0)}{P(z)} \right]$$

$$\alpha_{dB/km} = 4.343 \alpha_p \text{ per km}$$

This parameter is known as fiber loss or fiber attenuation.

- Attenuation is also a function of wavelength. Optical fiber wavelength as a function of wavelength is shown in Fig. 2.1.1.

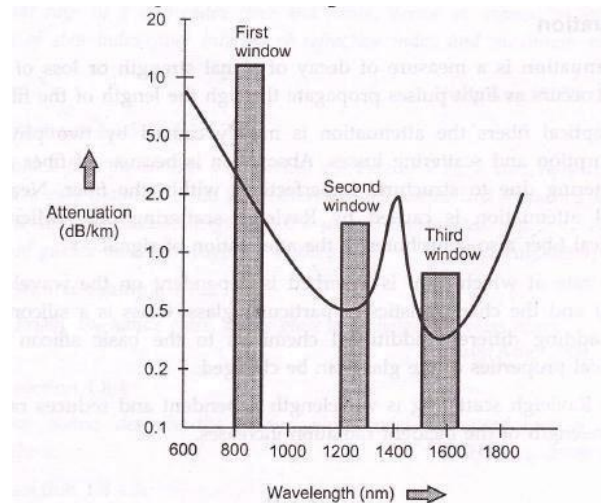


Fig. 2.1.1 Fiber attenuation as a function of wavelength

Determine –

Overall signal attenuation in dB.

The overall signal attenuation for a 10 km optical link using the same fiber with splices at 1 km intervals, each giving an attenuation of 1 dB.

Solution : Given : $z = 8 \text{ km}$

$$P(0) = 120 \mu\text{W}$$

$$P(z) = 3 \mu\text{W}$$

1) Overall attenuation is given by,

$$\alpha = 10 \cdot \log \left[\frac{P(0)}{P(z)} \right]$$

$$\alpha = 10 \cdot \log \left[\frac{120}{3} \right]$$

$$\alpha = 16.02 \text{ dB}$$

2) Overall attenuation for 10 km,

$$\alpha_{dB} = \frac{16.02}{z} = \frac{16.02}{8} = 2.00 \text{ dB/km}$$

Attenuation per km

$$\text{Attenuation in 10 km link} = 2.00 \times 10 = 20 \text{ dB}$$

In 10 km link there will be 9 splices at 1 km interval. Each splice introducing attenuation of 1 dB.

$$\text{Total attenuation} = 20 \text{ dB} + 9 \text{ dB} = \mathbf{29 \text{ dB}}$$

Absorption

- Absorption loss is related to the material composition and fabrication process of fiber. Absorption loss results in dissipation of some optical power as heat in the fiber cable. Although glass fibers are extremely pure, some impurities remain as residue after purification. The amount of absorption by these impurities depends on their concentration and light wavelength.
- Absorption is caused by three different mechanisms. Absorption by atomic defects in glass composition.

Extrinsic absorption by impurity atoms in glass matrix.

Intrinsic absorption by basic constituent atom of fiber.

Explanation Absorption by Atomic Defects. (BTL 2)

- Atomic defects are imperfections in the atomic structure of the fiber materials such as missing molecules, high density clusters of atom groups. These absorption losses are negligible compared with intrinsic and extrinsic losses.

□

- The absorption effect is most significant when fiber is exposed to ionizing radiation in nuclear reactor, medical therapies, space missions etc. The radiation damages the internal structure of fiber. The damages are proportional to the intensity of ionizing particles. This results in increasing attenuation due to atomic defects and absorbing optical energy. The total dose a material receives is expressed in rad (Si), this is the unit for measuring radiation absorbed in bulk silicon. □

$$1 \text{ rad (Si)} = 0.01 \text{ J.kg}$$

The higher the radiation intensity more the attenuation as shown in Fig 2.2.1.

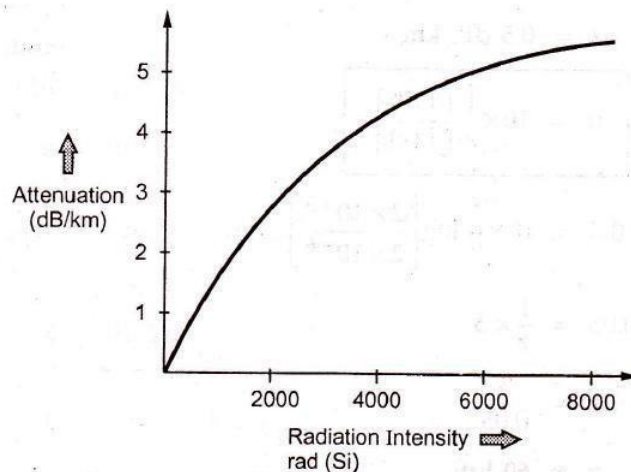


Fig. 2.2.1 Ionizing radiation intensity Vs fiber attenuation

Explain Extrinsic Absorption? (BTL 2)

- Extrinsic absorption occurs due to electronic transitions between the energy level and because of charge transitions from one ion to another. A major source of attenuation is

from transition of metal impurity ions such as iron, chromium, cobalt and copper. These losses can be upto 1 to 10 dB/km. The effect of metallic impurities can be reduced by glass refining techniques.

- Another major extrinsic loss is caused by absorption due to **OH (Hydroxyl)** ions impurities dissolved in glass. Vibrations occur at wavelengths between 2.7 and 4.2 μm .

The absorption peaks occurs at 1400, 950 and 750 nm. These are first, second and third overtones respectively. □

□

- Fig. 2.2.2 shows absorption spectrum for OH group in silica. Between these absorption peaks there are regions of low attenuation. □

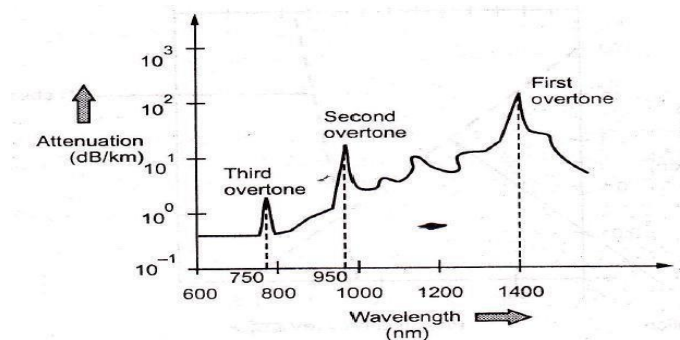


Fig. 2.2.2 Absorption spectra for OH group

Explain Intrinsic Absorption? (BTL 2)

- Intrinsic absorption occurs when material is in pure state, no density variation and inhomogeneities. Thus, intrinsic absorption sets the fundamental lower limit on absorption for any material.
- Intrinsic absorption results from electronic absorption bands in UV region and from atomic vibration bands in the near infrared region.
- The electronic absorption bands are associated with the band gaps of amorphous glass materials. Absorption occurs when a photon interacts with an electron in the valence band and excites it to a higher energy level. UV absorption decays exponentially with increasing wavelength (λ).
- In the IR (infrared) region above $1.2 \mu\text{m}$ the optical waveguide loss is determined by presence of the OH ions and inherent IR absorption of the constituent materials. The inherent IR absorption is due to interaction between the vibrating band and the electromagnetic field of optical signal this results in transfer of energy from field to the band, thereby giving rise to absorption, this absorption is strong because of many bonds present in the fiber.

The ultraviolet loss at any wavelength is expressed as,

$$\alpha_{uv} = \frac{154.2}{46.6 \times +60} \times 10^{-2} \times e^{\left(\frac{4.65}{\lambda}\right)} \quad \dots (2.2.1)$$

where, x is mole fraction of GeO_2 .

λ is operating
wavelength. α_{uv} is in
dB/km.

□□ The loss in infrared (IR) region (above $1.2 \mu\text{m}$) is given by expression :□

$$\alpha_{\text{IR}} = 7.81 \times 10^{11} \times e^{\left(\frac{-48.48}{\lambda}\right)} \quad \dots (2.2.2)$$

The expression is derived for GeO_2 - SiO_2 glass fiber.

2.3 Rayleigh Scattering Losses

Scattering losses exists in optical fibers because of microscopic variations in the material□ density and composition. As glass is composed by randomly connected network of molecules and several oxides (e.g. SiO_2 , GeO_2 and P_2O_5), these are the major cause of compositional structure fluctuation. These two effects results to variation in refractive index and Rayleigh type scattering of light.

Rayleigh scattering of light is due to small localized changes in the refractive index of the core and cladding material. There are two causes during the manufacturing of fiber.□

The first is due to slight fluctuation in mixing of ingredients. The random changes because of this are impossible to eliminate completely.

The other cause is slight change in density as the silica cools and solidifies. When light ray strikes such zones, it gets scattered in all directions. The amount of scatter depends on the size of the discontinuity compared with the wavelength of the light so the shortest wavelength (highest frequency) suffers most scattering. Fig. 2.3.1 shows graphically the

relationship between wavelength and Rayleigh scattering loss.

Scattering loss for component glass is

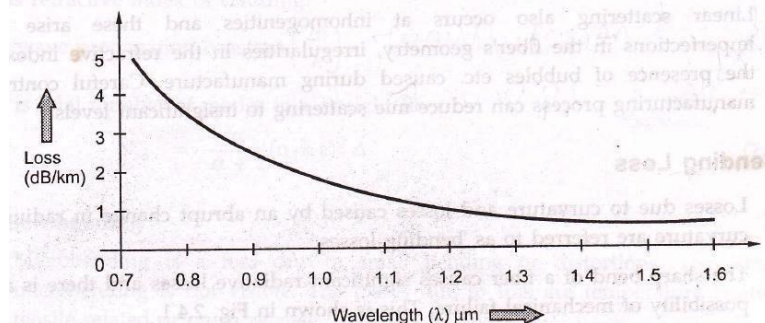


Fig. 2.3.1 Scattering loss

$$\alpha_{\text{scat}} = \frac{8\pi^3}{3\lambda^4} (n^2 - 1)^2 k_B T_f \beta_T \text{ nepers}$$

single given by,

... (2.3.1)

where, n = Refractive index

k_B = Boltzmann's constant

β_T = Isothermal compressibility of material

T_f = Temperature at which density fluctuations are frozen into the glass as it solidifies (fictive temperature)

Another form of

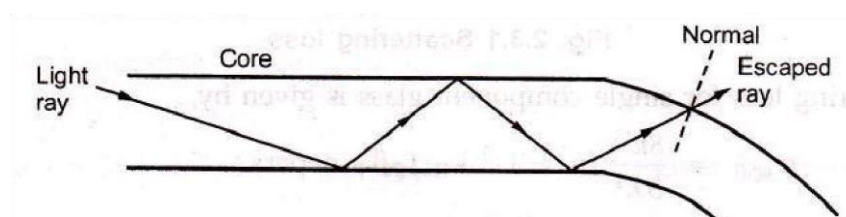
equation is

$$\alpha_{\text{scat}} = \frac{8\pi^3}{3\lambda^4} n^8 P^2 k_B T_f \beta_T \text{ neper} \quad \alpha_{\text{scat}} = \frac{8\pi^3}{3\lambda^4} (\delta_n^2)^2 \delta v$$

... (2.3.2)

where, P = Photoelastic coefficient

where, δ_n^2 = Mean square refractive index fluctuation



δv = Volume of fiber

- Multimode fibers have higher dopant concentrations and greater compositional

- fluctuations. The overall losses in this fibers are more as compared to single mode fibers. □ **Mie Scattering :**

- - Linear scattering also occurs at inhomogenities and these arise from imperfections in the fiber's geometry, irregularities in the refractive index and the presence of bubbles etc. caused during manufacture. Careful control of manufacturing process can reduce mie scattering to insignificant levels.

2.4 Bending Loss

- - Losses due to curvature and losses caused by an abrupt change in radius of curvature are referred to as 'bending losses.'
 - The sharp bend of a fiber causes significant radiative losses and there is also possibility of mechanical failure. This is shown in Fig. 2.4.1.

As the core bends the normal will follow it and the ray will now find itself on the wrong side of critical angle and will escape. The sharp bends are therefore avoided.

The radiation loss from a bent fiber depends on Field strength of certain critical distance x_c from fiber axis where power is lost through radiation.

The radius of curvature R .

The higher order modes are less tightly bound to the fiber core, the higher order modes radiate out of fiber firstly.

5 For multimode fiber, the effective number of modes that can be guided by curved fiber is

where, α is graded index profile.

□ is core – cladding index

difference. n_2 is refractive index of

cladding. k is

wave propagation constant $\left(\frac{2\pi}{\lambda}\right)$.

N_{∞} is total number of modes in a straight fiber.

$$N_{\infty} = \frac{\alpha}{\alpha+2} (n_1 k a)^2 \Delta \quad \dots (2.4.2)$$

Explain Microbending? (BTL 2)

- Micro bending is a loss due to small bending or distortions. This small micro bending is not visible. The losses due to this are temperature related, tensile related or crush related. □
- The effects of micro bending on multimode fiber can result in increasing attenuation (depending on wavelength) to a series of periodic peaks and troughs on the spectral attenuation curve. These effects can be minimized during installation and testing.

Macrobending

- The change in spectral attenuation caused by macrobending is different to microbending. Usually there are no peaks and troughs because in a macrobending no light is coupled back into the core from the cladding as can happen in the case of microbends.

□

-
- The macrobending losses are caused by large scale bending of fiber. The losses are eliminated when the bends are straightened. The losses can be minimized by not exceeding the long-term bend radii. Fig. 2.4.3 illustrates macrobending.

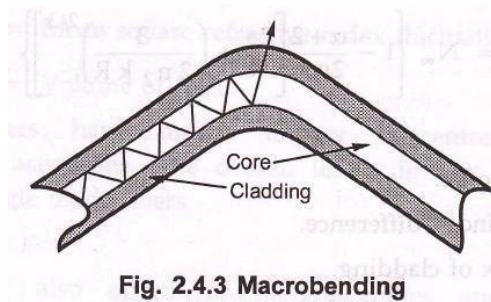


Fig. 2.4.3 Macrobending

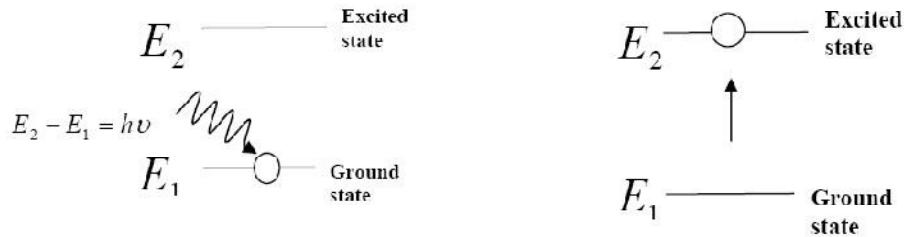
Ch.2 Lasers

LASER stands for light Amplification by Stimulated Emission of Radiation. The theoretical basis for the development of laser was provided by Albert Einstein in 1917. In 1960, the first laser device was developed by T.H. Maimann.

1. Definitions. (BTL 1.)

Stimulated absorption (or) Absorption

Let E_1 and E_2 be the energies of ground and excited states of an atom. Suppose, if a photon of energy $E_2 - E_1 = h\nu$ interacts with an atom present in the ground state, the atom gets excitation from ground state E_1 to excited state E_2 . This process is called stimulated absorption.

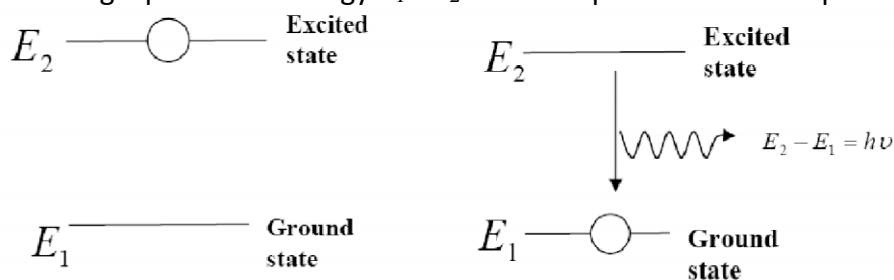


Stimulated absorption rate depends upon the number of atoms available in the lowest energy state as well as the energy density photons.

Stimulated absorption rate = $\frac{\text{number of atoms in the ground state}}{\text{Density of photons}}$

Spontaneous emission

Spontaneous emission was postulated by Bohr. Let E_1 and E_2 be the energies of ground and excited states of an atom. Suppose, if a photon of energy $E_2 - E_1 = h\nu$ interacts with an atom present in the ground state, the atom gets excitation from ground state E_1 to excited state E_2 . The excited atom does not stay in a long time in the excited state. The excited atom gets de-excitation after its life time by emitting a photon of energy $E_2 - E_1 = h\nu$. This process is called spontaneous emission.

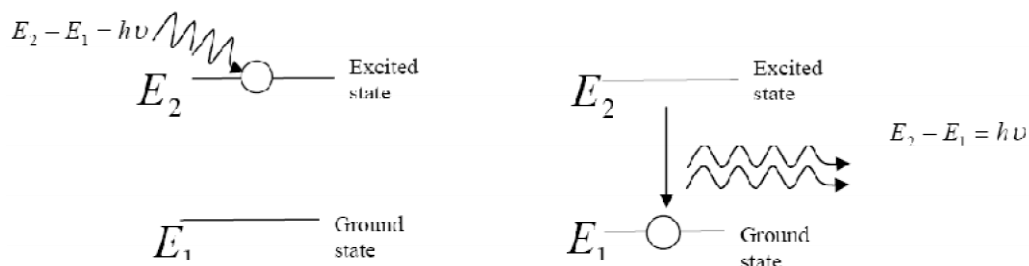


The spontaneous emission rate depends up on the number of atoms present in the excited state.

Spontaneous emission rate = $\frac{\text{number of atoms in the excited state}}{\text{Density of photons}}$

Stimulated emission

Stimulated emission was postulated by Einstein. Let E_1 and E_2 be the energies of ground and excited states of an atom. Suppose, if a photon of energy $E_2 - E_1 = h\nu$ interacts with an atom present in the ground state, the atom gets excitation from ground state E_1 to excited state E_2 . Let, a photon of energy $E_2 - E_1 = h\nu$ interacts with the excited atom within their life time; the atom gets de-excitation to ground state by emitting of another photon. These photons have same phase and it follows coherence. This phenomenon is called stimulated emission.



Stimulated emission rate depends upon the number of atoms available in the excited state as well as the energy density of photons.

Stimulated emission rate = $\frac{\text{number of atoms in the excited state}}{\text{Density of photons}}$

Spontaneous and Stimulated emission (BTL 2)

Spontaneous emission	Stimulated emission
1. The spontaneous emission was postulated by Bohr	1. The stimulated emission was postulated by Einstein
2. Additional photons are not required in spontaneous emission	2. Additional photons are required in stimulated emission
3. One photon is emitted in spontaneous emission	3. Two photons are emitted in stimulated emission
4. The emitted radiation is polychromatic	4. The emitted radiation is monochromatic
5. The emitted radiation is Incoherent	5. The emitted radiation is Coherent
6. The emitted radiation is less intense	6. The emitted radiation is high intense
7. The emitted radiation have less directionality Example: light from sodium or mercury lamp	7. The emitted radiation have high directionality Example: light from laser source.

2. Characteristic of laser radiation. (BTL 2)

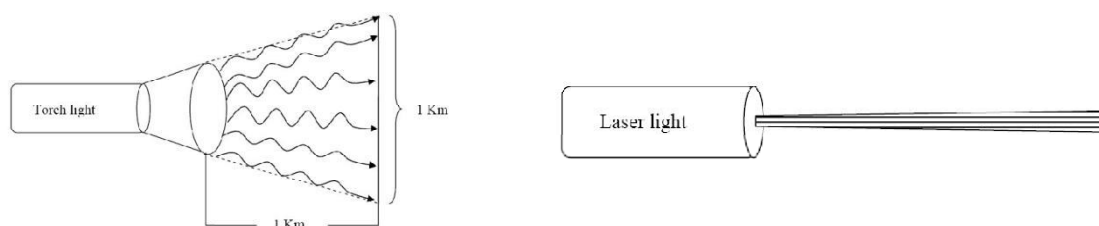
The laser light exhibits some peculiar properties than compare with the convectional light. Those are

1. Highly directionality
2. Highly monochromatic
3. Highly intense
4. Highly coherence

1. Highly directionality

The light ray coming ordinary light source travels in all directions, but laser light travels in single direction.

For example the light emitted from torch light spreads 1km distance it spreads 1 km distance. But the laser light spreads a few centimeters distance even it travels lacks of kilometer distance.

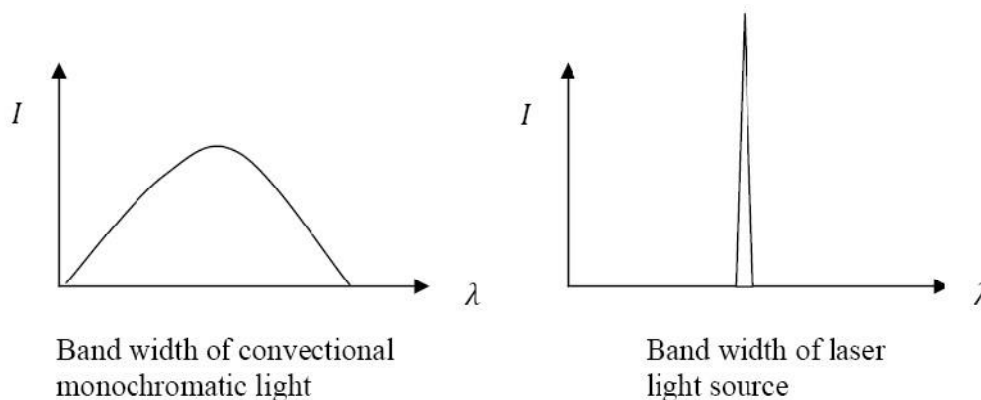


The directionality of laser beam is expressed
in terms of divergence Δ _____

Where r_1 and r_2 are the radii of laser beam spots at distances of L_1 and L_2 respectively from laser source.

2. What is Highly monochromatic? (BTL 2)

The laser light is more monochromatic than that of a conventional light source. This may be due to the stimulated characteristic of laser light. The band width of conventional monochromatic light source is 1000\AA . But the band width of ordinary light source is 10\AA . For high sensitive laser source is 10^{-5}\AA .



3. Highly intense

Laser light is highly intense than the convectional light. An one milliwatt He-Ne laser is highly intense than the sun intensity. This is because of coherence and directionality of laser. Suppose when two photons each of amplitude are in phase with other, then young's principle of superposition, the resultant amplitude of two photons is 2 and the intensity is 4 . Since in laser many number of photons are in phase with each other, the amplitude of the resulting wave becomes and hence the intensity of laser is proportional to . So 1mW He-Ne laser is highly intense than the sun.

4. Highly coherence

Definition:-

A predictable correlation of the amplitude and phase at any one point with other point is called coherence.

In case of convectional light, the property of coherence exhibits between a source and its virtual source where as in case of laser the property coherence exists between any two of more light waves.

There are two types of coherence

- i) Temporal coherence ii) Spatial coherence.

Temporal coherence (or longitudinal coherence):-

The predictable correlation of amplitude and phase at one point on the wave train w.r. t another point on the same wave train, then the wave is said to be temporal coherence

To understand this, let us consider two points P_1 and P_2 on the same wave train, which is continuous as in shown in figure (1). Suppose the phase and amplitude at any one point is known, then we can easily calculate the amplitude and phase for any other point on the same wave train by using the wave equation $\sin^2 \frac{2\pi x}{\lambda}$!

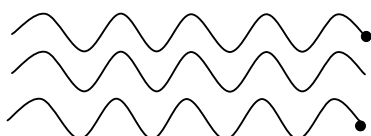
Where 'a' is the amplitude of the wave and 'x' is the displacement of the wave at any instant of time 't'.



P₂

Spatial coherence (or transverse coherence)

The predictable correlation of amplitude and phase at one point on the wave train with another point on a second wave, then the waves are said to be spatial coherence (or transverse coherence)



Two waves are said to be coherent, the waves must have

3. What is Population inversion? (BTL 2.)

Definition

The number of atoms present in the excited (or higher) state is greater than the number of atoms present in the ground state (or lower) state is called population inversion. Or
The population present in the excited (or higher) state is greater than the population present in the ground state (or lower) state is called population inversion.

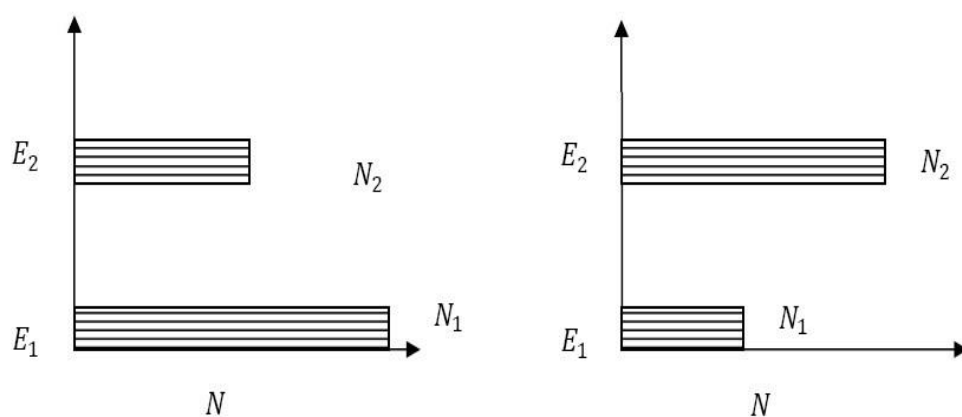
Let us consider two level energy system of energies " " and " " as shown in figure. Let N₁ and N₂ be the populations (means number of atoms per unit volume) of energy levels

According to Boltzmann's distribution the population of an energy level E, at temperature T is given by

Where N_0 is the population of the lower level or ground state and k is the Boltzmann's constant.

From the above relation, the population of energy levels

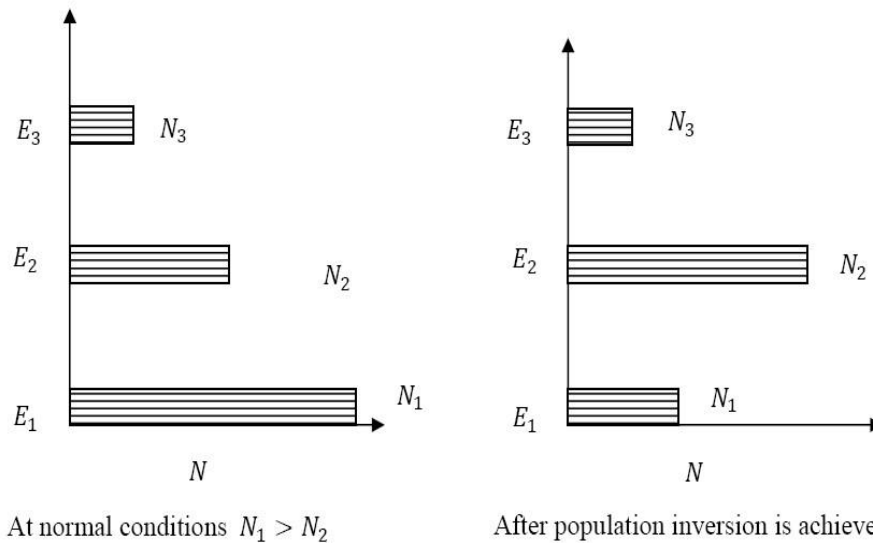
At ordinary conditions i.e., the population in the ground or lower state is always greater than the population in the excited or higher states. The stage of making, population of higher energy level is greater than the population of lower energy level is called population inversion



At normal conditions $N_1 > N_2$

After population inversion is achieved $N_2 > N_1$

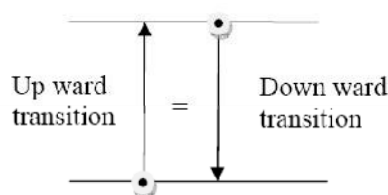
Consider a three energy level system with energies. At normal conditions,. In the ground state " the life in the intermediate state time of atom is more and the life time of atom in the excited state " the atom has more life time . But metastable state.



When a suitable energy is supplied to the system, atoms get excited into E_1 . After their lifetime the atoms are transit to E_2 . Due to more lifetime of an atom in state E_2 , the atoms stay for longer time than compare with the state E_1 . Due to the accumulation of atoms in E_2 , the population inversion is established in between the E_2 and E_1 states.

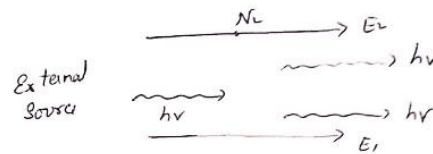
4. Einstein coefficients. (BTL 2)

Let N_1 be the number of atoms per unit volume with energy E_1 and N_2 be the number of atoms per unit volume with energy E_2 . Let ' n ' be the number of photons per unit volume at frequency ' ν ' such that $E_2 - E_1 = h\nu$. Then, the energy density of photons $\rho(\nu) = nh\nu$. When these photons interact with atoms, both upward (absorption) and downward (emission) transition occurs. At the equilibrium the upward transitions must be equal downward transitions.



Emission:

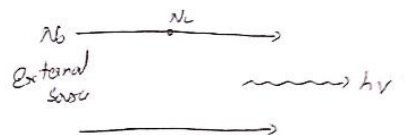
Stimulated emission



$$R_{21} \propto N_2 \nu(n)$$

$$R_{21} = B_{21} N_2 \nu(n) \quad \text{--- (1)}$$

Spontaneous Emission



$$R_{sp21} \propto N_2$$

$$R_{sp21} = A_{21} N_2 \quad \text{--- (2)}$$

Upward transition

Stimulated absorption rate depends upon the number of atoms available in the lowest energy state as well as the energy density photons.

Stimulated absorption rate $\propto N_1$

$$\propto \rho(\nu)$$

$$= B_{12} N_1 \rho(\nu)$$

Where B_{12} is the Einstein coefficient of stimulated absorption.

Downward transition (copy from running notes)

The spontaneous emission rate depends up on the number of atoms present in the excited state.

Spontaneous emission rate $\propto N_2$

$$= A_{21} N_2$$

At Equilibrium

Upward transition = Downward transition

$$R_R = R_{Lst} + R_{Lsp}$$

$$B_{12} N_1 U(\nu) = B_{21} N_2 U(\nu) + A_{21} N_2$$

$$B_{12} N_1 U(\nu) - B_{21} N_2 U(\nu) = A_{21} N_2$$

$$U(\nu) [B_{12} N_1 - N_2 B_{21}] = A_{21} N_2$$

$$U(\nu) = \frac{N_2 A_{21}}{B_{12} N_1 - N_2 B_{21}} \quad \text{--- (4)}$$

$\div R.H.S \ N_2$

$$U(\nu) = \frac{A_{21}}{\frac{B_{12} N_1}{N_2} - B_{21}}$$

$\div R.H.S \ \text{with } B_{21}$

$$U(\nu) = A_{21} / B_{21}$$

Where A_{21} is the Einstein coefficient of spontaneous emission.

Stimulated emission rate depends upon the number of atoms available in the excited state as well as the energy density of photons. Stimulated emission rate $\propto N_2$

$$\propto \rho(\nu)$$

$$\text{---} = \bar{B}_{21} N_2 \rho(\nu) \text{---} = \text{---}$$

From Maxwell Boltzmann distribution law

From Planck's law, the radiation

Comparing the two equations (2) and (3)

$$\frac{A_{21}}{B_{21}} = \frac{C}{B_{12}} = 8\pi h^3 \nu^3 \quad \text{and} \quad \frac{B_{21}}{B_{12}} = 1$$

The above relations referred to as Einstein relations

From the above equation for non degenerate energy levels the stimulated emission rate is equal to the stimulated absorption rate at the equilibrium condition.

$$B_{21} = B_{12}$$

5. Pumping mechanisms (or techniques) of population inversion

A system in which population inversion is achieved is called as an active system. The method of raising the particles from lower energy state to higher energy state is called pumping. (Or the process of achieving of population inversion is called pumping). This can be done by number of ways. The most commonly used pumping methods are

- I. Optical pumping
- II. Electrical discharge pumping
- III. Chemical pumping
- IV. Injection current pumping

Optical pumping

Optical pumping is used in solid laser. Xenon flash tubes are used for optical pumping. Since these materials have very broad band absorption, sufficient amount of energy is absorbed from the emission band of flash lamp and population inversion is created. Examples of optically pumped lasers are ruby, Nd: YAG Laser ($Y_3Al_5O_{12}$) (Neodymium: Yttrium Aluminum Garnet), Nd: Glass Laser

Electrical discharge pumping

Electrical discharge pumping is used in gas lasers. Since gas lasers have very narrow absorption band pumping them any flash lamp is not possible. Examples of Electrical discharge pumped lasers are He-Ne laser, CO₂ laser, argon-ion laser, etc

Chemical pumping

Chemical reaction may also result in excitation and hence creation of population inversion in few systems. Examples of such systems are HF and DF lasers.

Injection current pumping

In semiconductors, injection of current through the junction results in creates of population inversion among the minority charge carriers. Examples of such systems are InP and

Different Types of lasers

Based on active medium used in the laser systems, lasers are classified into several types

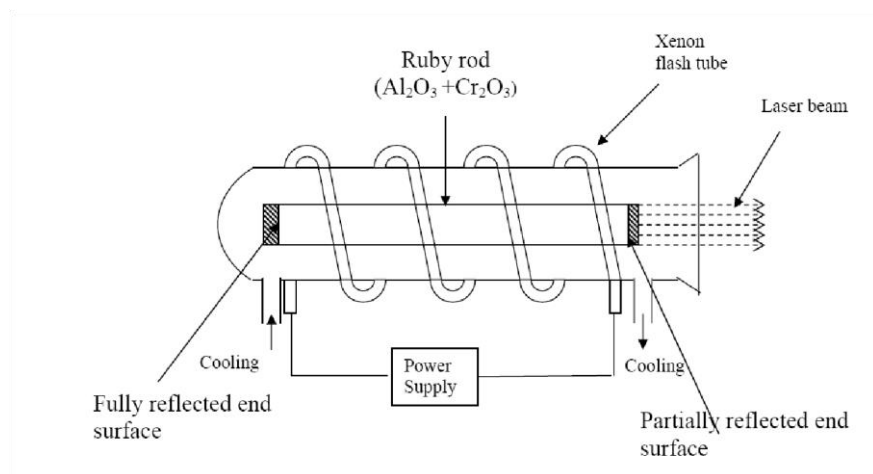
- | | |
|-------------------------|--|
| I. Solid lasers | : Ruby laser, Nd;YAG laser,
Nd;Glass |
| II. Liquid lasers | : Europium Chelate laser, SeOCl ₂ |
| III. Gas lasers | : CO ₂ , He-Ne, Argon-Ion Laser |
| IV. Dye lasers | : Rhodamine 6G |
| V. Semiconductor lasers | : InP, GaAs. |

6. Ruby laser explanation. (BTL 2)

Ruby laser is a three level solid state laser and was constructed by Mainmann in 1960. Ruby ($\text{Al}_2\text{O}_3 + \text{Cr}_2\text{O}_3$) is a crystal of Aluminium oxide, in which 0.05% of Al^{+3} ions are replaced by the Cr^{+3} ions. The colour of the rod is pink. The active medium in the ruby rod is Cr^{+3} ions.

Construction

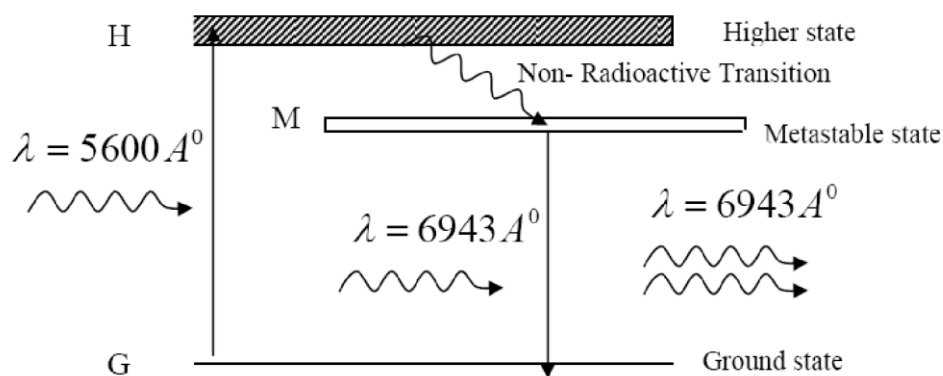
In ruby laser 4cm length and 5mm diameter rod is generally used. Both the ends of the rods are highly polished and made strictly parallel. The ends are silvered in such a way, one becomes partially reflected and the other end fully reflected. The ruby rod is surrounded by xenon flash tube, which provides the pumping light to excite the chromium ions in to upper energy levels.



Xenon flash tube emits thousands joules of energy in few milli seconds, but only a part of that energy is utilized by the chromium ions while the rest energy heats up the apparatus. A cooling arrangement is provided to keep the experimental set up at normal temperatures **Working**

The energy level diagram of chromium ions is shown in figure.

The chromium ions get excitation into higher energy levels by absorbing of 5600\AA of wave length radiation. The excited chromium ions stay in the level H for short interval of time (10^{-8} Sec). After their life time most of the chromium ions are de-excited from H to G and a few chromium ions are de-excited from H to M.



The transition between H and M is non-radioactive transition i.e. the chromium ions gives their energy to the lattice in the form of heat. In the Meta stable state the life time of chromium ions is 10^{-3} sec. The life time of chromium ions in the Meta stable state is 10^5 times greater than the life time of chromium ions in higher state.

Due to the continuous working of flash lamp, the chromium ions are excited to higher state H and returned to M level. After few milli seconds the level M is more populated than the level G and hence the desired population inversion is achieved. The state of population inversion is not a stable one. The process of spontaneous transition is very high. When the excited chromium ion passes spontaneously from H to M it emits one photon of wave length 6943\AA . The photon reflects back and forth by the silver ends and until it stimulates an excited chromium ion in M state and it to emit fresh photon in phase with the earlier photon. The process is repeated again and again until the laser beam intensity is reached to a sufficient value. When the photon beam becomes sufficient intense, it emerges through the partially silvered end of the rod. The wave length 6943\AA is in the red region of the visible spectrum.

Draw backs of ruby laser

The laser requires high pumping power

The efficiency of ruby laser is very small

It is a pulse laser **Uses o ruby**

laser

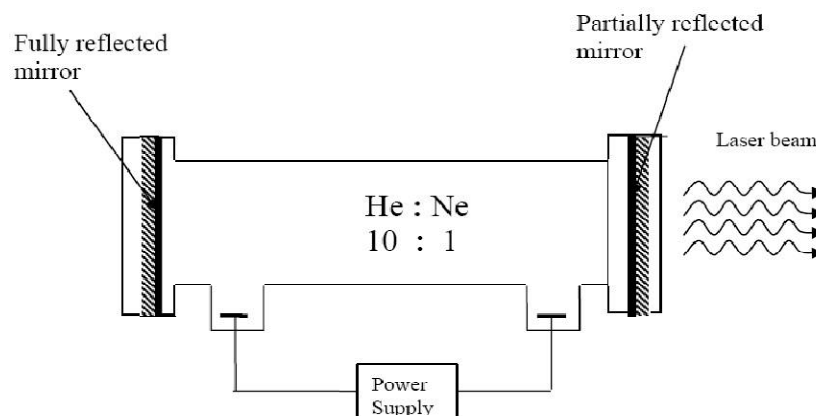
1. Ruby lasers are in optical photography
2. Ruby lasers can be used for measurement of plasma properties such as electron density and temperature.
3. Ruby lasers are used to remove the melanin of the skin.
4. Ruby laser can be used for recording of holograms.

7. He-Ne Laser explanation. (BTL 2)

Ruby laser is a pulse laser, even it have high intense out put. For continuous laser beam gas lasers are used. Using gas lasers, we can achieve highly coherence, high directionality and high monochromaticity beam. The out put power of the gas laser is generally in few milli watts. The first He-Ne gas laser was fabricated by Ali Javan and others.

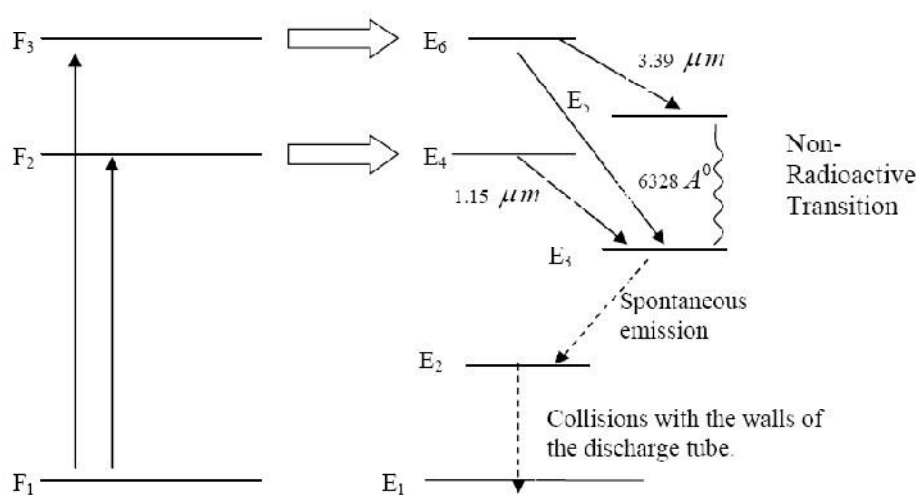
Construction

In He-Ne gas laser, the He and Ne gases are taken in the ratio 10:1 in the discharge tube. Two reflecting mirrors are fixed on either ends of the discharge tube, in that, one is partially reflecting and the other is fully reflecting. In He-Ne laser 80cm length and 1cm diameter discharge is generally used. The out power of these lasers depends on the length of the discharge tube and pressure of the gas mixture.



Working

When the electric discharge is passing through the gas mixture, the electrons accelerated towards the positive electrode. During their passage, they collide with He atoms and excite them into higher levels. F_2 and F_3 form F_1 . In higher levels F_2 and F_3 , the life time of He atoms is more. So there is a maximum possibility of energy transfer between He and Ne atoms through atomic collisions. When He atoms present in the levels F_2 and F_3 collide with Ne atoms present ground state E_1 , the Ne atoms gets excitation into higher levels E_4 and E_6 .



Due to the continuous excitation of Ne atoms, we can achieve the population inversion between the higher levels E_4 (E_6) and lower levels E_3 (E_5). The various transitions $E_6 \rightarrow E_5$, $E_4 \rightarrow E_3$ and $E_6 \rightarrow E_3$ leads to the emission of wavelengths

$3.39\mu m$, $1.15\mu m$ and 6328\AA . The first two corresponding to the infrared region while the last wavelength is corresponding to the visible region. The Ne atoms present in the E_3 level are de-excited into E_2 level, by spontaneously emitting a photon of around wavelength 6000\AA . When a narrow discharge tube is used,

the Ne atoms present in the level E_2 collide with the walls of the tube and get de-excited to ground level E_1 .

It is specifically fabricated p-n junction diode. This diode emits laser light when it is forward biased.

Principle:

When a p-n junction diode is forward biased, the electrons from n – region and the holes from the p- region cross the junction and recombine with each other.

During the recombination process, the light radiation (photons) is released from a certain specified direct band gap semiconductors like Ga-As. This light radiation is known as recombination radiation.

The photon emitted during recombination stimulates other electrons and holes to recombine. As a result, stimulated emission takes place which produces laser.

Construction:

Figure shows the basic construction of semiconductor laser. The active medium is a p-n junction diode made from the single crystal of gallium arsenide. This crystal is cut in the form of a platter having thickness of $0.5\mu\text{m}$

The platelet consists of two parts having an electron conductivity (n-type) and hole conductivity (p-type).

The photon emission is stimulated in a very thin layer of PN junction (in order of few microns). The electrical voltage is applied to the crystal through the electrode fixed on the upper surface.

The end faces of the junction diode are well polished and parallel to each other. They act as an optical resonator through which the emitted light comes out.

Working:

Figure shows the energy level diagram of semiconductor laser.

When the PN junction is forward biased with large applied voltage, the electrons and holes are injected into junction region in considerable concentration

The region around the junction contains a large amount of electrons in the conduction band and a large amount of holes in the valence band.

If the population density is high, a condition of population inversion is achieved. The electrons and holes recombine with each other and this recombination's produce radiation in the form of light.

When the forward – biased voltage is increased, more and more light photons are emitted and the light production instantly becomes stronger. These photons will trigger a chain of stimulated recombination resulting in the release of photons in phase.

The photons moving at the plane of the junction travels back and forth by reflection between two sides placed parallel and opposite to each other and grow in strength.

After gaining enough strength, it gives out the laser beam of wavelength 8400Å . The wavelength of laser light is given by

Where E_g is the band gap energy in joule.

Characteristics:

1. **Type:** It is a solid state semiconductor laser.
2. **Active medium:** A PN junction diode made from single crystal of gallium arsenide is used as an active medium.
3. **Pumping method:** The direct conversion method is used for pumping action
4. **Power output:** The power output from this laser is 1mW.
5. **Nature of output:** The nature of output is continuous wave or pulsed output.
6. **Wavelength of Output:** gallium arsenide laser gives infrared radiation in the wavelength 8300 to 8500Å .

Advantages:

1. It is very small in dimension. The arrangement is simple and compact.
2. It exhibits high efficiency.
3. The laser output can be easily increased by controlling the junction current
4. It is operated with lesser power than ruby and CO₂ laser.
5. It requires very little auxiliary equipment
6. It can have a continuous wave output or pulsed output.

Disadvantages:

1. It is difficult to control the mode pattern and mode structure of laser.
2. The output is usually from 5 degree to 15 degree i.e., laser beam has large divergence.
3. The purity and monochromaticity are poorer than other types of laser
4. Threshold current density is very large (400A/mm²).
5. It has poor coherence and poor stability.

Application:

1. It is widely used in fiber optic communication
2. It is used to heal the wounds by infrared radiation
3. It is also used as a pain killer
4. It is used in laser printers and CD writing and reading.

8. Applications of lasers. (BTL 3)

Due to high intensity, high monochromaticity and high directionality of lasers, they are widely used in various fields like

1. communication
2. computers
3. chemistry
4. photography
5. industry
6. medicine
7. military
8. scientific research

1. communication

In case of optical communication semiconductors laser diodes are used as optical sources and its band width is (10^{14}Hz) is very high compared to the radio and microwave communications.

More channels can be sent simultaneously

Signal cannot be tapped

As the band width is large, more data can be sent.

A laser is highly directional and less divergence, hence it has greater potential use in space crafts and submarines.

2. Computers

In LAN (local area network), data can be transferred from memory storage of one computer to other computer using laser for short time.

Lasers are used in CD-ROMS during recording and reading the data.

3. Chemistry

Lasers are used in molecular structure identification

Lasers are also used to accelerate some chemical reactions.

Using lasers, new chemical compounds can be created by breaking bonds between atoms and molecules.

4. Photography

Lasers can be used to get 3-D lens less photography.
Lasers are also used in the construction of holograms.

5. Industry

Lasers can be used to blast holes in diamonds and hard steel
Lasers are also used as a source of intense heat
Carbon dioxide laser is used for cutting drilling of metals and nonmetals, such as ceramics plastics glass etc.
High power lasers are used to weld or melt any material.
Lasers are also used to cut teeth in saws and test the quality of fabric.

6. Medicine

Pulsed neodymium laser is employed in the treatment of liver cancer.
Argon and carbon dioxide lasers are used in the treatment of liver and lungs. Lasers used in the treatment of Glaucoma.

Lasers used in endoscopy to scan the inner parts of the stomach.
Lasers used in the elimination of moles and tumors which are developing in the skin tissue.

7. Military

Lasers can be used as a war weapon.
High energy lasers are used to destroy the enemy air-crafts and missiles. Lasers can be used in the detection and ranging like RADAR.

8. Scientific research

Lasers are used in the field of 3D-photography
Lasers used in Recording and reconstruction of hologram.
Lasers are employed to create plasma.
Lasers used to produce certain chemical reactions.
Lasers are used in Raman spectroscopy to identify the structure of the molecule.
Lasers are used in the Michelson- Morley experiment.
A laser beam is used to confirm Doppler shifts in frequency for moving objects.