I.B.Tech (CSE/EEE/IT & ECE)

Engineering Physics Syllabus

UNIT-I

1. **Crystal Structures:** Lattice points, Space lattice, Basis, Bravais lattice, unit cell and lattice parameters, Seven Crystal Systems with 14 Bravais lattices , Atomic Radius, Co-ordination Number and Packing Factor of SC, BCC, FCC, Miller Indices, Inter planer spacing of Cubic crystal system.
2. **Defects in Crystals:** Classification of defects, Point Defects: Vacancies, Substitution, Interstitial, Concentration of Vacancies, Frenkel and Schottky Defects, Edge and Screw Dislocations (Qualitative treatment), Burger’s Vector.
3. **Principles of Quantum Mechanics:** Waves and Particles, de Broglie Hypothesis, Matter Waves, Davisson and Germer’s Experiment, Heisenberg’s Uncertainty Principle, Schrodinger’s Time Independent Wave Equation-Physical Significance of the wave Function-Particle in One Dimensional Potential Box.

UNIT –II

1. **Electron Theory of Metals:** Classical free electron theory, Derivation of Ohm’s law, Mean free path, Relaxation time and Drift velocity, Failures of Classical free electron theory, Quantum free electron theory, Fermi-Dirac distribution, Fermi energy, Failures of Quantum free electron theory.
2. **Band Theory of Solids:** Electron in a periodic potential, Bloch Theorem, Kronig-Penny Model(Qualitative Treatment), origin of Energy Band Formation in Solids, Classification of Materials into Conductors, Semi Conductors & Insulators, Effective mass of an Electron.
3. **Semiconductor Physics:** Intrinsic Semiconductors and Carrier Concentration, Extrinsic Semiconductors and Carrier Concentration, Fermi Level in Intrinsic and Extrinsic Semiconductors, Hall Effect and Applications.

UNIT – III

1. **Dielectric Properties:** Electric Dipole, Dipole Moment, Dielectric Constant, Polarizability, Electric Susceptibility, Displacement Vector, Types of polarization: Electronic, Ionic and Orientation Polarizations and Calculation of Polarizabilities (Electronic & Ionic) -Internal Fields in Solids, Clausius -Mossotti Equation, Piezo-electricity and Ferro- electricity.
2. **Magnetic Properties:** Magnetic Permeability, Magnetic Field Intensity, Magnetic Field Induction, Intensity of Magnetization, Magnetic Susceptibility, Origin of Magnetic Moment, Bohr Magnetron, Classification of Dia, Para and Ferro Magnetic Materials on the basis of Magnetic Moment, Hysteresis Curve on the basis of Domain Theory of Ferro Magnetism, Soft and Hard Magnetic Materials, Ferrites and their Applications.

UNIT – IV

1. **Lasers:** Characteristics of Lasers, Spontaneous and Stimulated Emission of Radiation, Meta-stable State, Population Inversion, Einstein’s Coefficients and Relation between them, Ruby Laser, Helium-Neon Laser, Semiconductor Diode Laser, Applications of Lasers.
2. **Fiber Optics:** Structure and Principle of Optical Fiber, Acceptance Angle, Numerical Aperture, Types of Optical Fibers (SMSI, MMSI, MMGI), Attenuation in Optical Fibers, Application of Optical Fibers, Optical fiber Communication Link with block diagram.

UNIT –V

1. **Nanotechnology:** Origin of Nanotechnology, Nano Scale, Surface to Volume Ratio, Bottom-up Fabrication: Sol-gel Process; Top-down Fabrication: Chemical Vapor Deposition, Physical, Chemical and Optical properties of Nano materials, Characterization (SEM, EDAX), Applications.

Unit -1:Crystal Structures,Crystal Defects & Principles of Quantum Mechanics

Part-A (SAQ-2Marks)

1) Define a) Space Lattice b) Basis c) Co-ordination number d) Packing factor e) Miller Indices.

a) Space lattice: is defined as an infinite array of points in three dimensions in which every point has surroundings identical to that of every other point in the array.

b) Basis: Group of atoms or molecules identical in composition.

Lattice + basis = crystal structure

c) Co-ordination number: The no of equidistant neighbors that an atom has in the given structure .Greater the co-ordination no, the atoms are said to be closely packed.

For Simple Cubic: 6, BCC: 8, FCC: 12

d) Packing factor (PF): It is the ratio of volume occupied by the atoms or molecule in unit cell to the total volume of the unit cell.

Atomic Packing Factor (APF) = $\frac{\text{Volume of all the atoms in Unit cell}}{Total\ Volume\ of\ the\ Unit\ cell}$

For Simple Cubic: 52%, BCC: 68%, FCC: 74%

e) Miller Indices: are the reciprocals of intercepts made by the planes on the crystallographic axis when reduced to smallest integers.

2) Describe seven crystal systems with lattice parameters and Bravais Lattice points.

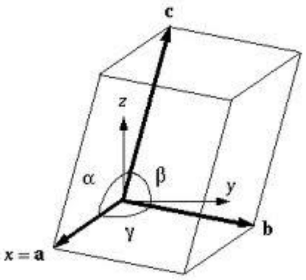
S:No	Name of the crystal systems	Primitives	Interfacial angles	Bravais Lattice points
1	Cubic	$a= b= c$	$\alpha=\beta=\gamma=90^o$	3(P,I,F)
2	Tetragonal	$a= b\neq c$	$\alpha=\beta=\gamma=90^o$	2(P,I)
3	Orthorhombic	$a\neq b\neq c$	$\alpha=\beta=\gamma=90^o$	4(P,C,I,F)
4	Monoclinic	$a\neq b\neq c$	$\alpha=\beta=90^o\neq\gamma$	2(P,C)
5	Triclinic	$a\neq b\neq c$	$\alpha\neq\beta\neq\gamma\neq90^o$	1(P)
6	Trigonal	$a= b= c$	$\alpha=\beta=\gamma\neq90^o$	1(P)
7	Hexagonal	$a= b\neq c$	$\alpha=\beta=90^o$and $\gamma=120^o$	1(P)

3) Define a) Crystal Structure b) Lattice Parameters c) Unit Cell d) Atomic radius (r).

a) Crystal structure: periodic arrangement of atoms or molecules in 3D space.

b) Lattice parameters: the primitives (a,b,c) and interfacial angles (α,β,γ,) are the basic lattice parameters which determine the actual size of unit cell.

c) Unit cell: is a minimum volume cell which on repetition gives actual crystal structure.



d) Atomic radius (r) – The atomic radius is defined as half the distance between neighboring atoms in a crystal of pure element.

4) What are properties of matter Waves.

De-Broglie proposed the concept of matter waves, according to which a material particle of mass 'm', moving with a velocity 'V' should have an associated wavelength 'λ' called de-Broglie wavelength.

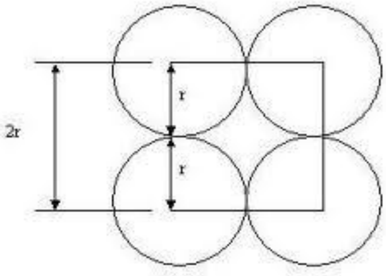
$$\lambda = \frac{h}{mv} = \frac{h}{p}$$

Wavelength is associated with moving particle and independent of charge of the particles. Greater the mass, velocity of the particle, lesser will be the wavelength.

Part- B (Descriptive- 10marks)

1) Calculate the Packing factor of SC, BCC, FCC (or) Show that FCC is the closest packing of all the three cubic structures.

Simple cubic: There are 8 atoms at 8 corners of the cube. The corner atoms touch with each other. If we take a corner atom as a reference, this atom is surrounded by 6 equidistant nearest neighbors.



Co-ordination number: - (N) = 6:- is defined as number of equidistant nearest neighbors that an atom has in the given structure.

Total number of atoms :- (n) =1:- each corner atom is shared by 8 unit cells, the share of each corner atom to a unit cell is 1/8 th of an atom (8×1/8 =1)

Nearest neighbor distance (2r):- the distance between centers of two nearest neighbor atoms will be 2r if 'r' is the radius of the atom.

Atomic radius: - (r) = 2r:- is defined as the distance between nearest neighbors in a crystal.

Lattice constant: - a =2r

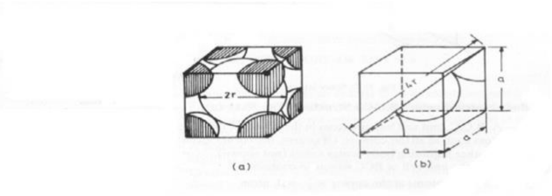
Atomic Packing Factor (APF) = $\frac{\text{Volume of all the atoms in Unit cell}}{Total\ Volume\ of\ the\ Unit\ cell}$

$$\frac{1 \times \frac{4}{3}\pi r^3}{a^3 = (2r)^3} = \mathbf{52\%}$$

Ex:-polonium at room temperature.

Body centered Cubic (BCC):

In a unit cell there are 8 atoms at 8 corners and another 1 atom at the body center. The 8 corner atoms are shared by 8 unit cells, and as the center atom is entirely within the unit cell, it is not shared by any surrounding unit cell.



Co-ordination number =8

Nearest neighbor distance = $\frac{a\sqrt{3}}{2}$

Lattice constant = a= $\frac{4r}{\sqrt{3}}$

Number of atoms per unit cell = v= 1

Volume of all atoms in unit cell = v = 2 × 4/3 π r^3

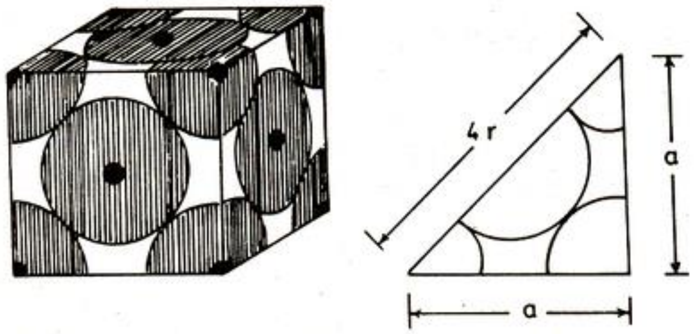
Volume of unit cell =V= a^3=$(\frac{4r}{\sqrt{3}})^3$

Atomic Packing Factor is $\frac{2\times\frac{4}{3}\pi r^3}{\left(\frac{4r}{\sqrt{3}}\right)^3}$ = 0.68 = 68%

Ex: - Li, Na, K, and Cr.

Face centered structure (FCC)

In FCC there are 8 atoms at 8 corners of the unit cell and 6 atoms at 6 faces. Considering the atoms at the face center as origin, it can be observed that this face is common to 2 unit cells and there are 12 points surrounding it situated at a distance equal to half the face diagonal of the unit cell.



Co- ordination number = N= 12

Number of atoms in unit cell = 8 ×1/8+ 6×1/2=4

Lattice constant =a=2r = $\frac{\sqrt{2}a}{2}$

Volume of the unit cell =V= a^3=$\left(\frac{4r}{\sqrt{2}}\right)^3$

Volume of all atoms in unit cell = v= $4 \times \frac{4}{3}\pi r^3$

Atomic Packing Factor = $\frac{v}{V} = \frac{4\times\frac{4}{3}\pi r^3}{\left(\frac{4r}{\sqrt{2}}\right)^3} = 0.74 = \mathbf{74}\%$

Ex:- Cu, Al, Pb, and Ag.

By the above values of Atomic packing factors we can say that FCC is the closest packed structure of all the three cubic structures.

2) Explain the significance of Miller indices and derive an expression for interplaner distance in terms of Miller indices for a cubic Structure.

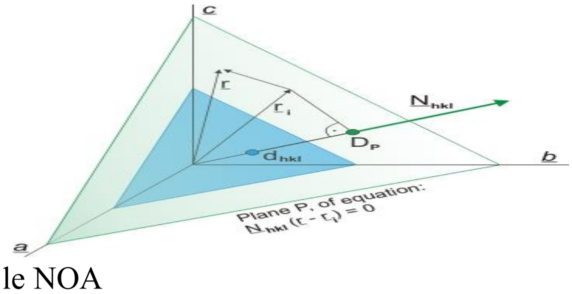
Miller indices: are the reciprocals of intercepts made by the crystal planes on the crystallographic axes when reduced to smallest integers.

Important features of Miller indices:

- Miller indices represent a set of parallel equidistant planes.
- All the parallel equidistant planes have the same Miller indices.
- If a plane is parallel to any axis, then the plane intersects that axis at infinity and Miller indices along that direction is zero.
- If the miller indices of the two planes have the same ratio (844,422,211), then the planes are parallel to each other.
- If a plane cuts an axis on the –ve side of the origin, then the corresponding index is –ve, and is indicated by placing a minus sign above the index.
  Ex: if a plane cuts –ve y-axis, then the miller index of the plane is (h $\bar{k}$ l)

Derivation:

- Consider a crystal in which the three axes are orthogonal and the intercepts are same. Take 'o' as origin, and the reference plane passes through the origin i.e entirely lies on the axis.
- The next plane ABC is to be compared with the reference plane which makes the intercepts $\frac{a}{h}, \frac{b}{k}, \frac{c}{l}$ on x,y,z axes respectively.
- Let (h k l) be the miller indices.
- Let ON=d be a normal drawn to the plane ABC from origin 'o' which gives the distance of separation between adjacent planes.
- Let the normal ON makes an angles α,β,γ with x,y,z axes respectively.
  Angle α= NOA, angle β=NOB, angle c = NOC.



- Then form Δ le NOA
  Cos α = $\frac{ON}{OA} = \frac{d}{a/h} = \frac{dh}{a}$
- Similarly cos β $= \frac{ON}{OB} = \frac{d}{b/k} = \frac{dk}{b}$
- Cos γ = $\frac{ON}{OC} = \frac{d}{c/l} = \frac{dl}{c}$
- According to cosine law of directions, cos^2 α + cos^2 β +cos^2 γ = 1
- Therefore $\left(\frac{dh}{a}\right)^2 + \left(\frac{dk}{b}\right)^2 + \left(\frac{dl}{c}\right)^2 = 1$
- $d^2\left[\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}\right] = 1$
- In a cubic crystal a = b = c,
- Therefore

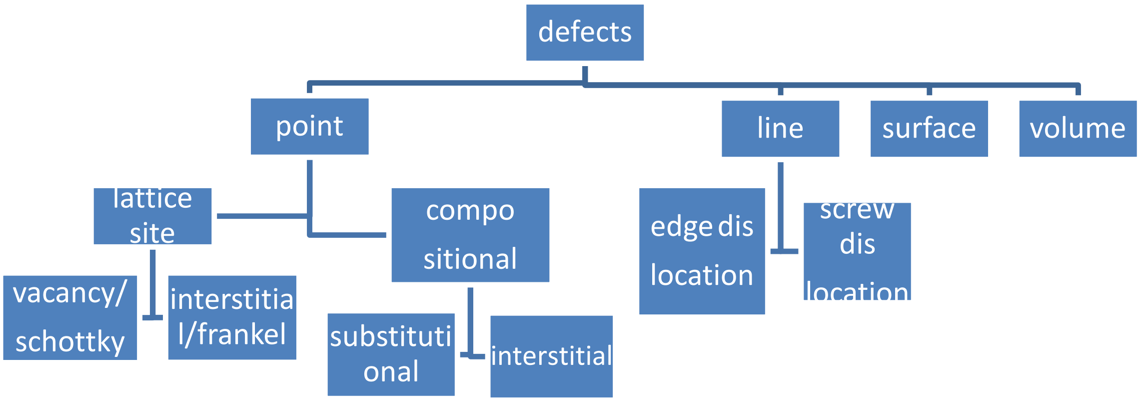
$$d^2\left[\frac{h^2}{a^2} + \frac{k^2}{a^2} + \frac{l^2}{a^2}\right] = 1$$

- Therefore $d^2 = \frac{a^2}{h^2+k^2+l^2}$

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

3) Classify the defects and write a short note on Point defects.

- Defects are broadly classified into



Point defects: (zero dimensional defects) arises when an atom is absent from the regular position, presence of impurity atom or atom in the wrong place during crystallization. These are small defects which extends its influence in all directions but limited to a specific region of small order (two or three atomic orders).

Vacancy: missing of an atom from its original lattice site. Generally arises due to thermal vibrations during crystallization and influenced by external parameters. Vacancies may be single, two or more depending on crystal type. For most of the crystals, in order to create one vacancy thermal energy of 1.1 eV is required.

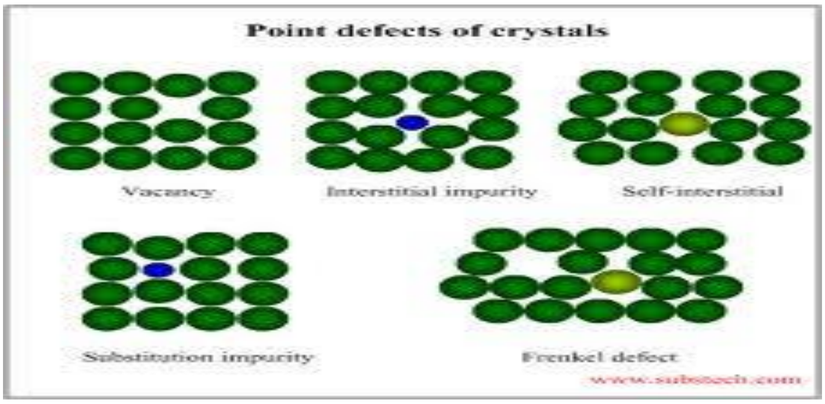
Interstitial: this defect arises when an atom of same kind or different kind occupies the void space between the regular atomic sites.

Impurity atom: an atom that does not belong to the parent lattice (original crystal).

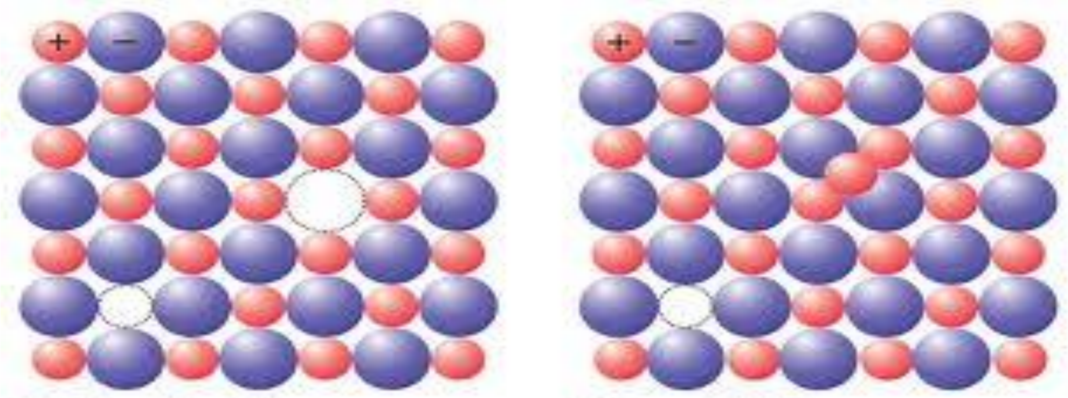
Substitution defects: this defect arises when an impurity atom replaces or substitutes parent atom. Ex: in brass, zinc is a substitution atom in a copper lattice

Interstitial impurity: this defect arises when an impurity atom which is small in size is placed between the regular atomic sites.

Ex: when pentavalent and trivalent impurities are added to pure Si or Ge, we get n- type and P-type semiconductors.



In case of ionic crystals imperfections appear in crystals while maintaining the electrical neutrality. Two types of defects (point defects) occur in ionic crystals.
1. Frenkel defect 2.Schottky defect.



(a) Schottky defect (b) Frenkel defect

Frenkel defect: When an ion is displaced from a regular lattice site to an interstitial site is called Frenkel defect. Generally cations which are small in size are displaced to an interstitial site as the interstitial space is small .A Frenkel imperfection does not change the overall electrical neutrality of the crystal.

Schottky defect: A pair of one cation and one anion missing from the original lattice site on to the surface of the crystal so that charge neutrality is maintained in the crystal is called Schottky defect.

4) Write a short note on line defects. (or) What are edge and screw dislocations?

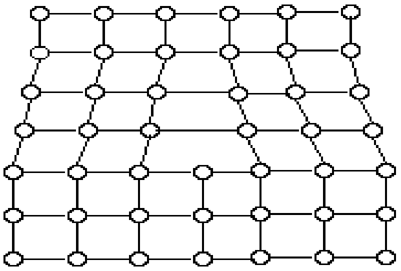
Line defects (or) dislocations (one dimensional defect) are defined as the disturbed region between the two perfect parts of the crystal and these defects are formed in the process of deformation.

Edge dislocation:

- A perfect crystal is composed of several parallel vertical planes which are extended from top to bottom completely and parallel to side faces. The atoms are in equilibrium positions and the bond lengths are in equilibrium value.
- If one of the vertical planes does not extend from top to bottom face of the crystal, but ends in midway within the crystal, then crystal suffers with a dislocation called edge dislocation.
- In imperfect crystal all the atoms above the dislocation plane are squeezed together and compressed there by the bond length decreases. And all the atoms below the dislocation plane are elongated by subjecting to the tension and thereby the bond length increases.
- There are two types of edge dislocation. They are 1.Positive edge dislocation 2.Negative edge dislocation.

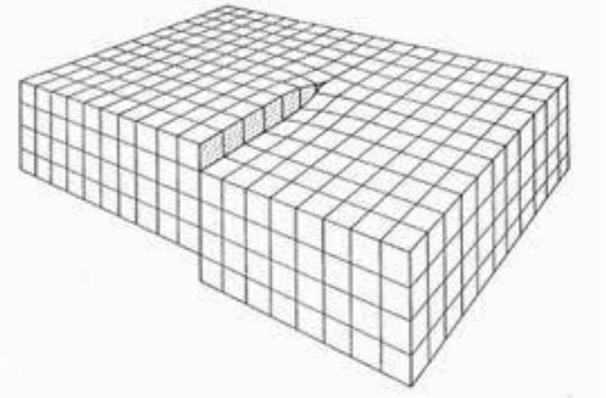
Positive edge dislocation: if the vertical plane starts from top of the crystal and never reaches to the bottom.

Negative edge dislocation: if the vertical plane starts from bottom of the crystal and never reaches top.



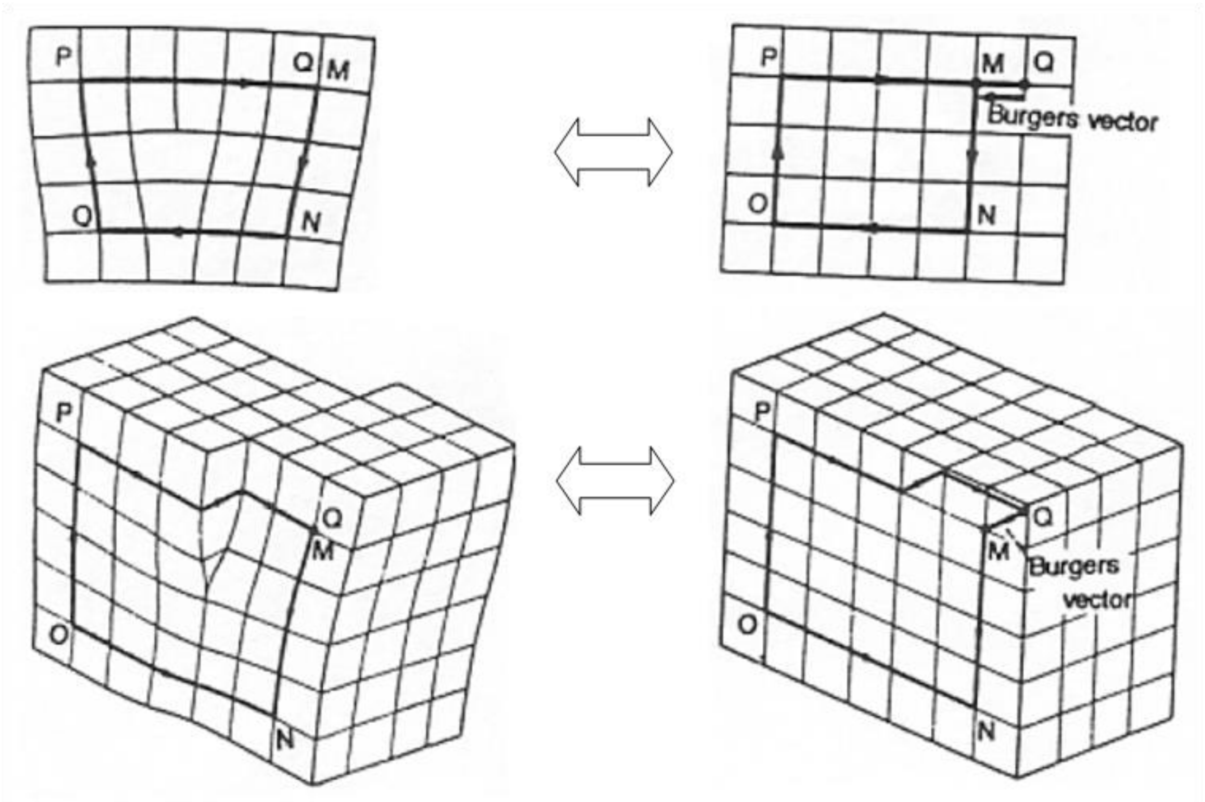
Screw dislocation:

- Atoms are displaced in two separate planes perpendicular to each other or defects forming a spiral around the dislocation line.
- A screw dislocation marks the boundary between slipped and unslipped parts of the crystal that can be produced by cutting the crystal partway and then sheering down one part relative to the other by atomic spacing horizontally.



5) What is a Burger's vector? Explain the significance of Burger's vector.

Burger's vector: It gives the magnitude and direction of dislocation line.



Construction of Burger’s vector:

- Starting from a point ‘p’ move same number of steps left, right, up and down in the clockwise direction.
- If the starting point ‘p’ and ending point ‘p^{l}’ coincide, then the region enclosed in the Burger’s circuit is free from imperfection.
- If the starting point and ending point do not coincide i.e. $pp^{l} = b$. b is the quantity indicating magnitude.
- Burgers’ vector is perpendicular to edge dislocation plane and parallel to screw dislocation plane.

6) Derive an expression for the number of vacancies at any temperature. Or derive an expression for the energy formation of vacancy.

Let ‘N’ be the number of atoms in a crystal, ‘E_v’ is the energy required to create ‘n’ vacancies. The total energy required for the creation of ‘n’ number of vacancies is called enthalpy and is given as $u=nE_v$…………………………..(1)

The number of ways of selecting ‘N’ atoms to create ‘n’ vacancies is p

$p = Nc_n = \frac{N!}{n!(N-n)!}$ --------------- (2), Here ‘p’ is disorder parameter.

In statistical mechanics, the relation between disorder parameter ‘p’ and entropy‘s’ is

s= k logp……………… (3), where K= Boltzmann constant.

Free energy (F) of the atoms in the crystal is given by $F = u - Ts$……………. (4)

$F = nE_V - KT\log p$……. (5). From 1 and 3

$F = nE_v - KT\log\frac{n!}{(N-n)!n!}$........... (6) , substitute 2 in 5

By applying sterling’s approximation, to eqn (6)

$logx! = xlogx - x$

$F = nE_V - KT(logN! - \log(N-n)! - logn!)$

$F = nE_v = KT(NlogN - N - (N-n)\log(N-n) + (N-N) - nlogn + n)$

$F = nE_v - KT(NlogN - (N-n)\log(N-n) - nlogn)$…. (7)

At thermal equilibrium, the free energy is minimum and constant .i.e.

$\frac{dF}{dn} = 0$ in (7)

$\frac{dF}{dn} = E_v - KT(0 - (N-n)\frac{1}{(N-n)}(-1)$-log$(N-n)\,(-1) - n\frac{1}{n} - logn)$

$$0 = E_v - KT(1 + \log(N-n) - 1 - logn)$$

$$0 = E_v - KT\left[log\left(\frac{N-n}{n}\right)\right]$$

$$E_v = KTlog\left(\frac{N-n}{n}\right)$$

$$\frac{E_v}{KT} = log\left(\frac{N-n}{n}\right)$$

Taking exponential on both sides

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

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

The number of vacancies in a crystal is very small when compared with the number of atoms.$N \gg n$

$N - n \cong N$

Therefore $e^{-E_v/KT}\,\frac{n}{N}$

$$n = Nexp^{-E_v/KT}$$

7)Derive an expression for the energy required to create a Frenkel defect.(or) Derive an expression for the no of Frenkel defects created in a crystal a at a given temperature.

Let ‘N’ be the number of atoms, ’N_i’ be the number of interstitial atoms, let ‘ E_i ’s the energy required to create ‘n’ number of vacancies and the total energy required is $u = nE_i$…..(1)

The total number of ways in which Frenkel defects can be formed is given by $p = N_n^c \times {N_i}_n^c$

$p = \frac{N!}{(N-n)!n!} \times \frac{N_i!}{(N_i-n)!n!}$........ (2)

The increase in entropy (s) due to Frenkel defect is given by $s = K\,logp$

$S = Klog\left[\frac{N!}{n!(N-n)!} \times \frac{N_i!}{(N_I-n)!n!}\right]$....... (3)

This increase in entropy produces change in Free energy $F = u - TS$……….. (4)

Substitute (1),(3) in (4)

$$F = nE_i - KTlog\left[\frac{N!}{n!\,(N-n)!} \times \frac{N_i!}{(N_i-n)!\,n!}\right]$$

Using Sterling’s approximation,$logx! = xlogx - x$

$$F = nE_i - KT\left[log\frac{N!}{n!\,(N-n)!} + log\frac{N_i!}{(N_I-n)!\,n!}\right]$$

$$F = nE_i - KT[logN! - logn! - log(N-n)\,! + logN_i! - log(N_i-n)\,! - logn!]$$

$$F = nE_i - KT[(NlogN - N) - (nlogn - n) - [(N-n)\log(N-n) - (N-n)] + N_ilogN_i - N_I - [(N_i-n)\log(N_i-n) - (N_i-n)] - (nlogn - n)]$$

$$F = nE_i - KT[NlogN - N - nlogn + n - (N-n)\log(N-n) + (N-n) + N_ilogN_I - N_i - (N_i-n)\log(N_i-n) + (N_i-n) - nlogn + n]$$

$$F = nE_I - KT[NlogN + N_ilogN_i - (N-n)\log(N-n) - (N_i-n)\log(N_i-n) - 2nlogn]$$

Differentiating w.r.to ‘n’, and equating to 0, we get

$$\frac{dF}{dn} = E_i - KT\left[0 + 0 - \left[(N-n)\frac{1}{(N-n)}(-1)) + \log(N-n)(-1)\right] - \left[(N_i - n)\frac{1}{(N_i - n)}(-1) + \log(N_i - n)(-1)\right] - 2\left[n \times \frac{1}{n} + \log n\right]\right]$$

$$0 = E_i - KT[1 + \log(N-n) + 1 + \log(N_i - n) - 2 - 2\log n]$$

$$0 = E_i - KT\left[\log\frac{(N-n)(N_i - n)}{n^2}\right]$$

$$E_i = KT\left[\log\frac{(N-n)(N_i - n)}{n^2}\right]$$

As $n \ll N, N - n \cong N$, similarly $N_i - n \cong N_i$

$$E_i = KT\log\left(\frac{NN_i}{n^2}\right)$$

Thus $E_i = KT[\log NN_i - 2\log n]$

$$\frac{E_i}{KT} = \log(NN_i) - 2\log n$$

$$2\log n = \log(NN_i) - \frac{E_i}{KT}$$

$$\log n = \frac{1}{2}\log(NN_i) - \frac{E_i}{2KT}$$

Taking exponentials on both sides

$$n = (NN_i)^{\frac{1}{2}}\exp^{\frac{-E_i}{2KT}}$$

8)Derive an expression for the energy required to create a Schottky defect.(or) Derive an expression for the no of Schottky defects created in a crystal a at a given temperature.

Let ‘N’ be the number of atoms, ’E_p’ is the energy required to create a pair of vacancies and ‘n’ be number of vacancies created. The total energy required to create vacancies is

U= nEp…………….(1)

The number of ways in which ‘n’ vacancies created is

$p = N_n^c \times N_n^c = (N_n^c)^2$

$$p = \left[\frac{N!}{(N-n)!\,n!}\right]^2$$

The relation between the disorder parameter ‘p’ and entropy ‘s’ is given by

$s = K\log p = k\log\left[\frac{N!}{(N-n)!n!}\right]^2$…………(2)

By applying Sterling’s approximation

$$\log\left[\frac{N!}{(N-n)!\,n!}\right]^2 = 2[\log N! - \log(N-n)! - \log n!]$$

$$= 2\left[N\log N - N - \left((N-n)\log(N-n) - (N-n)\right) - (n\log n - n)\right]$$

$$= 2[N\log N - N - (N-n)\log(N-n) + N - n - n\log n + n]$$

$$= 2[N\log N - (N-n)\log(N-n) - n\log n]$$

There fore $s = 2K[N\log N - (N-n)\log(N-n) - n\log n]$…..(3)

Free energy of the atoms in the crystal is given by $F = U - TS$…..(4)

Substitute (1),(3) in (4)

$$F = nE_p - 2KT[N\log N - (N-n)\log(N-n) - n\log n]$$

Differentiating above equation w.r.to ‘n’ and equating it to zero, we get

$$\frac{dF}{dn} = E_p - 2KT[\log(N-n) + 1 - \log n - 1 = 0]$$

$$E_p - 2KT\log\left(\frac{N-n}{n}\right) = 0$$

$$\frac{E_p}{2KT} = \log\left(\frac{N-n}{n}\right)$$

Taking exponentials on both sides

$$\frac{N-n}{n} = \exp^{\frac{E_p}{2KT}}$$

As $nn \ll N, N = n\exp^{\frac{E_p}{2KT}}$

$$n = N\exp^{\frac{-E_p}{2KT}}$$

9) Describe De-Broglie's hypothesis and provide an experimental validity for the De-Broglie's hypothesis. Or Explain the experimental verification of matter waves by Davison and Germer's experiment:

De-Broglie Hypothesis –Matter waves: An electromagnetic wave behaves like particles, particles like electrons behave like waves called matter waves, also called de-Broglie matter waves.

- The wave length of matter waves is derived on the analogy of radiation.
- Based on Planck's theory of radiation, the energy of a photon is given by
  $E = h\vartheta = \frac{hc}{\lambda}$….. (1)
  $c =$ Velocity of light, $\lambda =$ Wavelength of the photon, h= Planck's constant
- According to Einstein's mass energy relation, $E = mc^2$…… (2)
  m= mass of the photon
- Equating equations (1) and (2), $mc^2 = \frac{hc}{\lambda}$
- $\lambda = \frac{hc}{mc^2} = \frac{h}{mc} = \frac{h}{p}$…… (3), P = momentum of photon
- De-Broglie proposed the concept of matter waves, according to which a material particle of mass 'm', moving with a velocity 'v' should have an associated wavelength 'λ' called de-Broglie wavelength.
- $\lambda = \frac{h}{mv} = \frac{h}{p}$… (4) is called de-Broglie's wave equation.
- Wavelength is associated with moving particle and independent of charge of the particles.
- Greater the mass, velocity of the particle, lesser will be the wavelength.

De-Broglie wavelength associated with an electron:

- If a velocity 'v' is given to an electron by accelerating it through a potential difference 'V', then the work done on the electron is 'Ve', and the work done is converted into the kinetic energy of an electron.

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

$$v = \sqrt{\frac{2eV}{m}}$$

$mv = \sqrt{2meV}$…. (5) in (4)

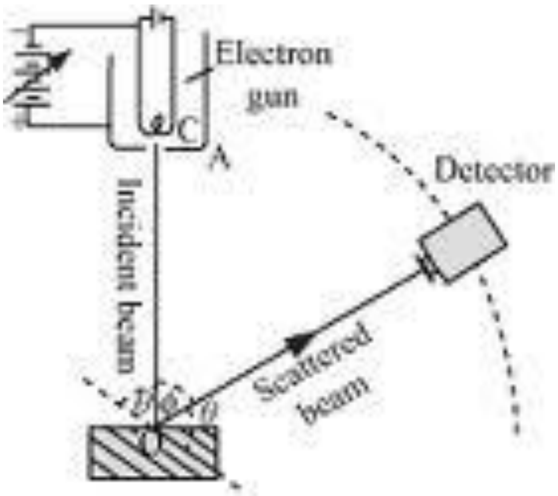
$\lambda = \frac{h}{\sqrt{2meV}}$…… (6)

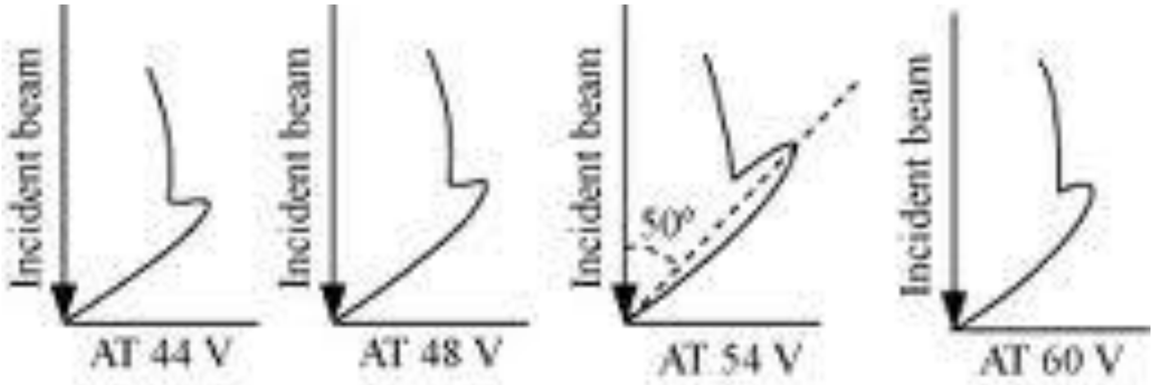
- Ignoring relativistic corrections, m_0= rest mass of electron, $\lambda = \frac{h}{\sqrt{2m_0eV}}$….. (7)

- By substituting the values of $h=6.625\times 10^{-34} Jsec$, $m_0= 9.1\times 10^{-31} Kg$ and c= charge of electron=1.6×10^{-19}C
  $\lambda = \frac{12.27}{\sqrt{V}} A^0$…… (8), Where V= in volt and $\lambda =$ in A^0

Experimental validity: Davison and Germer Experiment:

- The first experimental evidence of the wave nature of atomic particles was proved by C.J Davison and L.H Germer in 1927.
- They were studying scattering of electrons by a metal target and measuring the density of electrons scattered in different directions.





- From fig, the electron beam from electron gun which consists of a tungsten filament ‘F’ heated by a low tension battery ‘B_1’ are accelerated to a desired velocity by applying suitable potential from a high tension battery ‘B_2’.
- The accelerated electrons are collimated into a fine beam by allowing them to pass thorough a system of pinholes in the cylinder ‘C’.
- The fast moving electron beam is made to strike the target (nickel crystal) capable of rotating about an axis perpendicular to the plane of diagram.
- The electrons are scattered in all directions by atomic planes of a crystal and intensity of scattered electron beam in all directions can be measured by the electron collector and can be rotated about the same axis as the target.
- The collector is connected to a sensitive galvanometer whose deflection is proportional to the intensity of electron beam entering the collector.

- When electron beam accelerated by 54 V was directed to strike the given nickel crystal, a sharp max in the electron diffraction occurred at an angle of 50^0 with the incident beam.
- The incident beam and the diffracted beam make an angle of 65^0 with the family of Bragg's planes. The whole instrument is kept in an evacuated chamber.
- The spacing of planes in Nickel crystal as determined by x-ray diffraction is 0.091nm
- From Bragg's law 2dsinθ = n λ i.e $2 \times 0.091 \times 10^{-9} \times sin65^{\circ} = 1 \times \lambda$
  λ =0.615nm
- Therefore for a 54 V electron beam, the de-Broglie wavelength associated with the electron is given by $\lambda = \frac{12.27}{\sqrt{54}}$ A° = 0.166nm
- This wavelength agrees well with the experimental value. Thus division experiment provides a direct verification of de-Broglie hypothesis of wave nature of moving particles.

10) Explain the Physical significance of ψ (wave function).

- The wave function **ψ** enables all possible information about the particle. **ψ** is a complex quantity and has no direct physical meaning. It is only a mathematical tool in order to represent the variable physical quantities in quantum mechanics.
- Born suggested that, the value of wave function associated with a moving particle at the position co-ordinates (x,y,z) in space, and at the time instant 't' is related in finding the particle at certain location and certain period of time 't'.
- If **ψ** represents the probability of finding the particle, then it can have two cases.
  Case 1: certainty of its Presence: +ve probability
  Case 2: certainty of its absence: - ve probability, but –ve probability is meaningless,
  Hence the wave function **ψ** is complex number and is of the form a+ib
- Even though **ψ** has no physical meaning, the square of its absolute magnitude $|\boldsymbol{\psi}^2|$ gives a definite meaning and is obtained by multiplying the complex number with its complex conjugate then $|\boldsymbol{\psi}^2|$ represents the probability density 'p' of locating the particle at a place at a given instant of time. And has real and positive solutions.

$$\boldsymbol{\psi}\ (\mathbf{x}, \mathbf{y}, \mathbf{z}, \mathbf{t}) = \mathbf{a} + \mathbf{ib}$$

$$\boldsymbol{\psi}^*(\mathbf{x}, \mathbf{y}, \mathbf{z}, \mathbf{t}) = \mathbf{a} - \mathbf{ib}$$

$$\mathbf{p} = \boldsymbol{\psi}\boldsymbol{\psi}^* = |\boldsymbol{\psi}^2| = a^2 + b^2 \quad as\ i^2 = -1$$

Where 'P' is called the probability density of the wave function.

- If the particle is moving in a volume 'V', then the probability of finding the particle in a volume element dv, surrounding the point x,y,z and at instant 't' is Pdv

$$\int_{-\infty}^{\infty} |\boldsymbol{\psi}^2| dv = 1\ if\ particel\ is\ present$$

. = 0 if particle does not exist

This is called normalization condition.

11) Describe Heisenberg's uncertainty principle?

- According to Classical mechanics, a moving particle at any instant has fixed position in space and definite momentum which can be determined simultaneously with any desired accuracy. This assumption is true for objects of appreciable size, but fails in particles of atomic dimensions.

- Since a moving atomic particle has to be regarded as a de-Broglie wave group, there is a limit to measure particle properties.
- According to Born probability interpretation, the particle may be found anywhere within the wave group moving with group velocity.
- If the group is considered to be narrow, it is easier to locate its position, but the uncertainty in calculating its velocity and momentum increases.
- If the group is wide, its momentum is estimated easily, but there is great uncertainty about the exact location of the particle.

- Heisenberg a German scientist in 1927, gave uncertainty principle which states that "The determination of exact position and momentum of a moving particle simultaneously is impossible''.

- In general, if $\triangle$x represents the error in measurement of position of particle along x-axis, and $\triangle$p represents error in measurement of momentum, then

$$\triangle \mathrm{x}.\triangle \mathrm{p} = \mathrm{h}$$

Or limitation to find the position and momentum of a particle is

$$(\triangle \mathrm{x}).(\triangle \mathrm{p}) \geq \frac{\mathrm{h}}{4\pi}$$

i.e. Heisenberg uncertainty principle states that both the position and momentum Cannot be measured simultaneously with perfect accuracy.

12) Derive an expression for Schrodinger time independent wave equation.

- Schrodinger describes the wave nature of a particle in mathematical form and is known as Schrodinger's wave equation.
- Consider a plane wave moving along +ve x- direction with velocity 'v'. The equation of the wave is written in the from $y = a sin \frac{2\pi}{\lambda}(x - vt)$…(1)

  Where λ = wavelength of the wave, a= amplitude of wave
  y=displacement of wave in y- direction
  x= displacement along x- axis at any instant of time 't'.
- Taking first order derivative w.r.to 'x' on both sides of eqn (1)

$$\frac{dy}{dx} = a\cos\frac{2\pi}{\lambda}(x - vt)\frac{2\pi}{\lambda}$$

$$\frac{d^2y}{dx^2} = -a\left(\frac{2\pi}{\lambda}\right)^2 \sin\left(\frac{2\pi}{\lambda}\right)(x - vt)\text{….(2)}$$

Substitute (1) in (2)

$$\frac{d^2y}{dx^2} + \left(\frac{2\pi}{\lambda}\right)^2 y = 0\text{…(3)}$$

- This is known as differential plane wave equation.
- In complex wave, the displacement 'y' is replaced by 'ψ' and wavelength' λ' is replaced by de-Broglie's wavelength λ' $= \frac{\mathrm{h}}{\mathrm{mv}}$ in eqn (3)

$$\frac{d^2\psi}{dx^2} + \left(\frac{2\pi}{\lambda}\right)^2 \psi = 0$$

$\frac{d^2\psi}{dx^2} + \frac{4\pi^2 m^2 v^2}{h^2}\ \psi = 0$…. (4)

- For a moving particle, the\ total energy is $E = U + V\ i.e\ U = E - V$ ….(5)

Where E= total energy, V= potential energy, U= kinetic energy = $\frac{1}{2}mv^2$

$2mu = m^2v^2$…. (6), substitute (5) in (6)

$2m(E - V) = m^2v^2$…. (7) Substitute (7) in (4)

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

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

- This equation is known as Schrodinger’s time independent wave equation in one dimension.
- In three dimensions, it can be written as

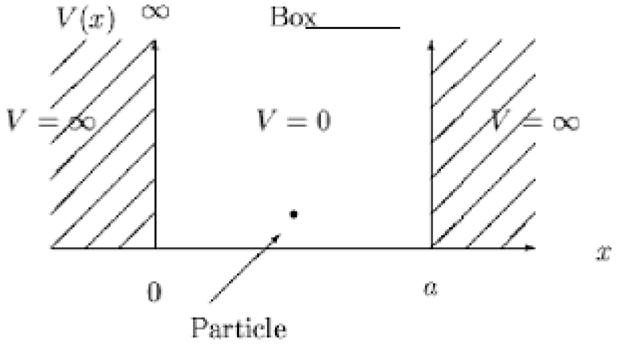
$\nabla^2\ \psi + \frac{8\pi^2 m(E-V)}{h^2}\ \psi = 0$… (9)

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

- For a free particle, the P.E is equal to zero i.e V=0 in equation (9)
- Therefore the Schrodinger’s time independent wave equation for a free particle is

$$\nabla^2\ \psi + \frac{8\pi^2 mE}{h^2}\ \psi = 0$$

13) Derive an expression for the energy states of a Particle trapped in 1-Dimensional potential box:



- The wave nature of a moving particle leads to some remarkable consequences when the particle is restricted to a certain region of space instead of being able to move freely .i.e when a particle bounces back and forth between the walls of a box.
- If one –dimensional motion of a particle is assumed to take place with zero potential energy over a fixed distance, and if the potential energy is assumed to become infinite at the extremities of the distance, it is described as a particle in a 1-D box, and this is the simplest example of all motions in a bound state.
- The Schrodinger wave equation will be applied to study the motion of a particle in 1-D box to show how quantum numbers, discrete values of energy and zero point energy arise.
- From a wave point of view, a particle trapped in a box is like a standing wave in a string stretched between the box’s walls.
- Consider a particle of mass ‘m’ moving freely along x- axis and is confined between x=0 and x= a by infinitely two hard walls, so that the particle has no chance of penetrating them and bouncing back and forth between the walls of a 1-D box.

- If the particle does not lose energy when it collides with such walls, then the total energy remains constant.
- This box can be represented by a potential well of width ‘a’, where V is uniform inside the box throughout the length ‘a’ i.e V= 0 inside the box or convenience and with potential walls of infinite height at x=0 and x=a, so that the PE ‘V’ of a particle is infinitely high V=∞ on both sides of the box.
- The boundary condition are

  $v(x) = 0\,, \psi(x) = 1 when\ 0 < x < a$…. (1)

  $v(x) = \infty\,, \psi(x) = 0 when\ 0 \geq x \geq a$… (2)

  Where $\psi(x)$ is the probability of finding the particle.
- The Schrodinger wave equation for the particle in the potential well can be written as

$\frac{d^2\psi}{dx^2} + \frac{8\pi^2 m}{h^2} \mathrm{E}\,\psi = 0,$ as $\mathrm{V} = 0$ for a free particle… (3)

- In the simplest form eqn (3) can be written as

$\frac{d^2\psi}{dx^2} + k^2\,\psi = 0$…. (4) Where k= propagation constant and is given by $k = \sqrt{\frac{8\Pi^2 mE}{h^2}}$….(5)

- The general solution of equation (4) is $\psi(\mathrm{x}) = \mathrm{Asinkx} + \mathrm{Bcoskx}$… (6)
- Where A and B are arbitrary constants, and the value of these constant can be obtained by applying the boundary conditions.
- Substitute eqn(1) in (6)

$0 = Asink(0) + Bcosk(0) \rightarrow$ B=0 in eqn (6)

$\psi(\mathrm{x}) = \mathrm{Asinkx}$… (7)

Substituting eqn (2) in (7)

$0 = Asink(a)$

$\rightarrow A = 0\ or\ sinka = 0$, But ‘A’ ≠ 0 as already B=0 & if A= 0, there is no solution at all.

- Therefore sinka=0(if sinθ=0,then general solution is θ=nΠ), i.e Ka=nΠ

$k = \frac{n\pi}{a}$…….(8), Where n= 1,2,3,4,…and n≠0,because if n=0,k=0,E=0 everywhere inside the box and the moving particle cannot have zero energy.

From (8) $k^2 = \left(\frac{n\pi}{a}\right)^2$

From (5) $\frac{8\Pi^2 mE}{h^2} = \frac{n^2\pi^2}{a^2}$

$$E = \frac{n^2h^2}{8ma^2}$$

$E_{n=} \frac{n^2h^2}{8ma^2}$= the discrete energy level… (9)

- The lowest energy of a particle is given by putting n=1 in the eqn (9), $E_{1=} \frac{h^2}{8ma^2}$ = lowest energy, minimum energy, ground state energy or zero point energy of the system.

  $E_{n=} n^2 E_1$

- The wave functions ψ_n corresponding to E_n are called Eigen functions of the particle, .the integer 'n' corresponding to the energy E_n is called the quantum number of the energy level E_n.
  Substituting (8) in (7), $\psi_n = A sin\frac{n\pi x}{a}$..(10)
- Normalization of wave function: The wave functions for the motion of the particle are

$$\psi_n = A sin\frac{n\pi x}{a}, for\ 0 < x < a$$
$$\psi_n = 0, for\ 0 \geq x \geq a$$

- According to normalization condition, the total probability that the particle is somewhere in the box must be unity.

$$\int_0^a p_x dx = \int_0^a |\psi_n|^2 dx = 1$$

- From eqn(10), $\int_0^a A^2 sin^2\frac{n\pi x}{a}dx = 1$

$$A^2\int_0^a \frac{1}{2}\left[1 - cos\frac{2\pi nx}{a}\right]dx = 1$$
$$\left(\frac{A}{2}\right)^2\left[x - \frac{a}{2\pi n}sin\frac{2\pi nx}{a}\right] = 1$$

- The second term of the integrand expression becomes zero at both the limits.

$$\frac{A^2}{2} = 1$$
$$A = \sqrt{\frac{2}{a}}$$

- The normalized wave function is $\psi_n = \sqrt{\frac{2}{a}\ \ sin\frac{n\pi x}{a}}$

UNIT-2: ELECTRON THEORY, BAND THEORY & SEMI CONDUCTORS

Part-A (SAQ-2Marks)

1) What are the failures of Classical Free electron theory?

Heat Capacities: - The internal energy of a molar substance, U = $\frac{3}{2}$ KTN

Molar specific heat $C_v = \frac{\partial V}{\partial T} = \frac{3}{2}KN = \frac{3}{2}R$

'N' is the Avogadro number, K is Boltzmann constant and `R` is the universal gas constant. The molar specific heat is 1.5 R theoretically, where as the experimental value obtained is too low. This is due to the fact that all free electrons do not contribute significantly to thermal or electrical conductivity. Therefore classical free e^- theory can`t hold good.

Mean free path: - It is calculated using the formula: $\lambda = \bar{C} \times T_r$

$$\lambda = \sqrt{\frac{3kT}{m}} \times \frac{m}{\rho n e^2}$$
$$\lambda = \frac{\sqrt{3kTm}}{\rho n e^2}.$$

For cu at 20˚ c, ρ = 1.69x 10¯ 8 ohm-m^{-1},e¯ concentration n = 8.5 x$10^{28}/m^{3}$.

$$\lambda = \mathbf{2.5 \times 10^{-9} m}$$

The experimental value of `λ`was obtained nearly 10 times its theoretical value. So classical theory could not explain the large variation in ‘λ' value.

Resistivity: - According to the classical free electron theory, the resistivity is given by the equation, $\rho = \frac{\sqrt{3kTm}}{\lambda ne^{2}}$

Which means the resistivity is proportional to the square root of absolute temperature. But according to theory at room temperature it does not change up to 10K and in intermediate range of temperature ρ is proportional to T^{5} .

- The conductivity of semiconductors and insulators cannot be explained by the free electron theory.

2) What are the applications of Hall Effect?

Determination of the type of Semi-conductors:

The Hall coefficient R_H is -ve for an n-type semiconductor and +ve for p-type semiconductor. Thus the sign of Hall coefficient can be used to determine whether a given Semi-conductor is n or p-type.

Calculation of carrier concentration:

$$R_H = \frac{I}{\rho} = \frac{I}{ne} \text{ (for e¯ s)}$$

$$R_H = \frac{I}{\rho e} \text{ (for holes)}$$

$$\Rightarrow n = \frac{I}{eR_H} \qquad \Rightarrow \rho = \frac{I}{eR_H}$$

Determination of Mobility: σ = neμ

$\mu = \frac{\sigma}{ne} = \sigma R_H$

$\mu = \sigma R_H \quad | \quad |$

Measurement of Magnetic Flux Density:

Hall Voltage is proportional to the magnetic flux density B for a given current I. So, Hall Effect can be used as the basis for the design of a magnetic flux density metal.

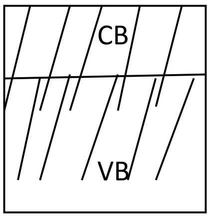
3) Define Fermi energy level.

The highest energy level that can be occupied by an electron at 0 K is called Fermi energy level. It is denoted by E_F .

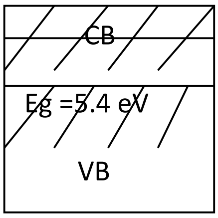
4) Distinguish between conductors, Insulator and Semiconductors.

Solids are classified into three types based on energy gap.

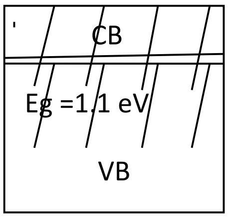
- Conductors(metals)
- Insulators
- Semiconductors
- In case of conductors, valence band and conduction band almost overlap each other and no significance for energy gap. The two allowed bands are separated by Fermi energy level. Here there is no role in Eg, as a result conduction is high.



Conductors



insulators



Semiconductors

- In case of insulator, valence band and conduction band are separated by large energy gap, hence conductivity is zero.
- In case of semiconductors, the valence band and conduction band are separated by relatively narrow energy gap; hence the conductivity lies in between conductors and insulators.

5) Define the following terms.
i. Collision time ii. Relaxation time iii. Mean free path iv .Drift velocity v. Mobility

i. Collision time: The time taken by the electron to complete one collision with the +ve ion center.
ii.Relaxation time: The time taken by the electron to reduce its velocity to 1/e of its initial velocity.
iii.Mean free path: The average distance covered by the electron between two successive collisions.
iv.Drift velocity: The steady state velocity of the electrons in the presence of Electric field.
v.Mobility: The steady state velocity of the electrons per unit electric field.

Part- B (Descriptive- 10marks)

1) What are the salient features of classical free electron theory of metals? What are its drawbacks?

Drude and Lorentz proposed free electron theory of on the basis of some assumptions.

- In conductors (metals), there are large number of free electrons moving freely within the metal i.e. the free electrons or valence electrons are free to move in the metal like gaseous molecules, because nuclei occupy only 15% metal space and the remaining 85% space is available for the electrons to move.
- Since free electrons behave like gaseous molecules, the laws of kinetic theory of gases can be applied. The mean K.E of a free electron is equal to that of a gas molecule at same temperature.
- In the absence of any electric field, the electrons move randomly while undergoing scattering at +ve ion centers. The collisions are regarded as elastic (no loss of energy).
- The electron speeds are distributed according to the Maxwell- Boltzmann distribution law.
- When an electric filed is applied, the free electrons are accelerated in a direction opposite to that of the field.
- The free electrons are confined to the metal due to surface potential.
- The electrostatic force of attraction between the + ve ion cores and the free electrons is assumed to be negligible.

Drawbacks:

1. Heat capacities: - The internal energy of a molar substance, U = $\frac{3}{2}$ KTN
Molar specific heat $C_v = \frac{\partial V}{\partial T} = \frac{3}{2}KN = \frac{3}{2}R$
'N' is the Avogadro number, K is Boltzmann constant and `R` is the universal gas constant. The molar specific heat is 1.5 R theoretically, where as the experimental value obtained is too low. This is due to the fact that all free electrons do not contribute significantly to thermal or electrical conductivity. Therefore classical free e^- theory can`t hold good.

2. Mean free path: - It is calculated using the formula, λ = C^- x Tr

λ= $\sqrt{\frac{3kT}{m}}$ x $\frac{m}{\rho n e^2}$

λ = $\frac{\sqrt{3kTm}}{\rho n e^2}$.

For cu at 20° c , ρ = 1.69x 10^- 8 ohm-m^{-1},e^- concentration n = 8.5 x$10^{28}/m^3$.

$$\lambda = \mathbf{2.5 \times 10^{-9} m}$$

The experimental value of `λ`was obtained nearly 10 times its theoretical value. So classical theory could not explain the large variation in 'λ' value.

3. Resistivity: - According to the classical free electron theory, the resistivity is given by the equation.ρ $= \frac{\sqrt{3kTm}}{\lambda n e^2}$

Which means the resistivity is proportional to the square root of absolute temperature. But according to theory at room temperature it does not change up to 10K and in intermediate range of temperature ρ is proportional to T^5 .

4. The conductivity of semiconductors and insulators cannot be explained by the free electron theory.

2) What are the assumptions of quantum free electron theory? State its drawbacks.

In 1929, Somerfield stated to apply quantum mechanics to explain conductivity phenomenon in metal. He has improved the Drude - Lorentz theory by quantizing the free electron energy and retained the classical concept of free motion of electron at a random.

ASSUMPTIONS:-

- The electrons are free to move within the metal like gaseous molecules. They are confined to the metal due to surface potential.
- The velocity distribution of the free electrons is described by Fermi-Dirac Statistics because electrons are spin half particles.
- The free electrons would go into the different energy levels by following Pauli's exclusion Principle which states that no two electrons have same set of Quantum numbers.
- The motion of electrons is associated with a complex wave called matter wave, according to De-Broglie hypothesis.
- The electrons cannot have all energies but will have discrete energies according to the equation, $E = n^2 h^2 / 8ma^2$.

Drawbacks:

Conductivity:_ According to Quantum free electron theory, the conductivity of a metal is σ = μne, here 'μ' is the mobility of electrons, 'n' is the free electron concentration and 'e' is the electron charge.

According to the above equation, polyvalent metals like Aluminum (Al) should be more conductive than mono valent metals like copper (Cu). But experimentally it is not so.

Hall coefficient: According to the free electron theory, the hall coefficients for all metals is negative where as there are certain metals like Be, Cd, Zn for which the Hall coefficient is +

ve. Free electron theory could not explain why certain substances behave as insulators and some other substances as semiconductors; in spite of they have free electrons in them.

3. Define Fermi energy level. Explain Fermi Dirac distribution function.

Energy levels – Fermi Dirac Distribution:

According to the Quantum theory quantization leads to discrete energy levels. The electrons are distributed among these energy levels according to Pauli's exclusions principle i.e., it allows a maximum number of two electrons with spins in opposite directions in any energy level. The pair of electrons, one with sign up and the other with spin down occupy the lowest energy level. The next pair occupies the next level. This process goes on until all the electrons in the metal occupy their position.

- The highest energy level that can be occupied by an electron at 0 K is called Fermi energy level. It is denoted by E_F .

When the metal is not under the influence of an external field, all the levels above the Fermi energy level are empty; those lying below are completely filled.

Fermi – Dirac Distribution:

When the material is at a temperature higher than OK, it receives thermal energy from surroundings i.e. electrons are thermally excited. As a result, they move into the higher energy levels which are unoccupied at OK. The occupation obeys a statistical distribution called Fermi – Dirac distribution law.

According to this distribution law, the probability F(E) that a given energy state E is occupied at a temperature T is given by $\frac{1}{\exp(E-Ef)/KT + 1}$

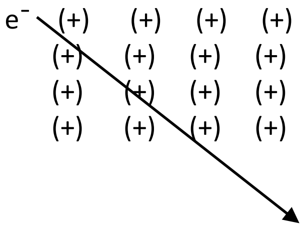
Here F(E) is called Fermi – Dirac probability function. It indicates that the fraction of all energy state (E) occupied under thermal equilibrium 'K' is Boltzmann constant.

4) Explain the motion of an electron in periodic potential using Bloch theorem? (or) Explain Band theory of solids in detail. (or) Discuss the Kronig- penny model for the motion of an electron in a periodic potential.

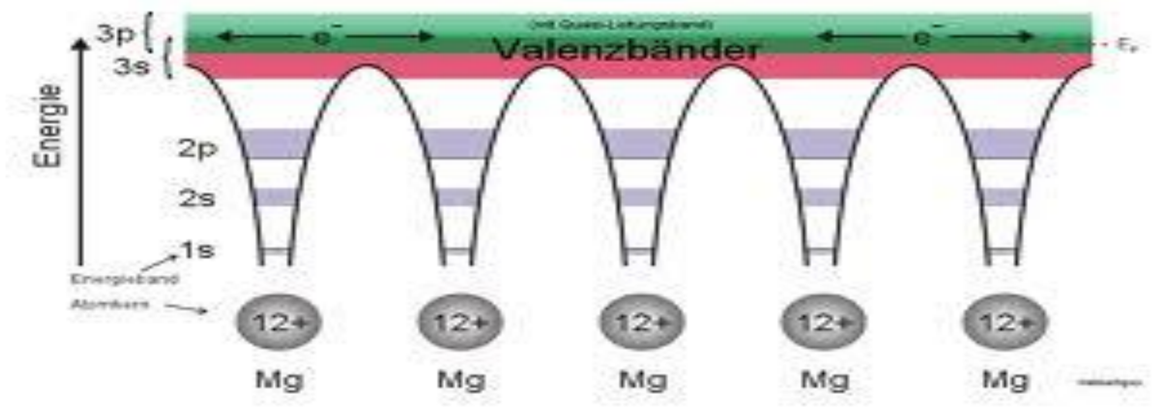
Electrons in a periodic potential –Bloch Theorem:

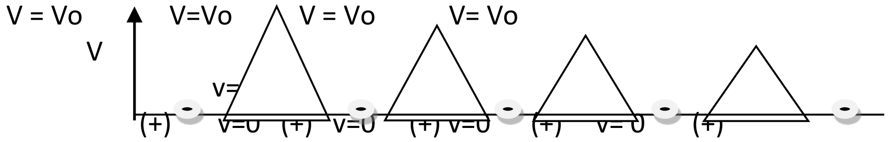
An electron moves through + ve ions, it experiences varying potential. The potential of the electron at the +ve ions site is zero and is maximum in between two +ve ions sites.

The potential experienced by an e^-, when it passes though +ve ions shown in fig.



i.e. The potential experienced by an e^-, in shown in Fig known as real periodic potential variation.

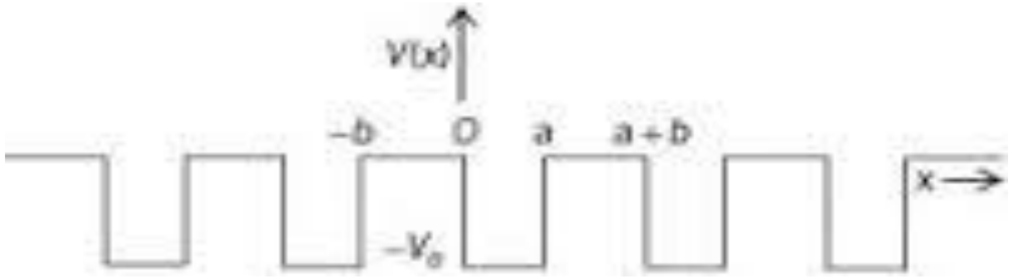




To study the motion of e⁻ in lattice and the energy states it can occupy, Schrodinger equation is necessary. Kronig-penny introduced a simple model for the shape of potential variation. The potential inside the crystal is approximated to the shape of rectangular steps.

KRONIG- PENNY MODEL:-

Kronig – penny consider a periodic arrangement of potential walls and barriers to represent the potential variation exhibited by the e⁻, known as ideal-periodic square well potential as shown in figure. New forms of boundary conditions are developed to obtain a simple solution known as cyclic or periodic boundary conditions.



The wave functions associated with this model can be calculated by solving Schrödinger's eq for two regions 1 and 2.

ie $\frac{d^2\varphi}{dx^2} + \frac{8\pi^2 m}{h^2} E\,\varphi = 0$, $0 < x < a$

$$\frac{d^2\varphi}{dx^2} + \alpha^2\varphi = 0,\ \alpha^2 = \frac{8\pi^2 m}{h^2} E$$

$\frac{d^2\varphi}{dx^2} = \frac{8\pi^2 m}{h^2}(v_0 - E)\varphi = 0$, $-b < x < o$

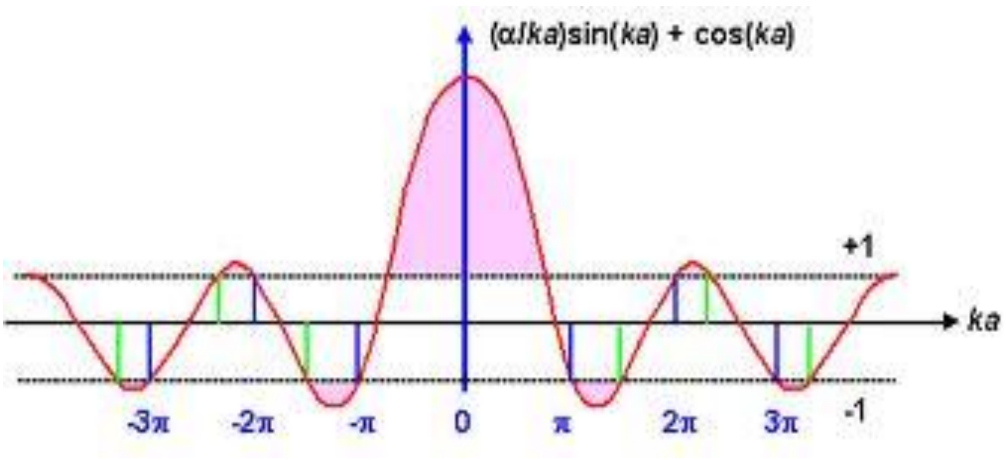
$\frac{d^2}{dx^2} - \beta^2\varphi = 0,\ \beta^2 = \frac{8\pi^2 m}{h^2}(v_0 - E)$

These two eqs are solved by using Bloch and Kronig-penny models, and applying boundary conditions the solution is

$$p\,\frac{\sin \alpha a}{\alpha a} + \cos \alpha a = \cos ka \qquad 1$$

Here $p = \frac{m v_0 b a}{h^2}$ is scattering power

And 'v_0 b' is known as barrier strength.



Conclusion from Kronig –Penny Model:

1) The energy spectrum of e^- consists of an infinite number of allowed energy bands separated by intervals in which, there are no allowed energy levels. These are known as forbidden regions.

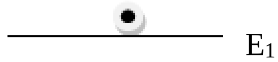
2)When αa increase, the first term of eq(1) on LHS decrease , so that the width of the allowed energy bands is increased and forbidden energy regions become narrow.

3) The width of the allowed band decrease with the increase of p value. When p → α, the allowed energy regions become infinity narrow and the energy spectrum becomes line spectrum.

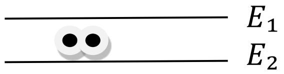
5. Explain the origin of energy band formation in solids based on band theory.

Energy band Formation in solids:

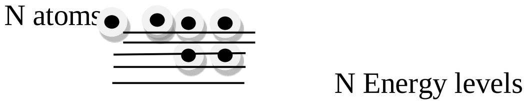
In isolated atom, the e^-s are tightly bound and have discrete, sharp energy levels.



When two identical atoms are brought closer the outermost orbits of these atoms overlap and interacts with the wave functions of the e^-s of the different atoms, then the energy levels corresponding to those wave functions split in to two.



If more atoms are brought together more levels are formed and for a solid of N atoms, each of these energy levels of an atom splits into N levels of energy.



- The levels are so close together that they form almost continuous band.
- The e^- first occupies lower energy bands and are of no importance in determining many of the physical properties of solid.
- These e^- present in higher energy bands are important in determining many of the physical of solids.
- These two allowed energy bands are called as valence and conduction bands.
- The band corresponding to the outermost orbit is called conduction band and the gap between those two allowed bands is called forbidden energy gap or band gap.

6. What is effective mass of an electron? Derive an expression for the effective mass of an electron.

Effective mass of the electron moving in a crystal lattice:

- Consider a crystal (metal) subjected to an electric field ‘E’, so the force experienced by an electron of charge ‘e’ is Ee.
- Acceleration of the electron in the crystal is given by a = F/m = Ee/m
- But acceleration of the electron is not constant because of the velocity changes i.e., the electron move faster near the +ve ions in the crystal. Since the electric field and charge of the electron are invariant, the effective mass m^* of the electron change accordingly.
  i.e $F = m^*a$ ———— (1)
- Consider a particle velocity ‘v’ is equal to group velocity ‘v_g’ of a wave packet, then
  $V = v_g = \frac{dw}{dk}$, w = angular frequency, k = wave propagation vector
  W=2πv dw = 2πdv
  Frequency of the complex wave v = E/h dv=1/hdE
  dw=2π dE/h=dE/ђ
  :. V= dw/dk=1/ђ dE/dk
  SO, $a = \frac{dk}{dt} = (\frac{1}{ђ}) \frac{d^2E}{dk\,dt}$
  $a = \frac{1}{ђ} \frac{d^2E}{dk^2} (\frac{dk}{dt})$
  Wave propagation vector $k = \frac{2\pi}{\lambda}$
  $k = \frac{2\pi}{h} P = \frac{p}{ђ}$
  \`P\` is momentum, \`$\lambda$\` is de-Broglie wavelength .
  $\therefore \frac{dk}{dt} = \frac{1}{ђ} (\frac{dp}{dt}) = \frac{F}{ђ}$.

  Since $\frac{dp}{dt}$ is the rate of change of momentum, which is nothing but force \`F\`.

  $a = \frac{1}{ђ} \frac{d^2E}{dk^2} \frac{1}{ђ} F$

  $a = \frac{F}{ђ^2} (\frac{d^2E}{dk^2})$

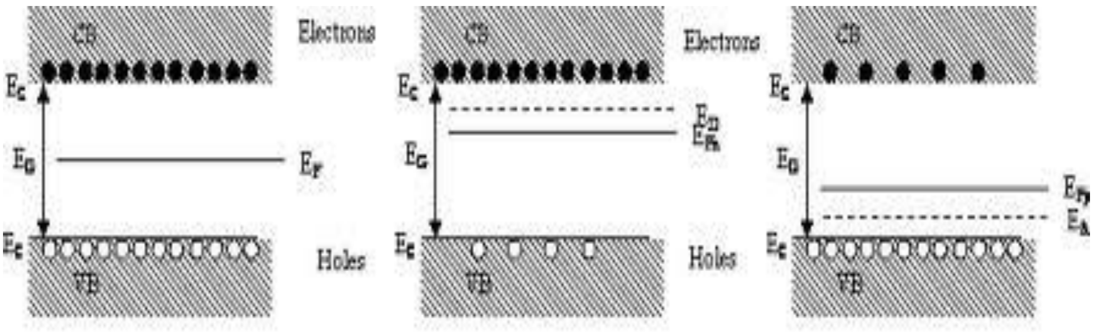
  i.e. $F = \frac{ђ^2}{\frac{d^2E}{dk^2}} a$ (2)

  Compare 1 & 2

  Effective mass $m^* = \frac{ђ^2}{\frac{d^2E}{dk^2}}$

7. Derive an expression for carrier concentration of intrinsic semiconductors?

Intrinsic Semi conductors:



Intrinsec semiconductor (a) n-type semiconductor (b) p-type semiconductor (c)

- A semi conductor in which holes in the valance band and electrons in the conduction band are solely created by thermal excitations is called intrinsic semiconductors i.e., A pure semi-conductor is considered as intrinsic semiconductor.
- The no. of electrons moving into the conduction band is equal to the no. of holes created in the valence band.
- The Fermi level lies exactly in the middle of forbidden energy gap.
- Intrinsic semi-conductors are not of practical use in view of their poor conductivity.

Carrier concentration in intrinsic semi-conductors:

- In the conduction band, the level density D (E) at an energy E is given by the expression.

$$D(E)dE = \frac{4\pi}{h^3}(2\text{m})^{3/2}\ \text{E}^{1/2}\ \text{dE}$$

- The probability of an energy level filled with electrons is given by Fermi-Dirac function.

$$\text{F (E)} = \frac{1}{1+\exp(\frac{\text{E}-\text{EF}}{KT})}$$

- The no of electrons ‘n’ filling into energy level between the energies E and E+dE is

$$\text{n = D(E) F(E) dE}$$

- $\text{n}= \frac{4\pi}{h^3}(2\text{me})^{3/2}\ \text{E}^{1/2}\frac{1}{1+\exp(\frac{\text{E}-\text{EF}}{KT})}\ \text{dE}$
- In the above expression, mass of the electron ‘m’ is replaced with effective mass m_e^* and factor ‘2’ for the two possible spins of the electrons.
- The number of electrons in the conduction band is obtained by making integration between the limits Ec to ∞. Since minimum energy in the conduction band is Ec and at the bottom of the conduction band we write E- Ec for E

$$\text{n}= \frac{4\pi}{h^3}(2m_e^*)^{3/2}\int_0^\infty \frac{(E-E_C)^{\frac{1}{2}}}{1+\exp(\frac{\text{E}-E_F}{KT})}\,dE$$

For all possible temperatures E-E_F >>>> KT

Hence F (E) = $\exp -(\frac{(\text{E}-E_F)}{KT}) = \exp(\frac{E_F-\text{E})}{KT})$

Equation 1 becomes

$\text{n} = \frac{4\pi}{h^3}(2m_e^*)^{3/2}\int_{E_c}^\infty(\text{E}-\text{Ec})1/2\ \exp(\frac{\text{EF}-\text{E}}{KT})\text{dE}$

$\text{n} = \frac{4\pi}{h^3}(2m_e^*)^{3/2}\ \exp\ (\text{E}_\text{F}/\text{KT})\int_{E_c}^\infty(\text{E}-\text{Ec})1/2\ \exp(\frac{-\text{E}}{KT})\text{dE}$

To solve this Integral Part

E-Ec = x

E = Ec+x

dE = dX

$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2}\exp(E_F/KT)\int_0^\infty x^{\frac{1}{2}}\exp-(\frac{Ec+x}{KT})dx$

$n = \frac{4\pi}{h^3}(2m_e^*)3\,/^2\exp(\frac{EF-Ec}{KT})\ \int_0^\infty x^{\frac{1}{2}}\exp-(\frac{x}{KT})$

Using gamma function, it can be shown that
$\int_0^\infty x^{\frac{1}{2}}\exp-(\frac{Ec+x}{KT}) = (KT)^{3/2}\frac{\pi}{2}^{1/2}$
Hence, $n = \frac{4\pi}{h^3}(2m_e^*)^{3/2}\exp(\frac{EF-Ec}{KT})(KT)^{3/2}\frac{\pi}{2}^{1/2}$
No of electrons per unit volume is given by
$n = 2(\frac{2\pi m_e^* KT}{h^2})\exp(\frac{E_F-Ec}{KT})$
The expression for no of holes in the valance band is given by the expression
$P = 2(\frac{2\pi m_p^{*v} KT}{h^2})\exp(\frac{Ev-E_F}{KT})$
In Intrinsic semi conductor n=p then the Intrinsic carrier concentration is n=p=ni;
$ni^2 = 4(\frac{2\pi KT}{h^2})^3(m_e^* m_p^*)^{3/2}\quad\exp(\frac{Ev-Ec}{KT})$
$ni^2 = 4(\frac{2\pi KT}{h^2})^3(m_e^* m_p^*)^{3/2}\quad\exp(\frac{-Eg}{KT})$
Here Ec - Ev = Eg (forbidden energy gap)
Hence $ni = 2(\frac{2\pi KT}{h^2})^{3/2}(m_e^* m_p^*)^{3/4}\exp(\frac{-Eg}{2KT})$
Fermi Level: In Intrinsic semi conductor n=p and assuming the effective mass of e and hole to be same, i.e. $m_e^* = m_p^*$
$\text{Exp}(\frac{Ef-Ec}{KT}) = \exp(\frac{Ev-Ef}{KT})$
$E_F - Ec = Ev - E_F$
$2E_F = Ev+Ec$
$E_F = \frac{Ev+Ec}{2}$
Thus the Fermi level is located half way between the valance band and conduction band and its position is independent of the temperature.

8. Derive an expression for carrier concentration in n-type extrinsic semiconductors?

- When pentavalent impurities like P, As, Sb is added to the intrinsic semi-conductors, resultant semi conductor is called N-Type semi-conductor.
- The concentration of free electrons is more when compared to concentration of holes.

Expression for carriers' concentration in N-type semi conductors:

- In this type of semi conductor, there will be donor levels formed at an energy Ed.
- N_d represents no. of impurities per unit volume of semi conductor.
- At low temperature all donor levels are filled with electrons, with increase of temperature, more and more donor atoms get ionized and the density of electrons in the conduction band increases.
- Density of electrons in the conduction band is given by

  $n = 2(\frac{2\pi m_e^{*v} KT}{h^2})^{3/2}\quad\exp(\frac{EF-Ec}{KT}) \rightarrow 1$
- The Fermi level (E_F) lies in between Ed & Ec
- The density of empty donor levels is given by

  $Nd[1-F(E_d)] \approx N_d[1-1+\exp(\frac{Ed-Ec}{KT})] = Nd[1-F(E_d)] \approx Nd\exp(\frac{Ed-Ec}{KT})$

- At low temperature, there are no excitations of the electrons from donor level to the conduction band.
- Hence, density of empty donors and the electron density in conduction band should be same

  i.e. $2(\frac{2\pi m_e^* KT}{h^2})^{3/2} \exp(\frac{Ef-Ec}{KT}) = N_d \exp(\frac{Ed-Ef}{KT})$
- Taking log on both the sides & rearranging

  $(\frac{Ef-Ec}{KT}) - (\frac{Ed-Ef}{KT})$ -log Nd – log $2(\frac{2\pi m_e^* KT}{h^2})^{3/2}$

  $E_F - Ec - Ed/KT = \log(\frac{Nd}{2(\frac{2\pi m_e^{*v} KT}{h^2})\ 3/2})$

  2Ef – (E_c+E_d) KT log $(\frac{Nd}{2(\frac{2\pi m_e^{*v} KT}{h^2})\ 3/2}) \rightarrow 2$
- At absolute zero $E_F = \frac{Ec+E_d}{2}$

  i.e. Fermi level lies exactly at the middle of donor level E_d and the bottom of the Conduction band E_c.

  Substituting equation 2 in eqn. 1 & re-arranging,

  $N = (2^{Nd})\ ½\ (\frac{2\pi m_e^* KT}{h^2})^{3/4} \exp(\frac{E_d-Ec}{2KT})$
- Hence the density of the electrons in the conduction band is proportional to the square root of the donor concentration.

9. Derive an expression for carrier concentration in p-type extrinsic semiconductors?

- P-type semi-conductors are fabricated by addition of trivalent atoms like Al as impurity to the intrinsic semi-conductor.
- Hence, holes are majority charge carriers and free electrons are minority charge carriers.

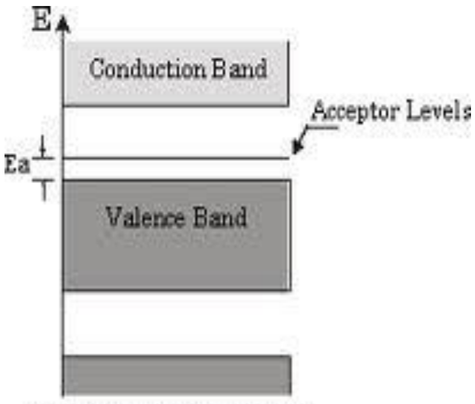
Expression for Carrier concentration in P type semi-conductors:

- In this type of semi-conductor, there will be there will be acceptor levels formed at an energy Ea.
- Na represents no. of impurities per unit volume of semi-conductor.
- At low temperatures, all the acceptor levels are empty.
- With increase of temperature, acceptor atoms get ionized i.e. the electrons moves from valance band and occupy the vacant sites in the acceptor energy levels, there by leaving holes in the valence band
- Density of holes in the valance band is given by

  $P = 2(\frac{2\pi m_p^* KT}{h^2})^{3/2} \exp(\frac{Ev-Ef}{KT})$
- Since Ef lies below the acceptor levels, the density of ionized acceptors is given by

  $N_a F(E_a) = N_a \exp(\frac{Ef-Ea}{KT})$
- Hence, density of holes in the valance band is equal to the density of ionized acceptors.

  $2(\frac{2\pi m_p^* KT}{h^2})^{3/2} \exp(\frac{Ev-Ef}{KT}) = N_a \exp(\frac{Ef-Ea}{KT})$

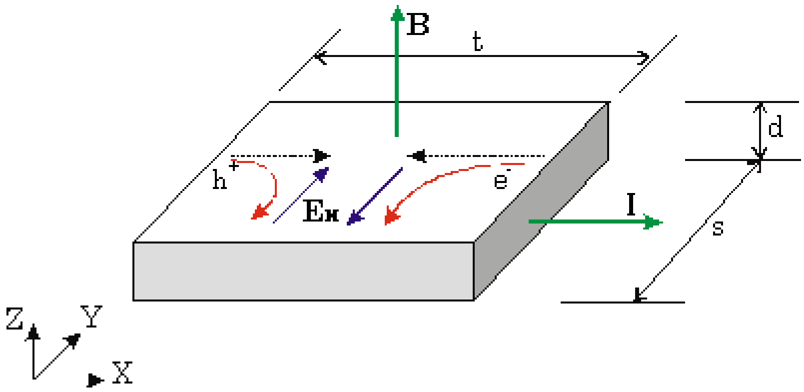


B) p-type semiconductor

i.e. $2\frac{Ev-Ef-Ef+Ea}{KT} = \frac{Na}{2\left(\frac{2\pi m_p^* KT}{h^2}\right)^{3/2}}$

- Taking log, $\frac{Ev+Ea-2Ef}{KT} = \log \frac{Na}{2\left(\frac{2\pi m_p^* KT}{h^2}\right)^{3/2}}$ → 2
- At 0° K, $E_f = \frac{Ev+Ea}{2}$
  i.e. At 0 K, Fermi level lies exactly at the middle of the acceptor level and in the top of the valance band.
- Sub. eqn. 2 in eqn. 1 & re-arranging, $P=(2Na)\,½\left(\frac{2\pi m_p^* KT}{h^2}\right)^{3/4} \exp\left(\frac{Ev-Ea}{KT}\right)$
- Thus the density of the holes in the valance band is proportional to the square root of the acceptor concentration.

10. Explain Hall Effect in detail? What are its applications?



Hall-Effect:

- When a material carrying current is subjected to a magnetic field in a direction perpendicular to direction of current, an electric field is developed across the material in a direction perpendicular to both the direction of magnetic field and current direction. This phenomenon is called “Hall-effect”.

Explanation:

- Consider a semi-conductor, and current passes along the X-axis and a magnetic field Bz is applied along the Z-direction, a field Ey is called the Hall field which is developed in the Y-direction.

- In P-tpe semi-conductor, holes move with the velocity "V" in the "+"ve X-direction. As they move across the semi conductor the holes experience a transverse force 'Bev' due to the magnetic field.
- This force drives the holes down to the lower face. As a result, the lower face becomes +vely charged and –ve charge on the upper surface creating the hall field in the Y-direction. The Hall field exerts an upward force on holes equal to Ee.
- In the steady sate, two forces just balance and as a result, no further increase of + ve charge occurs on Face1.
- In N type semiconductor, the majority charge carriers are electrons experiences a force in the downward direction and lower face gets – vely charged. As a result, Hall field will be in the Y – direction.

Demonstration:

- Consider a rectangular slab of n-type semi conductor carrying current in the + ve X-direction.
- If magnetic field "B' is acting in the Z-direction as shown then under the influence of magnetic field, electrons experience a force given by F_L = -Bev.
- As a result of force F_H acting on the electrons in the Y – direction as a consequence the lower face of the specimen gets – vely charged and upper surface is + vely charged.
- Hence a potential V_H called the Hall Voltage present between the top and bottom faces of the specimen.
- The Hall fieldF_H, exerts an upward force on the electrons given by F= -eE_H
- The two opposing forcesF_L and F_H establish an equilibrium under which

  $|F_L| = |F_H|$ i.e -Bev =-eE_H

  E_H = BV

- If 'd' is the thickness of the specimen, then $E_H = \frac{V_H}{d}$

  $V_H = E_H d$

  V_H = Bvd

- If 'W' is the width of the specimen, then $J = \frac{I}{wd}$

  J= nev =ρV

  $=> V_H = \frac{\text{Bid}}{\rho wd} = \frac{\text{Bi}}{pw}$

Hall Coefficient:

- Hall fieldE_H, for a given material depends on the current density J and the applied magnetic field B.

  i.e. E_Hα JB

  $E_H = R_H$ α JB

  Since, $V_H = \frac{\text{Bi}}{\rho w}$, $E_H = \frac{V_H}{d}$

  $E_H = \frac{\text{Bi}}{\rho wd}$

  $J = \frac{\text{i}}{wd}$, $\frac{\text{Bi}}{\rho wd}$ $= R_H = (\frac{\text{i}}{wd})$ B

  i.e $R_H = \frac{I}{\rho}$

Applications:

Determination of the type of Semi-conductors:

The Hall coefficient R_H is -ve for an n-type semiconductor and +ve for p-type semiconductor. Thus the sign of Hall coefficient can be used to determine whether a given Semi-conductor is n or p-type.

Calculation of carrier concentration:

$$R_H = \frac{I}{\rho} = \frac{I}{ne} \text{ (for e}^{-}\text{ s)}$$

$$R_H = \frac{I}{\rho e} \text{ (for holes)}$$

$$\Rightarrow n = \frac{I}{eR_H}$$

$$\Rightarrow \rho = \frac{I}{eR_H}$$

Determination of Mobility:

If the conduction is due to one type carriers, ex: electrons

$$\sigma = ne\mu$$

$$\mu = \frac{\sigma}{ne} = \sigma R_H$$

| | $$\mu = \sigma R_H$$

Measurement of Magnetic Flux Density:

Hall Voltage is proportional to the magnetic flux density B for a given current I. so, Hall Effect can be used as the basis for the design of a magnetic flux density metal.

UNIT- 3: DIELECTRIC PROPERTIES & MAGNETIC MATERIALS

Part-A (SAQ-2Marks)

(1)Define the following terms (i)Electric dipole (ii)Dipole moment (iii) Dielectric constant (iv)Polarization (v)Polarization vector(vi) Electric displacement vector.

Electric dipole: Two equal and opposite charges small in magnitude and separated by a small distance constitute a electric dipole.

Dipole moment: The product of magnitude of both charge and the distance between the two charges. i.e. $\mu = q\, r$.
It is a vector quantity.
The direction of μ is from negative to positive.

Dielectric constant:$(\boldsymbol{\varepsilon_r})$**:** Dielectric constant is the ratio between the permittivity of the medium to the permittivity of the free space. $\boldsymbol{\varepsilon_r} = \frac{\boldsymbol{\varepsilon}}{\boldsymbol{\varepsilon_o}}$
Since it is the ratio of same quantity, $\boldsymbol{\varepsilon_r}$ has no unit.

Polarization: The process of producing electric dipoles which are oriented along the field direction is called polarization in dielectrics.

Polarization vector (P): The dipole moment per unit volume of the dielectric material is called polarization vector P.

$$P = \frac{\mu}{V}$$

If μ is the average dipole moment per molecule and N is the number of molecules per unit volume, then polarization vector, $P = N\mu = N\alpha E$

Electric displacement vector is a quantity which is a very convenient function for analyzing the electrostatic field in the dielectrics and is given by $D=\varepsilon_o E+P$

2) Write a short note on Ferro Electricity.

Ferro Electricity: Substances exhibiting electronic polarization even in the absence of external field are called Ferroelectric Materials. This phenomenon is known as Ferroelectricity. Examples: Rochelle salt ($NaKC_4H_4O_6.4H_2O$), Lead Titanate, $PbTiO_3$, Lead zirconate Titanate (PZT), Lead lanthanum zirconate Titanate (PLZT).

Properties

- Have peculiarly large dielectric constant.
- They exhibit hysteresis phenomena like ferromagnetic materials.

3) Write a short note on Piezo Electricity.

Piezo Electricity: When certain crystals are subjected to stress, the electric charges appear on their surface with certain distance of separation. This is called the piezoelectric effect. The crystals exhibiting Piezo electric effect are called piezoelectric crystals and this phenomenon is called Piezo electricity. Examples: Quartz, Rochelle salt, Tourmaline.

- Non-Centro Symmetric crystals are exhibiting this property.

4) **Define the following terms (a) Magnetic flux (b) Magnetic induction(c) Magnetic field strength (d) Intensity of magnetization(e) Magnetic susceptibility(f) Magnetic permeability of medium**

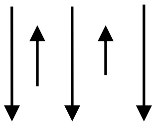
Magnetic flux(φ): The number of lines passing normally through an area. Its unit is Weber.
Magnetic induction (or) Magnetic flux density (B): The magnetic induction in any material is the number of lines of magnetic force passing through unit area perpendicularly. Its unit is Weber/m^2or tesla.
Magnetic field intensity (or) strength (H): Magnetic field intensity at any point in the magnetic field is the force experienced by a unit North Pole placed at that point. Its unit is ampere m^{-1}
Magnetization (or) Intensity of magnetization (I): The term of magnetization is the process of converting a non magnetic material into a magnetic material.
It is also defined as the magnetic moment per unit volume.$I = \frac{M}{V}$. Its units is ampere m^{-1}
Magnetic susceptibility (χ): The ratio of intensity of magnetization (I) produced to the magnetic field strength (H) in which the material is placed.

$$x = \frac{I}{H}$$

Magnetic permeability of medium (μ): It is defined as the ratio of magnetic induction B in a substance to the applied magnetic field intensity. $\mu = \frac{B}{H}$

5) What are ferrites? Mention any two applications.

- Ferri magnetic substances are the materials in which the atomic or ionic dipoles in one direction are having unequal magnitudes. This alignment of dipole gives a net magnetization and those magnetic substances which have two or more different kind of atoms. These are also called Ferrites.



Applications of ferrites:

- They are used to produce ultrasonics by magnetization principle.
- Ferrites are used in audio and video transformers.

Part- B (Descriptive- 10marks)

(1) Define polarization? Explain the various types of polarization in dielectrics?

Polarization: The process of producing electric dipoles which are oriented along the field direction is called polarization in dielectrics.

Types of Polarizations:

Polarization occurs due to several atomic mechanisms. When the specimen is placed inside electric field, mainly three types of polarizations are possible. Those are

- Electronic polarization
- Ionic polarization
- Orientational or Dipolar polarization

Electronic polarization:

- Electronic polarization occurs due to the displacement of negatively charged electron in opposite direction.
- When an external field is applied and there by creates a dipole moment in the dielectric.
- Therefore induced dipole moment $\mu=\alpha_e E$.
- Where α_e is the electronic polarizability.
- Electronic polarizability is proportional to the volume of atoms.
- This Polarization is independent of temperature.

Ionic polarization:

- This is due to the displacement of cations and anions in opposite directions and occurs in an ionic solid. This type of polarization occurs in ionic dielectrics like Nacl.
- When such a dielectric material is subjected to an external electric field, adjacent ions of opposite sign undergoes displacement and this displacement results either increase or decrease in the distance of separation between ions.
- If x_1 and x_2 are the displacements of positive and negative ions in an ionic crystal due to the application of electric field E, then dipole moment $\mu = q \times (x_1 + x_2)$.

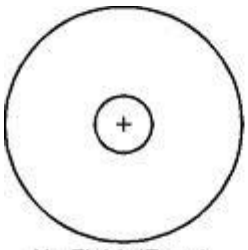
Orientational or Dipolar polarization:

- This type of polarization occurs in materials with polar molecules.
- Without the external field the molecules are oriented at random. So the net dipole moment is zero.
- When external field is applied the polar molecules orient favorably into the field direction. The process of orientation becomes easy at high temperature.
- Hence the Orientational polarizability is strongly dependent on temperature. $\alpha_o=\frac{P_o}{NE} = \frac{\mu^2}{3KT}$

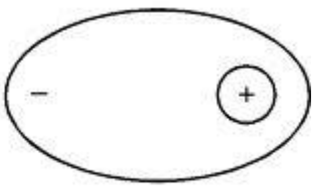
(2) Derive the expression for electronic and ionic polarizations.

Electronic polarization and calculation of Electronic polarizability:

- Electronic polarization occurs due to the displacement negative electron cloud of each atom with respect to its nucleus in the presence of electric field. When an external field is applied and there by creates a dipole moment in the dielectric.



No Field, (E = o)



Applied Field, (E ≠ o)

- Therefore induced dipole moment μ=α_eE.
- Where α_e is the electronic polarizability.
- Electronic polarizability is proportional to the volume of atoms.
- Polarizability is independent of temperature.

Calculation of electronic polarizability:

(I)Without Electric field:

- Let us consider a classical model of an atom. Assume the charge of the nucleus is +Ze and the nucleus is surrounded by an electron cloud of charge –Ze which is distributed in sphere of radius R.
- The charge density of the charged sphere = $\frac{-Ze}{\frac{4}{3}\pi R^3}$
- Charge density $\rho = \frac{-3}{4}\,\frac{Ze}{\pi\, R^3}$-------------------1

(II) With Electric field:

When the dielectric is placed in an electric field E, two phenomena occurs

- Lorentz force due to the electric field tends to separate the nucleus and the electron cloud from their equilibrium position.
- After the separation, an attractive coulomb force arises between the nucleus and electron cloud which tries to maintain the original equilibrium position.
- Let x be the displacement made by the electron cloud from the positive core .Since the nucleus is heavy it will not move when compared to the movement of electron cloud here x<<R, where R is the radius of the atom.
- Since the Lorentz and coulombs forces are equal and opposite in nature, equilibrium is reached.
- At equilibrium Lorentz force = Coulomb force
  Lorentz force = charge × field = -ZeE--------------2
  Coulomb force=charge × field = +Ze×$\frac{Q}{4\pi\varepsilon_O\ x^2}$
- Then Coulomb force=charge X $\frac{\text{total negative charges(Q)enclosed in the sphere of redius x}}{4\pi\varepsilon_O\ x^2}$---3
- Here the total number of negative charges (Q) encloses in the sphere of radius R is

  X= charge density of the electron × volume of the sphere ---------------4

- Substitute ρ from 1 in 4 we get
  Q= $\frac{-3}{4}\,\frac{Ze}{\pi\, R^3}\times\frac{4}{3}\,\pi x^3$, i.e Q= $\frac{Zex^3}{R^3}$ ------------------------------5

- Substitute Q from 5 in 3 we get

  Coulomb force = $\frac{Ze}{4\pi\varepsilon_O\ x^2}\ (\frac{Zex^3}{R^3})$----------6
- At equilibrium Lorentz force= Coulomb force

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

  X= $\frac{4\pi\varepsilon_o\ R^3 E}{Ze}$---------------------------------7
- Therefore the displacement of electron cloud x is proportional to the applied electric field E.

Dipole moment:

- Now the two electric charges +Ze and –Ze are displaced by a distance under the influence of the field and form a dipole.
- Induced dipole moment = magnitude of charge × displacement = Ze X -----------8
- Substitute the value of X from 7 in 8 we have

  μ_e= Ze × $\frac{4\pi\varepsilon_o\ R^3 E}{Ze}$

  μ_e= $4\pi\varepsilon_o\ R^3 E$

  μ_e= α_eE--------------------------------9

  $\boldsymbol{\alpha_e = 4\pi\varepsilon_o\ R^3}$ is called electronic polarizability

Calculation of ionic polarization:

- Ionic polarization is due to the displacement of cations and anions in opposite directions and occurs in an ionic solid.
- Suppose an electric field is applied in the +ve x direction, the +ve ions move to the right by x_1 and the –ve ions move to the left by x_2.
- Assuming the each unit cell has one cation and one anion, the resultant dipole moment per unit cell due to ionic displacement is given by $\mu = \boldsymbol{e}(x_1 + x_2)$ ------------1
- If β_1 and β_2 are restoring force constants of cation and anion and F Newton's is the force due to the applied field, $F = \beta_1 x_1 = \beta_2 x_2$-------------------------2
- Hence $x_1 = \frac{F}{\beta_1}$
- Restoring force constants depend upon the mass of the ion and angular frequency of the molecule in which ions are present.

  $x_1 = \frac{eE}{m\omega_0^2}$----------------------3, where 'm' is the mass of +ve ion.

  $x_2 = \frac{eE}{M\omega_0^2}$ --------------------------4, Where 'M'is the mass of -ve ion.

  $x_1 + x_2 = \frac{eE}{\omega_0^2}\left(\frac{1}{M} + \frac{1}{m}\right)$ --------------------------5

  And $\boldsymbol{\mu} = \boldsymbol{e}(x_1 + x_2) = \frac{e^2 E}{\omega_0^2}\left(\frac{1}{M} + \frac{1}{m}\right)$ --------------------------6

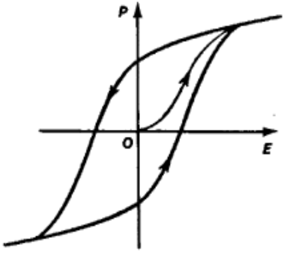
$$\propto_i = \frac{\mu}{E} = \frac{e^2}{\omega_0^2}\left(\frac{1}{M} + \frac{1}{m}\right)$$

- Thus the ionic polarizability $\propto_i$ is inversely proportional to square of the natural frequency of the ionic molecule and is reduced mass is equal to $\left(\frac{1}{M} + \frac{1}{m}\right)^{-1}$.

(3) Write a short note on (a) Ferro electricity (b) Piezo electricity.

(a)Ferro Electricity: Substances exhibiting electronic polarization even in the absence of external field are called Ferroelectric Materials. This phenomenon is known as Ferroelectricity.
Examples: Rochelle salt ($NaKC_4H_4O_6.4H_2O$), Lead Titanate, $PbTiO_3$, Lead zirconate Titanate (PZT), Lead lanthanum zirconate Titanate (PLZT).
Properties:

- Have peculiarly large dielectric constant.
- They exhibit hysteresis phenomena like ferromagnetic materials.

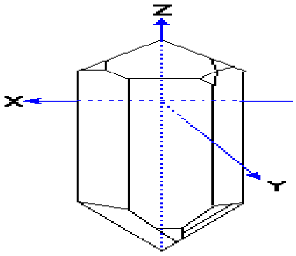


- The polarization is not zero even when external field is zero.
- Ferroelectrics follow Curie-Weiss law, the electric susceptibility $\Psi = \frac{C}{T-\theta}$
- Here C=Curie temperature, θ= transition temperature, above which Ferro electric substance becomes Para electric substances. Spontaneous polarization becomes zero at transition temperature.
- All Ferro electric materials are Pyro electric; however the converse is not true.
- They exhibit the phenomenon of Double refraction.

(b)Piezoelectricity:

- When certain crystals are subjected to stress, the electric charges appear on their surface with certain distance of separation. This is called the piezoelectric effect. The crystals exhibiting Piezo electric effect are called piezoelectric crystals and this phenomenon is called Piezo electricity.
  Examples: Quartz, Rochelle salt, tourmaline are piezoelectric substances.
- Piezoelectric strains are very small, and the corresponding electric fields are very large.
- Non-Centro Symmetric crystals are exhibiting this property.

Explanation:



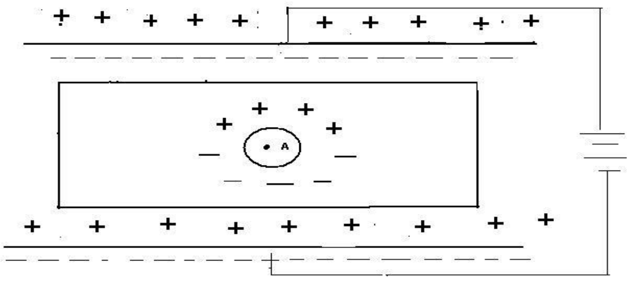
Structure of Quartz

- In 3-dimensional lattices of quartz crystal before the constraint is applied the dipole moment at each lattice point is zero.
- When pressure is applied along X-axis the angle increases giving rise to polarization along Y-axis.
- In structure with centre of symmetry, the opposite ends are identical in any direction. So constraints do not produce any polarization.

(4) Define the local/internal field of cubic structure and derive the expression for it? Or Derive the expression for local field in a symmetrical dielectric material?

- **Local Field:** In presence of Electric field, every dipole experiences its own medium of influence called Local field or internal field.

INTERNAL FIELD OR LOCAL FIELD:



CALCLATION OF LOCAL FIELD

- When an external electric field is applied across a dielectric, the intensity of electric field felt by a given atom is not equal to the applied electric field E, because the atoms are surrounded on all sides by other polarized atoms.
- The internal field E_{int} is defined as the electric field acting on the atom is equal to the sum of the electric fields created by the neighboring polarized atoms and the applied field. This field is responsible for polarizing the atom.
- Where E_{int} is called internal field or Lorentz field.

LORENTZ METHOD TO FIND INTERNAL FIELD:

- A dielectric material is placed in an external electric field. It is placed in between two plates of a parallel plate capacitor.
- Consider an imaginary sphere inside the solid dielectric of radius ‘r’. Radius of the sphere is greater than the radius of the atom.
- Thus there are many atomic dipoles within the sphere. Electric field at the centre of the sphere is called internal field which is made up of the following four factors.

$$E_{int} = E_1 + E_2 + E_3 + E_4 \quad \text{------------------- (1)}$$

E_1 = Electric field due to the charges on the capacitor plates (externally applied).
E_2 = Electric field due to polarized charges on the plane surface of the dielectric.
E_3 = Electric field due to polarized charges induced on the surface of the sphere.
E_4 = Electric field due to permanent dipoles of atoms inside the sphere.

- We can take $E = E_1 + E_2$, where E_1 is the field externally applied and E_2 is the field due to the polarized charges on the plane surface of the dielectric.
- If we consider the dielectric as highly symmetric then the dipoles present inside the sphere will cancel each other.
  - $E_4 = 0$.
  - Equation (1) becomes
- $E_{int} = E + E_3$ ------- (2)

To find E_3:

- Let us consider small area ds on the surface of the sphere. This area is confined within an angle dθ, making an angle θ with the direction of field E.
- 'q' is the charge on the area ds. Polarization P is parallel to E. P_N is the component of polarization perpendicular to the area ds.
- Polarization is defined as the surface charges per unit area.

  Here q'$= P\ \cos\theta ds$
- Electric field intensity at A due to charge q' , E= $\frac{q'}{4\pi\varepsilon_O\ r^2} = \frac{P\ \cos\theta ds}{4\pi\varepsilon_O\ r^2}$
- Electric field intensity at c due to charge q' is given by coulombs law .Electric field intensity E is along the radius r. E is resolved into two components.
- Component of intensity parallel to the field direction Ex = E cos θ.
- Component perpendicular to the field direction Ey = E sinθ.
- The perpendicular components E_y and ($-E_y$) are in opposite directions and hence cancel each other the parallel components alone are taken into consideration. By revolving ds about AB, we get a ring of area dA and radius
- $E_x = E = \frac{P\cos\theta^2 dA}{4\pi\varepsilon_O\ r^2}$
- Ring area dA = Circumference × Thickness

  = 2πy × rdθ ∵ sin θ = y/r

  = 2πr sinθ.rdθ y = r sinθ

  dA = $2\pi r^2 \sin\theta\, d\theta$
- Electric field intensity = $\frac{P\cos\theta^2\ \sin\theta d\theta}{2\varepsilon_O}$
- Electric field intensity due to whole sphere is $E_3 = \int_0^\pi \frac{P\cos\theta^2\ \sin\theta d\theta}{2\varepsilon_O}$

  $= \frac{P}{3\varepsilon_O}$

  - $E_{int} = E + \frac{P}{3\varepsilon_O}$

(5) Derive the Clasius-Mosotti relation based on local field? (Or) Derive an expression relating macroscopic dielectric constant and microscopic polarizability in case of symmetrical dielectric material?

- Let us consider the elemental dielectric having cubic structure as diamond, si, carbon etc. which have cubic structure. Since there is no ions or no permanent dipoles in these material the ionic polarizability α_i & orientational polarizability $\alpha_\circ$ are zero.

  i.e. $\alpha_i = \alpha_\circ = 0$
- Polarization $p = N\alpha_e E_i = N\alpha_e (E + \frac{P}{3\varepsilon_O})$
- p= $\frac{N\alpha_e\ E}{(1 - \frac{N\alpha_e}{3\varepsilon_O})}$------------- (1)
- We know $D = p + \varepsilon_O\, E$ and $P = \varepsilon_O\, E(\varepsilon_r\ - 1)$------------------- (2)

$$\frac{N\alpha_e\ E}{(1 - \frac{N\alpha_e}{3\varepsilon_O})} = \varepsilon_O\, E(\varepsilon_r\ - 1)$$

$$\frac{\varepsilon_r\ -1}{\varepsilon_r\ +2} = \frac{N\alpha_e}{3\varepsilon_O}$$

(6) Explain the classification of magnetic materials on the basis of magnetic moment and mention the important properties of various magnetic materials?

Classification of magnetic materials:

- By the application of magnetic field some materials will not show any effect that are called non magnetic materials and those which show some effects are called magnetic materials.
- All magnetic materials magnetized in the presence of external magnetic field.
- Depending on the direction and magnitude of magnetization and also the effect of temperature on magnetic properties, all magnetic materials are classified into Dia, Para and Ferro magnetic materials.
- Two more classes of materials have structure very close to Ferro magnetic materials, but shows quiet different magnetic properties. They are Anti-Ferro magnetic and Ferri magnetic materials.

Diamagnetism:

- The number of orientations of electronic orbits in an atom be such that vector sum of magnetic moment is zero
- The external field will cause a rotation action on the individual electronic orbits this produces an induced magnetic moment which is in the direction opposite to the field and hence tends to decrease the magnetic induction present in the substance.
- Thus the diamagnetism is the phenomena by which the induced magnetic moment is always in the opposite direction of the applied field.

Properties of diamagnetic materials:

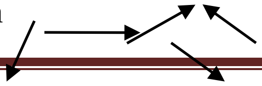
- Diamagnetic material gets magnetized in a direction opposite to the magnetic field.
- Weak repulsion is the characteristic property of diamagnetism.
- Permanent dipoles are absent.
- Relative permeability is less than one but positive.
- The magnetic susceptibility is negative and small. It is not affected by temperature.
- Diamagnetism is universal i.e. all materials when exposed to external magnetic fields, tend to develop magnetic moments opposite in the direction to the applied field.
- When placed inside a magnetic field, magnetic lines of force are repelled.

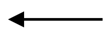
Para magnetism:

- The number of orientations of orbital and spin magnetic moments be such that the vector sum of magnetic moment is not zero and there is a resultant magnetic moment in each atom even in the absence of applied field.
- The net magnetic moments of the atoms are arranged in random directions because of thermal fluctuations, in the absence of external magnetic field. Hence there is no magnetization.
- If we apply the external magnetic field there is an enormous magnetic moment along the field direction and the magnetic induction will be increase. Thus induced magnetism is the source of par magnetism.

Properties of paramagnetic materials:

- Paramagnetic materials get magnetized in the direction of the magnetic field.
- Weak attraction is characteristic property of Para magnetism.
- Paramagnetic material has magnetic dipoles.
- Relative permeability is greater than one but small i.e. this indicate that when paramagnetic substance is placed in a uniform magnetic field, the field inside the material will be more than the applied field.
- The magnetic susceptibility is small and positive. The magnetic susceptibility of paramagnetic is inversely proportional to absolute temperature i.e. χ=C/T. This is called curie law, c is called Curie constant.
- Paramagnetic susceptibility is independent of the applied field strength.
- Spin alignment is random



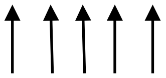


- When placed inside a magnetic field it attracts the magnetic lines of force.
- Examples: Aluminum, Manganese, oxygen.

Ferromagnetism:

- Ferromagnetism arises when the magnetic moments of adjacent atoms are arranged in a regular order i.e all pointing in the same direction.
- The ferromagnetic substances posses a magnetic moment even in the absence of the applied magnetic field, this magnetization is known as the spontaneous magnetization.
- There is a special form of interaction called "exchange "coupling occurring between adjacent atoms, coupling their magnetic moment together in rigid parallelism.

Properties of ferromagnetic materials:

- In ferromagnetic materials, large magnetization occurs in the direction of the field.
- Strong attraction is the characteristic property of ferromagnetism.
- They exhibit spontaneous magnetization.
- The relative permeability is very high for Ferro magnetic.
- The magnetic susceptibility is positive and very high.
- Magnetic susceptibility is fairly high and constant up to a certain temperature according the equation $\chi=\frac{C}{T-T_C}$ C= curie constant $T_c =$ Curie temperature.
- Ferromagnetism is due to the existence of magnetic domains which can be spontaneously magnetized.
- Exhibit hysteresis phenomenon.
- Spin alignment is parallel in the same direction 
- When placed inside a magnetic field they attract the magnetic lines of forces very strongly.
- Examples: Iron, Nickel, Cobalt.

(7)Explain the hysteresis curve based on domain theory of ferromagnetism?

(OR)

Explain the hysteresis in a ferromagnetic material.

Domain theory of ferromagnetism:

- According to Weiss, the specimen of ferromagnetic material having number regions or domains which are spontaneously magnetized. In each domain spontaneous magnetization is due to parallel alignment of all magnetic dipoles.
- The direction of spontaneous magnetization varies from domain to domain.
- The resultant magnetization may hence be zero or nearly zero.
- When an external field is applied there are two possible ways for the alignment of domains.

(i)**<u>By motion of domain walls</u>:** The volume of domains that are favorably oriented with respect to the magnetizing field increases at the cost of those that are unfavorably oriented. [Fig (b)]

(ii)**<u>By rotation of domains</u>**: when the applied magnetic field is strong, rotation of the direction of magnetization occurs in the direction of the field. [Fig(c)]

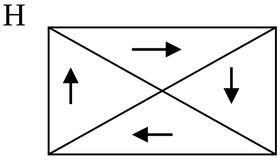


Fig (a)

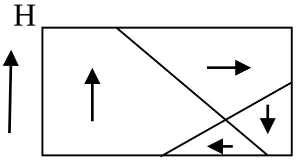
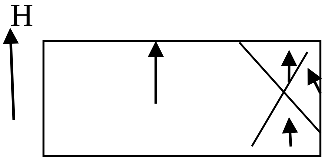
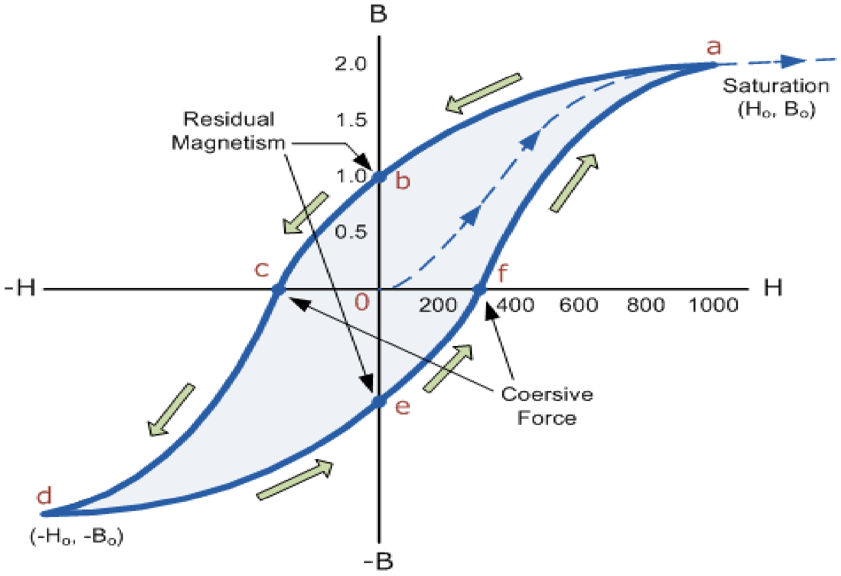


fig (b)



fig(c)

Hysteresis curves

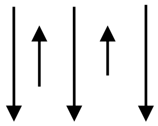


- **Hysteresis**: Lagging of magnetization behind the magnetizing field (H).
- When a Ferro magnetic material is subjected to external field, there is an increase in the value of the resultant magnetic moment due to two processes.
- The movement of domain walls
- Rotation of domain walls
- When a weak magnetic field is applied, the domains are aligned parallel to the field and magnetization grows at the expense of the less favorably oriented domains.
- This results in the Bloch wall (or) domain wall movement and the weak field is removed the domains reverse back to their original state. This reversible wall displacement is indicated by OA the magnetization curve.
- When the field becomes stronger than the domain wall movement, it is mostly reversible movement. This is indicated by path AB of the graph. The phenomenon of hysteresis is due to the irreversibility.
- At the point B all domains have got magnetized, application of higher field rotates the domains into the field direction indicated by BC. Once the domains rotation is complete the specimen is saturated denoted by C.
- Thus the specimen is said to be attain the maximum magnetization. At this position if the external field is removed (H=0), the magnetic induction B will not fall rapidly to zero ,but falls to D rather than O. This shows that even when the applied field is zero the material still have some magnetic induction (OD) which is called residual magnetism or retentivity.
- Actually after the removal of the external field the specimen will try to attain the original configuration by the movement of domain walls. But this movement is stopped due to the presence of impurities, lattice imperfections.
- Therefore to overcome this, large amount of reverse magnetic field (H_c) is applied to the specimen .The amount of energy spent to reduce the magnetization (B) to zero is called “coercivity” represented by OE in the fig.
- **HSTERESIS:** lagging of magnetization (B) behind the magnetizing field (H) is called hysteresis.

- **Hysteresis loss:** It is the loss of energy in taking a ferromagnetic body through a complete cycle of magnetization and this loss is represented by the area enclosed by the hysteresis loop.

(8) Write short notes on Ferri magnetic materials? What their applications?

- Ferri magnetic substances are the materials in which the atomic or ionic dipoles in one direction are having unequal magnitudes. This alignment of dipole gives a net magnetization and those magnetic substances which have two or more different kind of atoms. These are also called Ferrites.



- In Ferri magnetic materials there, they may have large net magnetization as compared to anti Ferro magnetic materials.
- Ferrimagnetic materials generally known as ferrites consist of two or more different kind of atoms their formula is $M_e^{++}Fe_2^{++}O_4^{--}$.
- Where M_e^{++} stands for a suitable divalent metal ion such as Fe^{++}, CO^{++}, Ni^{++}, Mg^{++}, etc, Fe_2^{++} is a trivalent ferric ion.

Applications of ferrites:

- They are used to produce ultrasonics by magnetization principle.
- Ferrites are used in audio and video transformers.
- Ferrites rods are used in radio receivers to increase the sensitivity.
- They are also used for power limiting and harmonic generation.
- Ferrites are used in computers and data processing circuits.
- Ferrites are used in switching circuits and in storage devices of computers.
- Ferrites are not metals but their resistivity lies in the range of insulators or semiconductors.

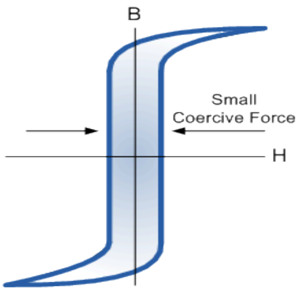
(9) Write short notes on soft and hard magnetic materials?

(Or)

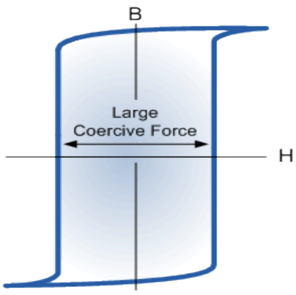
Distinguish soft and hard magnetic materials.

Hard and soft magnetic materials:

- The process of magnetization of a Ferro or Ferri magnetic material consist of moving domains walls so that favorably oriented domains grow and shrink. If the domain walls are easy to move and coercive field is low and the material is easy to magnetize. Such a material is called soft magnetic material.
- If it is difficult to move the domain walls, the coercive field is large then the material is magnetically hard .These are called hard magnetic material.



“Soft” Ferromagnetic Material



“Hard” Ferromagnetic Material

Hard magnetic materials	Soft magnetic materials
(i)Hard magnetic materials have large hysteresis loss due to large hysteresis is loop area.	(i)Soft magnetic materials have low hysteresis Loss due to small hysteresis loop area.
(ii)In these materials the domain wall movement is difficult because of presence of impurities and crystal imperfection and it is irreversible in nature.	(ii)In these materials the domain wall movement is relatively easier, even for small changes in the magnetizing field the magnetization changes by large amount.
(iii) The coercivity and retentivity are large. Hence these materials cannot be easily magnetised and demagnetized	(iii)The coercivity and retentivity are small .Hence these materials can be easily magnetized and demagnetized.
(iv) In these materials, because of the presence of impurities and crystal imperfection the mechanical strain is more. Hence magneto static energy is large.	(iv)These materials are free from irregularities; the magneto static energy is small.
(v)These materials have small values of susceptibility and permeability.	(v)These materials have large values of susceptibility and permeability.
(vi)These are used to make permanent magnets. Example 1. copper nickel iron alloy 2. copper nickel cobalt alloy 3.iron-nickel-aluminum alloys with certain amount of cobalt called alnico alloy	(vi)These are used to make electronic magnets. Example 1. iron silicon alloys 2. ferrites 3.garnets
(vii) Applications: For production of permanent magnets used in magnetic detectors, microphones flux meters, voltage regulators, damping devices, magnetic separators, and loud speakers.	(Vii)Applications: Mainly used in electromagnetic machinery and transformer cores. They are used in switching circuits, microwave insulators and matrix storage of computers.

UNIT- 4 : LASERS & OPTICAL FIBERS

Part-A (SAQ-2Marks)

1) Explain i) Metastable state ii) optical pumping iii) population inversion

Metastable state: The excited state, which has a long life time, is known as metastable state.
Optical pumping: This process is required to achieve population inversion and used in Ruby laser.
Pumping process is defined as: "The process which excites the atoms from ground state to excited state to achieve population inversion".
Population Inversion:
Generally, number of atoms in the ground state is greater than the number of atoms in higher energy states.
But in order to produce a laser beam, the minimum requirement is stimulated emission.
Stimulated emission takes place only if the number of atoms in the higher energy level is greater than the number of atoms in the lower energy level.
Simply population inversion is nothing but number of atoms in higher energy level is greater than the number of atom in lower energy level.

2) Define spontaneous and stimulated emission of radiation?

Spontaneous Emission: When an atom in the excited state emits a photon of energy 'hv' coming down to ground state by itself without any external agency, such an emission is called spontaneous emission. Atom* → atom + hv.
Photons released in spontaneous emission are not coherent. Hence spontaneous emission is not useful for producing lasers.
Stimulated Emission: When an atom in the excited state, emits two photons of same energy 'hv' while coming to down to ground state with the influence of an external agency, such an emission is called stimulated emission. Atom* → atom + 2hv.

- In the two photons one photon induces the stimulated emission and the second one is released by the transition of atom from higher energy level to lower energy level.
- Both the photons are strictly coherent. Hence stimulated emission is responsible for laser production.

3) Explain the basic principle of optical fiber?

- Optical fibers are the waveguides through which electromagnetic waves of optical frequency range can be guided through them to travel long distances.
- An optical fiber works on the principle of total internal reflection (TIR).
- **Total Internal Reflection**: when a ray of light travels from a denser medium into a rarer medium and if the angle of incidence is greater than the critical angle then the light gets totally reflected into the denser medium

4) Explain i) Numerical Aperture ii) Acceptance angle

i) Numerical Aperture:
Numerical aperture of a fiber is a measure of its light gathering power.
"The Numerical Aperture (NA) is defined as the sine of the maximum acceptance angle"
The light gathering ability of optical fiber depends on two factors i.e.,

- Core diameter
- NA

NA is defined as sine of the acceptance angle
i.e., NA = Sin θ_A i.e NA = $\sqrt{n_1^2-n_2^2}$
The efficiency of optical fiber is expressed in terms of NA; it is called as figure of merit of optical fiber.

ii) Acceptance Angle:

All right rays falling on optical fiber are not transmitted through the fiber.
Only those light rays making $\theta_i > \theta c$ at the core-cladding interface are transmitted through the fiber by undergoing TIR. For which angle of incidence, the refraction angle is greater than 90^0 will be propagated through TIR.
There by Acceptance Angle is defined as: The maximum angle of incidence to the axis of optical fiber at which the light ray may enter the fiber so that it can be propagated through TIR.

5. What are the main sections of optical fiber? Describe the step index optical fiber?

- An optical fiber consists of three (3) co-axial regions.
- The inner most region is the light-guiding region known as "Core". It is surrounded by a middle co-axial regional known as "cladding". The outer most regions which completely covers the core & cladding regions is called "sheath or buffer jacket".
- Sheath protects the core & cladding regions from external contaminations, in addition to providing mechanical strength to the fiber.
- The refractive index of core (n_1) is always greater than the refractive index of cladding (n_2) i.e., $n_1 > n_2$ to observe the light propagation structure of optical fiber.

Step Index optical fiber:

- Based on variation in the core refractive index (n_1), optical fibers are divided in to two types
  1. Step index fiber
  2. Graded index fiber
- Step index fibers have both single & multimode propagations.

6) Write a short note on attenuation in optical fibers.

Usually, the power of light at the output end of optical fiber is less than the power launched at the input end, then the signal is said to be attenuated.

Attenuation: It is the ratio of input optical power (P_i) in to the fiber to the power of light coming out at the output end (P_o).
Attenuation coefficient is given as, $\alpha = 10/L \log_{10} P_i / P_o$ db/km.
Attenuation is mainly due to

1. Absorption.
2. Scattering.
3. Bending.

7) **Write down advantages of fiber optics in communication system Or What are the Advantages of optical fibers over metallic cables**?

- Optical fibers allow light signals of frequencies over a wide range and hence greater volume of information can be transmitted either in digital form or in analog form within a short time.

- In metallic cables only 48 conversations can be made at once without cross talks where as in optical fibers more than 15000 conversations can be made at once without cross talks.
- Light cannot enter through the surface of the optical fiber except at the entry interface i.e., interference b/w different communication channels is absent. Hence purity of light signal is protected.
- Optical signal do not produce sparks like electrical signals and hence it is safe to use optical fibers.
- External disturbances from TV or Radio Stations power electronic systems and lightening cannot damage the signals as in case of metallic cables.
- Materials used in the manufacture of optical fibers are SiO_2, plastic, glasses which are cheaper & available in plenty.

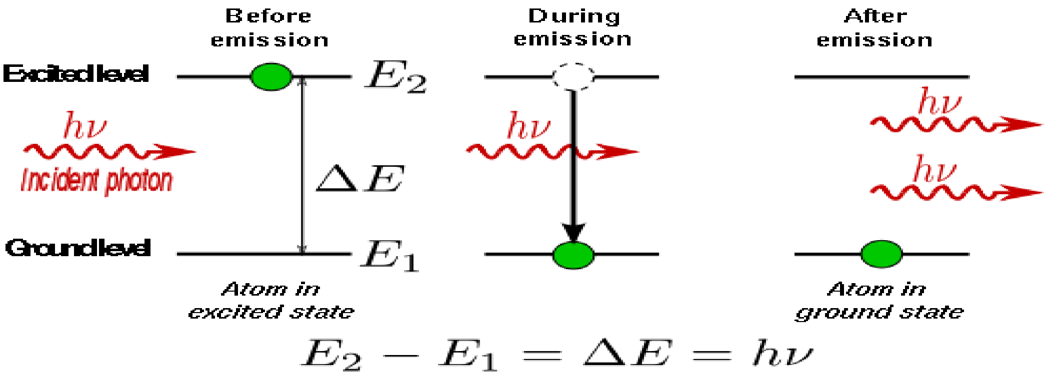
Part- B (Descriptive- 10marks)

1) What is Acronym of a Laser, absorption, spontaneous and stimulated emissions?

- **Laser:** Laser means **Light Amplification by Stimulated Emission of Radiation.**
- **Absorption:** When at atom absorbs an amount of energy 'hv' in the form of photon from the external agency and excited into the higher energy levels from ground state, then this process is known as absorption. Atom + hv → atom*
- **Spontaneous Emission:** When an atom in the excited state emits a photon of energy 'hv' coming down to ground state by itself without any external agency, such an emission is called spontaneous emission. Atom* → atom + hv
- Photons released in spontaneous emission are not coherent. Hence spontaneous emission is not useful for producing lasers.
- **Stimulated Emission:** When an atom in the excited state, emits two photons of same energy 'hv' while coming to down to ground state with the influence of an external agency, such an emission is called stimulated emission. Atom* → atom + 2hv
- In the two photons one photon induces the stimulated emission and the second one is released by the transition of atom from higher energy level to lower energy level.
- Both the photons are strictly coherent. Hence stimulated emission is responsible for laser production.

2) Explain principle of laser/lasing action?

- **Laser Production Principle:**
- Two coherent photons produced in the stimulated emission, interacts with other two excited atoms, resulting in four coherent photons.
- Thus, coherent photons are multiplied in a lasing medium. The continuous successive emission of photons results for the production of laser beam.



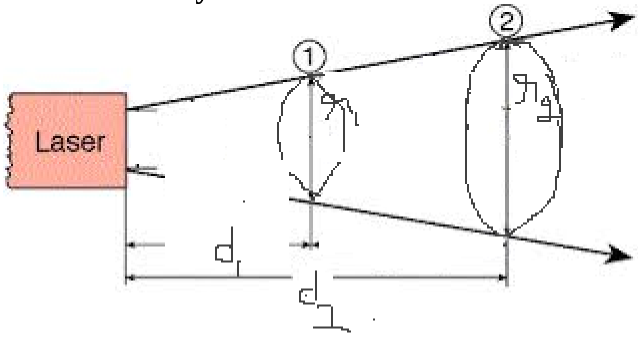
$$E_2 - E_1 = \Delta E = h\nu$$

3) What are the characteristics/striking features/Properties of Laser Light?

Characteristics of Laser Beam: Some of the special properties which distinguish lasers from ordinary light sources are characterized by:

1. Directionality
2. High Intensity
3. Mono- chromacity
4. Coherence

1.Directionality:



Laser emits radiation only in one direction. The directionality of laser beam is expressed in terms of angle of divergence (Φ)
Divergence or Angular Spread is given by **$\Phi = r_2 - r_1 / d_2 - d_1$**
Where d_1, d_2 are any two distances from the laser source emitted and r_1, r_2 are the radii of beam spots at a distance d_1 and d_2 respectively as shown in above figure. Laser light having less divergence, it means that laser light having more directionality.
2. High Intensity: Generally, light from conventional source spread uniformly in all directions. For example, take 100 watt bulb and look at a distance of 30 cm, the power enter into the eye is less than thousand of a watt. This is due to uniform distribution of light in all directions.
But in case of lasers, light is a narrow beam and its energy is concentrated within the small region. The concentration of energy accounts for greater intensity of lasers.
3. Monochromacity: The light emitted by laser is highly monochromatic than any of the other conventional monochromatic light. A comparison b/w normal light and laser beam, ordinary sodium (Na) light emits radiation at wave length of $5893A^0$ with the line width of $1A^0$. But He-Ne laser of wave length $6328A^0$ with a narrow width of only 10^{-7} A^0 i.e., Monochromacity of laser is 10 million times better than normal light.
The degree of Monochromacity of the light is estimated by line of width (spreading frequency of line).

4. Coherence: If any wave appears as pure sine wave for longtime and infinite space, then it is said to be perfectly coherent.

Practically, no wave is perfectly coherent including lasers. But compared to other light sources, lasers have high degree of coherence because all the energy is concentrated within the small region. There are two independent concepts of coherence.

i) Temporal coherence (criteria of time)

ii) Spatial coherence (criteria of space)

4) Explain the concept of population inversion and pumping in lasers?

Population Inversion:

- Generally, number of atoms in the ground state is greater than the number of atoms in higher energy states.
- But in order to produce a laser beam, the minimum requirement is stimulated emission.
- Stimulated emission takes place only if the number of atoms in the higher energy level is greater than the number of atoms in the lower energy level.
- Simply population inversion is nothing but number of atoms in higher energy level is greater than the number of atom in lower energy level.
- So, if there is a population inversion there by only stimulated emission will able to produce laser beam.
- Population inversion is associated with three Phenomenon.
  - Stimulated emission
  - Amplification
  - Pumping Process
- Stimulated Emission: If majority of atoms are present in higher energy state than the process becomes very easy.
- Amplification: If 'N', represents number of atoms in the ground state and 'N_2' represents number of atoms in the excited state than the amplification of light takes place only when $N_2 > N_1$.
- If $N_2 > N_1$, there will be a population inversion so induced beam and induced emission are in the same directions and strictly coherent than the resultant laser is said to be amplified.
- Boltzmann's principle gives the information about the fraction of atom found on average in any particulars energy state at equilibrium temperature as
- $\frac{N1}{N2} = \exp(E_2\text{-}E_1/KT) = \exp(\Delta E/KT)$

$$\frac{N1}{N2} = \exp(hv/KT)$$

Pumping Process:

- This process is required to achieve population inversion.
- Pumping process is defined as: "The process which excites the atoms from ground state to excited state to achieve population inversion".
- Pumping can be done by number of ways
- i) Optical Pumping → excitation by strong source of light (flashing of a Camera)
- ii) Electrical Pumping → excitation by electron impact
- iii) Chemical Pumping → excitation by chemical reactions
- iv) Direct Conversion → Electrical energy is directly converted into

radiant Energy in devices like LED's, population Inversion is achieved in forward bias.

5) What are Einstein's coefficients and explain the relation among them?

or

Derive the relation between the probabilities of spontaneous emission and stimulated emission in terms of Einstein's coefficient?

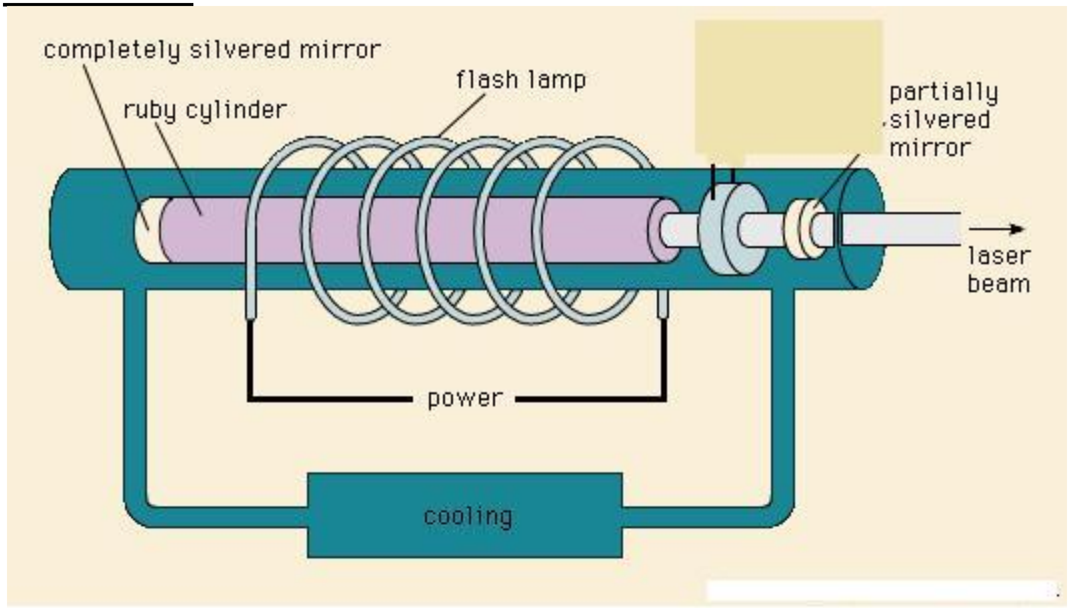
Einstein's Theory of Radiation:

- In 1917, Einstein predicted the existence of two different kinds of processes by which an atom emits radiation.
- Transition b/w the atomic energy states is statistical process. It is not possible to predict which particular atom will make a transition from one state to another state at a particular instant. For an assembly of very large number of atoms it is possible to calculate the rate of transitions b/w two states.
- Einstein was the first to calculate the probability of such transition, assuming the atomic system to be in equilibrium with electromagnetic radiation.
- The number of atoms excited during absorption in the time'Δt' is given by: $N_{ab} = Q N_1 B_{12} \Delta t$, Where N_1 = number of atoms in state 'E_1', Q = Energy density of induced beam and B_{12} = Probability of an absorption transition coefficient.
- The number of spontaneous transitions N_{sp} taking place in time 'Δt' depends on only no. of atoms N_2 lying in excited state. $N_{sp} = A_{21} N_2 \Delta t$, Where A_{21} = probability of spontaneous transition.
- The number of stimulated transitions N_{st} occurring during the time Δt may be written as: $N_{st} = B_{21} N_2 \Delta t$, Where B_{21} = probability of stimulated emission.
- Under the thermal equilibrium number of upward transitions = number of downward transitions per unit volume per second.
- So, we can write: $A_{21}N_2+B_{21}N_2Q = B_{12}N_1Q \rightarrow 1$
- $Q = A_{21}N_2 / B_{12}N_1 - B_{21}N_2$ ----------------> 2
- Dividing by $B_{21}N_2$ in all terms, $Q = (A_{21}/ B_{21}) \times 1 / (B_{12}N_1 / B_{21}N_2) - 1$ --------> 3
- By substituting $N_1/N_2 = \exp(h\upsilon/kT)$ from Boltzmann Distribution law,
- $Q = (A_{21}/ B_{21})\ 1/(B_{12} / B_{21}) \exp(h\upsilon/kT) - 1$ ------------> 4
- Above equation must agree with planks energy distribution – radiation formula.
  $Q = \hbar\upsilon^3/\prod^2 C^3\ 1/\exp(h\upsilon/kT) - 1$ ------------------------> 5
- From equations 4 & 5, $B_{12} = B_{21}$, we get $A_{21}/ B_{21} = \hbar\upsilon^3/\prod^2 C^3$
- The co-efficients A_{21}, B_{12}, B_{21} are known as Einstein coefficients.
- Note: Since we are applying same amount of energy (Q) and observing in the same time (Δt), number of atoms excited into higher energy levels (absorption) = number of atoms that made transition into lower energy levels (stimulated emission)
  $B_{12} = B_{21}$ i.e. absorption = stimulated emission

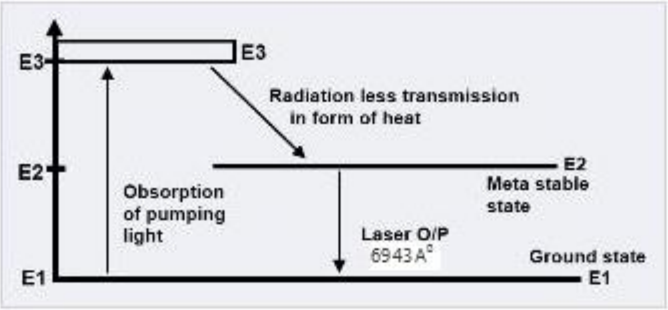
6) Describe the principle, construction and working of ruby laser with relevant energy level diagram?

- **Ruby Laser:** It is a 3 level solid state laser, discovered by Dr.T.Maiman in 1960.
  Principle:
- The chromium Ions raised to excited states by optical pumping using xenon flash lamp
- Then the atoms are accumulated at metastable state by non-radiative transition.

- Due to stimulated emission the transition of atoms take place from metastable state to ground state, there by emitting laser beam.
- **Construction:**



- Ruby is a crystal of aluminum oxide (Al_2O_3) in which some of the aluminum ions (Al^{3+}) is replaced by chromium ions (Cr^{3+}). This is done by doping small amount (0.05%) of chromium oxide (Cr_2O_3) in the melt of purified Al_2O_3.
- These chromium ions give the pink color to the crystal. Laser rods are prepared from a single crystal of pink ruby. Al_2O_3 does not participate in the laser action. It only acts as the host.
- The ruby crystal is in the form of cylinder. Length of ruby crystal is usually 2 cm to 30 cm and diameter 0.5 cm to 2 cm.
- The ends of ruby crystal are polished, grounded and made flat.
- The one of the ends is completely silvered while the other one is partially silvered to get the efficient output. Thus the two polished ends act as optical resonator system.
- A helical flash lamp filled with xenon is used as a pumping source. The ruby crystal is placed inside a xenon flash lamp. Thus, optical pumping is used to achieve population inversion in ruby laser.
- As very high temperature is produced during the operation of the laser, the rod is surrounded by liquid nitrogen to cool the apparatus.
- **Working with Energy Level Diagram (ELD):**

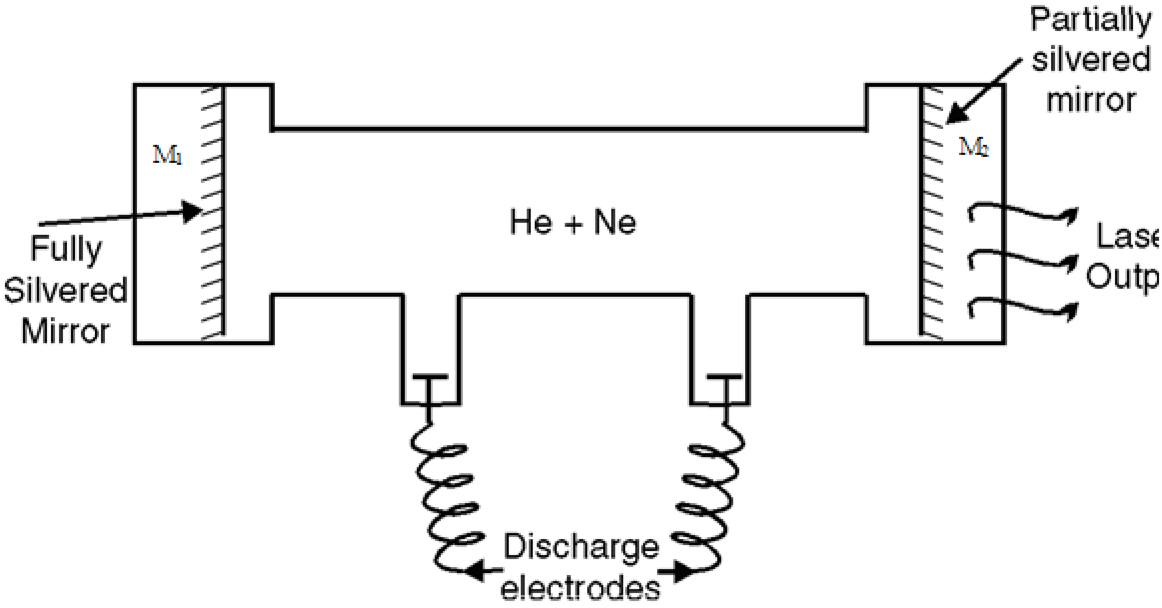


- Fig: Energy Level Diagram of Ruby Laser

- The flash lamp is switched on, a few thousand joules of energy is discharged in a few milliseconds.
- A part of this energy excites the Cr^{3+} Ions to excited state from their ground state and the rest heats up the apparatus can be cooled by the cooling arrangement by passing liquid nitrogen.
- The chromium ions respond to this flash light having wavelength 5600 A^0(Green),[4200 A^0(Red)Also]
- When the Cr^{3+} Ions are excited to energy level E_3 from E_1 the population in E_3 increases.
- Cr^{3+} Ions stay here(E_3) for a very short time of the order of 10^{-8} sec, then they drop to the level E_2 which is metastable state of lifetime 10^{-3} sec .Here the transitions from E_3 to E_2 is non radiative in nature.
- As the lifetime of the state E_2 is much longer, the number of ions in this state goes on increasing while in the ground state (E_1) goes on decreasing. By this process population inversion is achieved between E_2 & E_1.
- When an excited ion passes spontaneously from the metastable state E_2 to the ground state E_1 it emits a photon of wavelength $6943A^0$.
- This photon travels through the ruby rod and if it is moving parallel to the axis of the crystal, is reflected back & forth by silvered ends until it stimulates an excited ion in E_2 and causes it to emit fresh photon in phase with the earlier photon. This stimulated transition triggers the laser Transition.
- The process is repeated again and again, because the photons repeatedly move along the crystal being reflected from ends. The photons thus get multiplied.
- When the photon beam becomes sufficiently intense, such that a part of it emerges through the partially silvered end of the crystal.

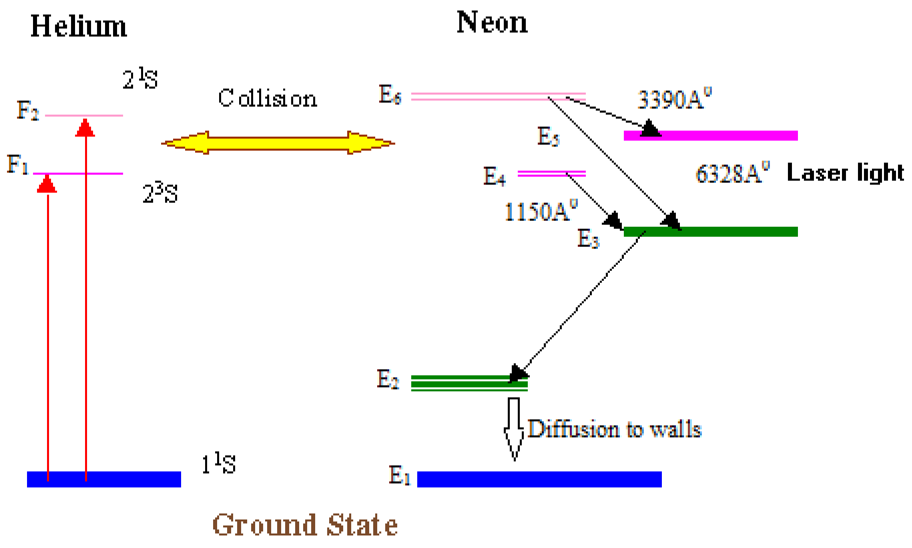
7) Describe the principle, construction and working of He-Ne laser with relevant energy level diagram?

- **He-Le Laser:**
- **Principle:** This laser is based on the principle of stimulated emission, produced in the active medium of gas. Here, the population inversion achieved due to the interaction between the two gases which have closer higher energy levels.
- **Construction:**



- Fig: He-Ne laser

- The first gas laser to be operated successfully was the He-Ne laser in 1961 by the scientist A. Jawan.
- In this method, two gases helium & Neon were mixed in the ratio 10:1 in a discharge tube made of quartz crystal.
- The dimensions of the discharge tube are nearly 80 cm length and 1.5 cm diameter, with its windows slanted at Brewster's angle i.e., $\theta = \mathrm{Tan}^{-1}(n)$,Where n = refractive index of the window substance.
- The purpose of placing Brewster windows on either side of the discharge tube is to get plane polarized laser output.
- Two concave mirrors M_1 & M_2 are made of dielectric material arranged on both sides of the discharge tube so that their foci lines within the interior of discharge tube.
- One of the two concave mirrors M_1 is thick so that all the incident photons are reflected back into lasing medium.
- The thin mirror M_2 allows part of the incident radiation to be transmitted to get laser output.
- <u>Working:</u>



- Fig:(E.L.D) Energy Level Diagram corresponding to He-Ne laser

- The discharge tube is filled with Helium at a pressure of 1 mm of Hg & Neon at 0.1mm of Hg.
- When electric discharge is set-up in the tube, the electrons present in the electric field make collisions with the ground state He atoms.
- Hence ground state He atoms get excited to the higher energy levels F_1 ($2S_1$), F_2 ($2S_3$).
- Here Ne atoms are active centers.
- The excited He atoms make collision with the ground state Ne atoms and bring the Ne atoms into the excited states E_4 & E_6.
- The energy levels E_4 & E_6 of Ne are the metastable states and the Ne atoms are directly pumped into these energy levels.
- Since the Ne atoms are excited directly into the levels E_4 & E_6, these energy levels are more populated than the lower energy levels E_3&E_5.
- Therefore, the population inversion is achieved between E_6&E_5,E_6&E_3,E_4&E_3
- The transition between these levels produces wavelengths of 3390 A^0,6328 A^0,1150 A^0 respectively.
- Now The Ne atoms undergo transition from E_3 to E_2 and E_5 to E_2 in the form of fast decay giving photons by spontaneous emission. These photons are absorbed by optical elements placed inside the laser system.
- The Ne atoms are returned to the ground state(E_1) from E_2 by non radiative diffusion and collision process, therefore there is no emission of radiation.
- Some optical elements placed inside the laser system are used to absorb the IR laser wavelengths 3390 A^0, 1150 A^0.
- Hence the output of He-Ne laser contains only a single wavelength of $6328A^0$.
- The released photons are transmitted through the concave mirror M_2 there by producing laser.
- A continuous laser beam of red color at a wavelength of $6328A^0$.
- By the application of large potential difference, Ne atoms are pumped into higher energy levels continuously.
- A Laser beam of power 0.5 to 50 MW comes out from He-Ne laser.

8) Describe the principle, construction and working of Semiconductor laser with relevant energy level diagram?

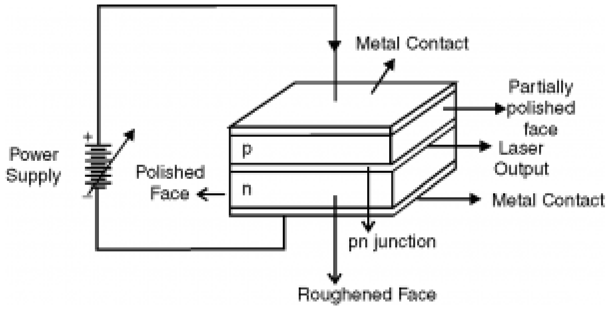
Semi Conductor Laser:

- Semiconductor lasers are of two types, Except the Construction, Principle and working are same for both.
  1. Homojunction semiconductor Laser
  2. Hetrojunction semiconductor Laser

Principle:

- After the invention of semi conductor leaser in 1961, laser have become at common use.
- In conventional lasers, lasers are generated due to transition of electrons from higher to lower energy level.
- But in semi-conductor lasers the transition takes place from conduction band to valence band.
- The basic mechanism responsible for light emission from a semi conductor laser is the recombination of e’s and holes at PN-junction when current is passed through the diode.
- Stimulated emission can occur when the incident radiation stimulates an e in conduction band to make a transition into valence band in that process radiation will be emitted.
- When current is passed through PN – junction under forward bias, the injected e’s & holes will increase the density of e in CB & holes in VB. At some value of current the stimulated emission rate will exceed the absorption rate.
- As the current is further increased at some threshold value of current the amplification will takes place and laser begin to emit coherent radiation.
- The properties of semi conductor laser depends upon the energy gap

- **Fabrication/construction:**



- Fig:Homojunction Semiconductor Laser

Homojunction Semiconductor Laser:

- Ga – As is heavily doped with impurities in both P & N regions. N region is doped with tellurium & P – region by Germanium.
- The concentration of doping is of the order of 10^{17} to 10^{19} impure atoms per cm.
- The size of the diode is small i.e., 1mm each side & the depletion layer’s thickness varies from 1 to 100 μAm.
- These values depend on diffusion condition and 40 mp at the time of fabrication.

Hetrojunction Semiconductor Laser:

- Hetrojunction means the material on one side of the junction differs from that on the other side.i.e;Ga-AS on one side and GaAlAs on other side.
- Generation amd recombination tales place very fastly.

Working:

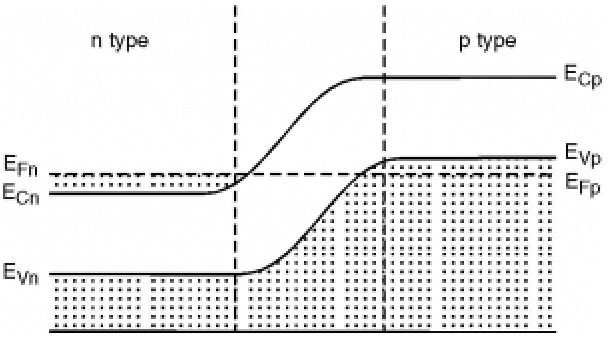


Fig a) when no biasing

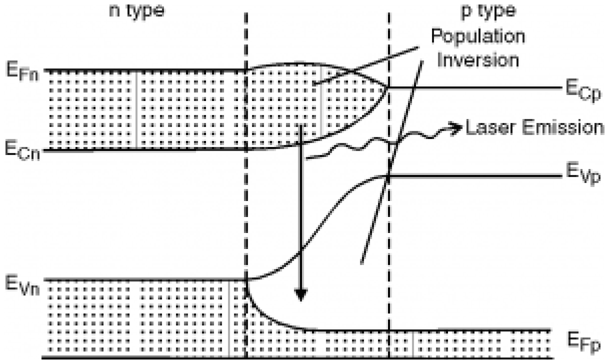


Fig b) with biasing

- When a forward bias with the source is applied to a semiconductor, e from N-region & holes from P-region move to cross the junction in opposite directions.
- In natural region the e’s & holes combine recombination is possible due to transition of e from CB to VB.
- For low currents the population inversion does not take place hence only spontaneous emission takes place and photon released are not coherent.
- When forward current is further increased beyond the certain threshold value population inversion takes place and coherent photons are released.
- The energy gap of Gallium Arsenide (Ga-As) is 1.487eV and corresponding wavelength of radiation is 6435 A^0 which is responsible for laser emission.

9) Mention some important applications of Lasers in various fields?

Applications of Lasers: Lasers have wide applications in different branches of science and engineering because of the following.

- Very narrow band width
- High directionality
- Extreme brightness

1. Communication:

- Lasers are used in optical communications, due to narrow band width.
- The laser beam can be used for the communication b/w earth & moon (or) other satellites due to the narrow angular speed.
- Used to establish communication between submarines i.e; under water communication.

2. Medical:

- Identification of tumors and curification.
- Used to detect and remove stones in kidneys.
- Used to detect tumors in brain.

3. Industry:

- Used to make holes in diamond and hard steel.
- Used to detect flaws on the surface of aero planes and submarines.

4. Chemical &Biological:

- Lasers have wide chemical applications. They can initiate or fasten chemical reactions.
- Used in the separation of isotopes.
- Lasers can be used to find the size & shape biological cells such as erythrocytes.

10. with the help of a suitable diagram explain the principle, structure and working of an optical fiber as a wave guide?

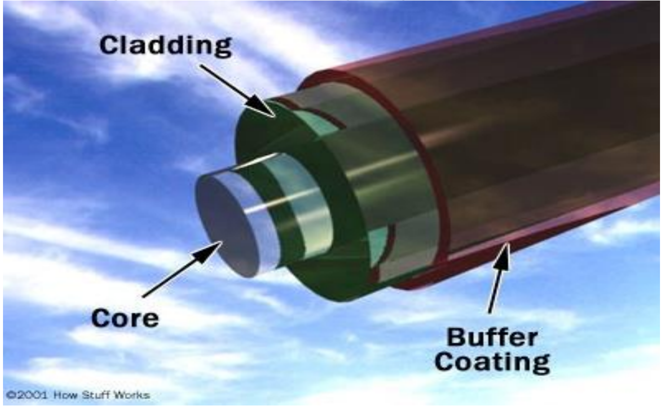
Principle: Optical fibers are the waveguides through which electromagnetic waves of optical frequency range can be guided through them to travel long distances.

- An optical fiber works on the principle of total internal reflection (TIR).

Total Internal Reflection: when a ray of light travels from a denser medium into a rarer medium and if the angle of incidence is greater than the critical angle then the light gets totally reflected into the denser medium

Structure & Working:

- An optical fiber consists of three (3) co-axial regions.
- The inner most region is the light-guiding region known as “Core”. It is surrounded by a middle co-axial regional known as “cladding”. The outer most regions which completely covers the core & cladding regions is called “sheath or buffer jacket”.
- Sheath protects the core & cladding regions from external contaminations, in addition to providing mechanical strength to the fiber.
- The refractive index of core (n_1) is always greater than the refractive index of cladding (n_2) i.e., $n_1 > n_2$ to observe the light propagation structure of optical fiber.
- When light enters through one end of optical fiber it undergoes successive total internal reflections and travel along the fiber in a “zig-zag” path.



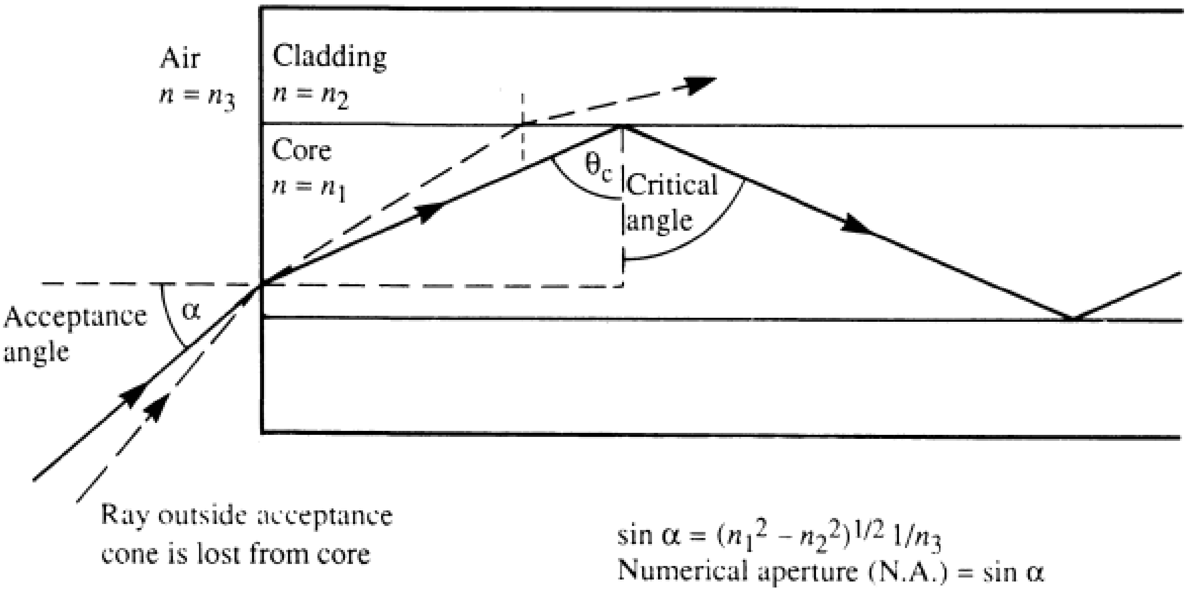
11) Define and derive the expressions for acceptance angle and numerical Aperture?

Expressions for acceptance angle & Numerical Aperture (NA):

Acceptance Angle:

- All right rays falling on optical fiber are not transmitted through the fiber. Only those light rays making $\theta_i > \theta c$ at the core-cladding interface are transmitted through the fiber by undergoing TIR. For which angle of incidence, the refraction angle is greater than 90^0 will be propagated through TIR.

- There by Acceptance Angle is defined as: The maximum angle of incidence to the axis of optical fiber at which the light ray may enter the fiber so that it can be propagated through TIR.



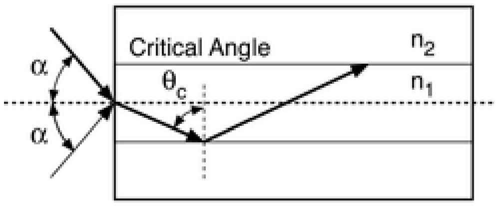
$\sin\alpha = (n_1^2 - n_2^2)^{1/2}\, 1/n_3$

Numerical aperture (N.A.) = $\sin\alpha$

- Consider the optical fiber with core refractive index n_1 and cladding refractive index n_2. Light is incident on the axis of optical fiber at an angle θ_1. It can produce an angle of refraction θ_2.
- The relationship at the interface is given by snell's law as:
  At air-core interface (A), $n_o\sin\theta_1 = n_1\text{sins}\theta_2$ - -----------------------1
  At core-clad interface (B), for TIR, $n_1\sin(90-\theta_2) = n_2\sin 90^0$
  $n_1\cos\theta_2 = n_2$, $\cos\theta_2 = n_2/n_1$ ------------------------------ 2
- Eq'n 1 can be written as ,$n_0\text{Sin}\theta_1 = n_1\sqrt{1-\cos^2\theta_2}$-----------------------------3
- Substituting 3 in 2 , $n_0\text{Sin}\theta_1 = n_1\sqrt{1-n_2^2/n_1^2}$
  $n_0\text{Sin}\theta_1 = \sqrt{n_1^2 - n_2^2}$
- For air $n_0=1$, then $\sin\theta_1 = \sqrt{n_1^2 - n_2^2}$
- $\theta_1 = \theta_A = \text{Sin}^{-1}\sqrt{n_1^2 - n_2^2}$, Here θ_A is called Acceptance angle
- This gives max value of external incident angle for which light will propagate in the fiber.

<u>Numerical Aperture (NA):</u>

Numerical Aperture



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

Full Acceptance Angle = 2α

- Numerical aperture of a fiber is a measure of its light gathering power.
- “The Numerical Aperture (NA) is defined as the sine of the maximum acceptance angle”
- The light gathering ability of optical fiber depends on two factors i.e.,
  Core diameter & NA.
- NA is defined as sine of the acceptance angle i.e., NA = Sin θ_A
  NA = $\sqrt{n_1^2 - n_2^2}$
- The efficiency of optical fiber is expressed in terms of NA, so it is called as figure of merit of optical fiber.
- # NA is also expressed like this: NA = $\sqrt{n_1^2 - n_2^2} = \sqrt{(n_1 - n_2)(n_1 + n_2)}$
- Fractional index change $\Delta = n_1 - n_2 / n_1 = n_1 - n_2 = \Delta n_1$
  Then NA = $\sqrt{\Delta n_1 (n_1 + n_2)}$
  Let $n_1 = n_2$, then $n_1 + n_2 = 2n_1$
- Then NA = $\sqrt{\Delta n_1 - 2n_1} = n_1\sqrt{2\Delta} = n_1\sqrt{2\Delta}$

12) How optical fibers are classified on the basis of refractive index profile?

Or

Describe the Step index and graded index optical fibers in detail and explain the transmission of signal through them?

Classification of Optical Fibers:

- Based on variation in the core refractive index (n_1), optical fibers are divided in to two types
  1. Step index fiber
  2. Graded index fiber
- Based on mode of propagation, fibers are further classified in to
  1. Single mode propagation
  2. Multi mode propagation
- Step index fibers have both single & multimode propagations.
- Graded index fibers have multimode propagation only
- All together in total three (3) types of fibers
  1. Single mode step index fiber
  2. Multi mode step index fiber
  3. Multi mode graded index fiber

Transmission of Signal in Optical Fibers:

1. Step Index Fiber: The refractive index of core material is uniform throughout and undergoes a sudden change in the form of step at the core-clad interface.

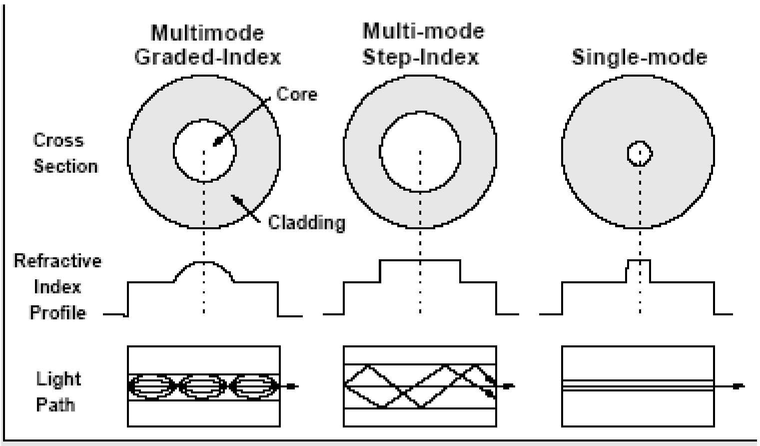


Fig: Refractive index profile & propagation in single mode, step index& graded index fibers

a) Single Mode Step Index Fiber:

- The variation of the refractive index of a step index fiber as a function of distance can be mathematically represented as longitudinal cross section.

Note: Mode of propagation: It is defined as the number of paths available for the light ray to transfer through the optical fiber.

Structure:

i) Core Diameter: 8 to 12 μm, usually 8.5μm
ii) Cladding Diameter: Around 125μm
iii) Sheath Diameter: 250 to 1000 μm
iv) NA: 0.08 to 0.15 usually 0.10

Performance Characteristics:

i) Band Width: Greater than 500 MHZ Km.
ii) Attenuation: 2 to 5 dB / Km.
iii) Applications: These fibers are ideally suited for high band width applications using single mode injection coherent (LASER) sources.

B) Multi Mode Step Index Fibers:

- These fibers have reasonably large core diameters and large NA to facilitate efficient transmission to incoherent or coherent light sources.
- These fibers allow finite number of modes.
- Normalized frequency (NF) is the cut off frequency, below which a particular mode cannot exist. This is related to NA, Radius of the core, and wave length of light as $NF = 2\pi/\lambda\, a\, (NA)$, Where a = radius of core

Structure:

i) Core Diameter: 50 to 200 μm
ii) Cladding Diameter: 125 to 400 μm
iii) Sheath Diameter: 250 to 1000 μm
iv) NA: 0.16 to 0.5

Performance Characteristics:

i) Band Width: 6 to 50 MHZ Km.
ii) Attenuation: 2.6 to 50 db/km.
iii) Applications: These fibers are ideally suited for limited band width and relatively low cost applications.

c) Multi Mode Graded Index Fibers:

- In case of graded index fibers, the refractive index of core is made to vary as a function of radial distance from the centre of the optical fiber.

- Refractive index increases from one end of core diameter to center and attains maximum value at the centre. Again refractive index decreases as moving away from center to towards the other end of the core diameter.
- The refractive index variation is represented as $n(r) = n_1(1-2\Delta)^{1/2} = n_2$
  Here Δ = fractional change in refractive index = n_1-n_2/n_1
- The number of modes is given by the expression $N = 4.9[d(NA)/ \lambda]^2$
  Where d = core diameter, λ = wavelength of radiation

Structure:

i) Core Diameter: 30 to 100 μm
ii) Cladding Diameter: 105 to 150 μm
iii) Sheath Diameter: 250 to 1000 μm
iv) NA: 0.2 to 0.3

Performance Characteristics:

i) Band Width: 300 MHZ Km to 3 GHZ Km.
ii) Attenuation: 2 to 10 dB/km.
iii) Applications: These are ideally suited for medium to high band width applications using incoherent and coherent multimode sources.

13) Distinguish Step index & Graded index fibers And Single mode & Multi mode fibers?

Step Index	Graded Index
1. RI of core is uniform throughout except at one stage. 2. Single & multimode propagations exist. 3. Used for short distance applications. 4. Attenuation losses are of the order 100 dB/km. 5. Mer4dinol rays propagation takes place. 6. Easy to manufacture.	1. Refractive index varies gradually with radial distance. 2. It is a multi mode fiber. 3. Used for long distance applications. 4. 4. Attenuation losses are of the order 10 dB/km. 5. Skew rays propagation takes place. 6. Difficult to manufacture.
Single Mode	**Multi Mode**
1. Core diameter is small. 2. Signal entry is difficult. 3. Exists in step index fiber. 4. Light must be coherent.	1. Core diameter is large. 2. Signal entry is easy. 3. Exists in both step & graded index fibers. 4.Light source may be coherent or incoherent source .

14) What are the Advantages of optical fibers over metallic cables?

- Optical fibers allow light signals of frequencies over a wide range and hence greater volume of information can be transmitted either in digital form or in analog form within a short time.
- In metallic cables only 48 conversations can be made at once without cross talks where as in optical fibers more than 15000 conversations can be made at once without cross talks.
- Light cannot enter through the surface of the optical fiber except at the entry interface i.e., interference b/w different communication channels is absent. Hence purity of light signal is protected.

- Optical signal do not produce sparks like electrical signals and hence it is safe to use optical fibers.
- External disturbances from TV or Radio Stations power electronic systems and lightening cannot damage the signals as in case of metallic cables.
- Materials used in the manufacture of optical fibers are SiO_2, plastic, glasses which are cheaper & available in plenty.

15) How optical fibers are used in communication field? Or Explain optical fiber communication link with help of block diagram.

Optical Fiber Communication Link:

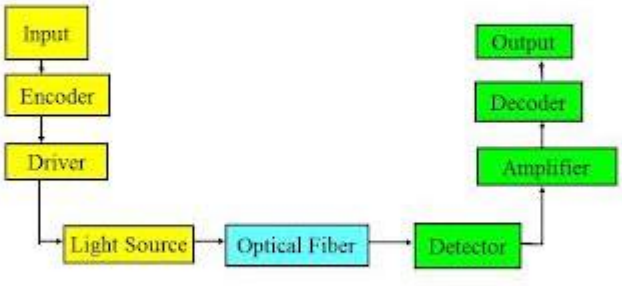


Fig:Block Diagram of Optical fiber communication link

Optical fiber is an ideal communication medium by systems that require high data capacity, fast operation and to travel long distances with a minimum number of repeaters.
Encoder: It is an electronic system that converts the analog information signals, such as voice of telephone user, in to binary data. The binary data consists of series of electrical pulses.
Transmitter: Transmitter consists of a driver which is a powerful amplifier along with light source. The o/p of amplifier feeds to light source, which converts electrical pulses in to light pulses.
Source to Fiber Connector: It is a special connector that sends the light from sources to fiber. The connector acts as temporary joint b/w the fiber and light source, misalignment of this joint, leads to loss of signal.,
Fiber to Detector Connector: It is also temporary joint, which collects the source from fiber.
Receiver: Receiver consists of a detector followed by amplifier. This combination converts light pulses in to electrical pulses.
Decoder: Electrical pulses containing information are fed to the electronic circuit called decoder. Decoder converts binary data of electrical pulses in to analog information signals.

16) Write a short note on attenuation in optical fibers.

Usually, the power of light at the output end of optical fiber is less than the power launched at the input end, then the signal is said to be attenuated.
Attenuation: It is the ratio of input optical power (P_i) in to the fiber to the power of light coming out at the output end (P_o).
Attenuation coefficient is given as, $\alpha = 10/L \log_{10} P_i / P_o$ db/km.
Attenuation is mainly due to
1. Absorption.
2. Scattering.
3. Bending.

1. <u>Absorption Losses</u>: In glass fibers, three different absorptions take place.
Ultra violet absorption: Absorption of UV radiation around 0.14μm results in the ionization of valence electrons.
Infrared absorption: Absorption of IR photons by atoms within the glass molecules causes heating. This produces absorption peak at 8μm, also minor peaks at 3.2, 3.8 and 4.4μm.
Ion resonance/OH^- absorption: The OH^- ions of water, trapped during manufacturing causes absorption at 0.95, 1.25 and 1.39μm.

2. <u>Scattering Losses</u>:

The molten glass, when it is converted in to thin fiber under proper tension creates sub microscopic variations in the density of glass leads to losses.

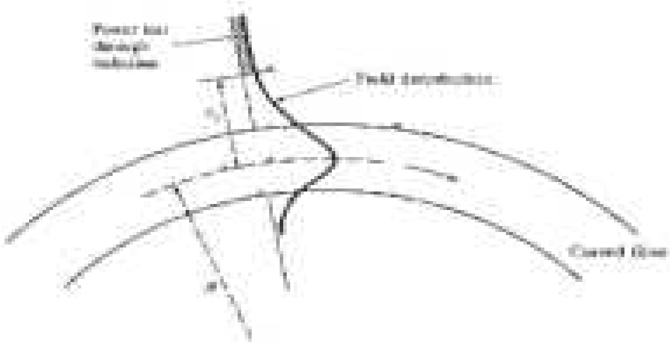
The dopents added to the glass to vary the refractive index also leads to the inhomogenities in the fiber. As a result losses occur.

Scattering losses are inversely proportional to fourth power of λ.(λ^4)

3. <u>Bending Losses:</u>

In a bent fiber, there is a loss in power of the transmitted signal called as Bending Loss. According to the theory of light, the part of the wave front travelling in cladding (rarer medium) should travel with more velocity than the wave front in the core (denser medium). But according to Einstein's theory of relativity, in a single wave front one part should not travel with higher velocity than the other part.

So the part of wave front travelling in cladding medium lost in the form of radiation leads to bending losses.



<u>UNIT-5 :Science & Technology of Nano Materials</u>

<u>Part-A (SAQ-2Marks)</u>

1. Define the terms a) Nano Materials b) Nano Science c) Nano Technology

a) Nano Materials: Nano materials can be defined as the materials which have structured Components with size less than 100 nm at least in one dimension.

b) Nano Science: Nano Science can be defined as the study and manipulation of materials at atomic, molecular and micro molecular scales, where the properties different from those at bulk scale.

c) Nano Technology: Nano Technology can be defined as the design, characterization, Production and application of structures, devices and system by controlling shape and Size at the Nano meter scale.

2. Briefly write about surface to volume ratio and its importance in Nano technology.

- Surface to volume ratio is very important in Nanotechnology because it shows direct effect on material properties.
- Starting from bulk, the first effect of reducing particle size is to create more surface sites i.e. surface to volume ratio increases. As a result inter atomic spacing decreases with size and change in surface pressure shows effect on material properties.
- Then the properties such as physical, chemical, Optical, Electrical, Magnetic and Mechanical properties are changed with size.

3. What are the important applications of Nano Technology?

Nano materials possess unique, beneficial chemical, physical and mechanical properties; they can be used for a wide variety of applications.

- Manufacture of efficient computer clips.
- Used in production of better insulation materials.
- Used ion high definition plasma TV, to improve the pixel size.
- Used in the manufacture of low-cost flat panel displays.
- Cutting tools made of Nano materials are tougher and harder.
- Nano technology is used for the manufacture of high energy density batteries.
- Nano materials are sued to produce high power magnets.
- Used to improve fuel efficiency in auto mobiles.
- Used to manufacture aerospace components.
- Used to produce longer lasting satellites.
- Used to produce medical implants.
- Used in the preparation of Nano drugs.

Part- B (Descriptive- 10marks)

1. Explain the basic concepts, origin and importance of Nanotechnology.

- Nano means 10^{-9} i.e., A Nanometer (nm) is one thousand millionth of the meter (i.e. 10^{-9} m)
- Atoms are extremely small and the diameter of a single atom can vary from 0.1 to 0.5 nm depending on the type of the element. The radius of the atom can be half the distance between neighboring atoms when they present in the solid phase.
- At the Nano-scale, materials exhibit different or New Properties, changed properties include grater material strength, enhanced reactivity, better catalytic functioning and higher conductivity.
- The first concept related to Nano technology was proposed by the scientist Richard Feynman in 1959, made a statement “There is plenty of room at the bottom”. According to Feynman, all materials are composed of grains, which in turn comprise of many atoms.
- Nano materials can be defined as the materials which have structured components with size less than 100 nm at least in one dimension.
- Nano Science can be defined as the study and manipulation of materials at atomic, molecular and micro molecular scales, where the properties different from those at Bulk scale.

- Nano Technology can be defined as the design, characterization, production and application of structures, devices and system by controlling shape and size at the nano meter scale.

Various forms of Nano materials :

One dimension – surface coatings and films
Two dimensions – Nano wires, Nano tubes
Three dimensions – Nano particles i.e. precipitates, colloids, quantum dots etc.

Approaches of Nano technology:

- Two main approaches are used in Nano technology
- 1. Bottom up : Materials and devices are built from molecular components which assemble chemically using principles of molecular recognition.
- 2. Top down : Nano objects are constructed from larger entities without Atomic level control.

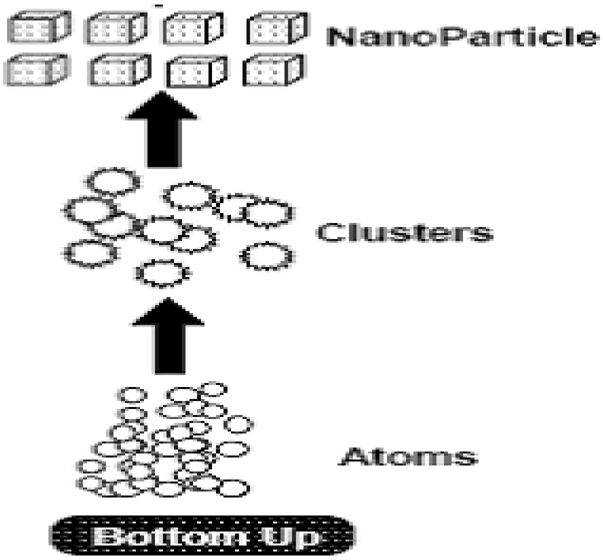
Basic Principles of Nano Technology:

- It uses a basic unit of measure called a "Nano Meter" (nm), indicates a billionth part 10^{-9}. They are very small, about 40,000 times smaller than the width of an average human hair. Based on Nano meters, i.e., considered as basic principle, chemistry, health sciences, material science, space programs and engineering applications are designed.
- Materials referred as "Nano Materials" are divided in to two categories.

Organic Nano materials (fullerenes)
Inorganic Nano materials

2. Explain Bottom-up and Top-down fabrication with examples.

- Materials will be fabricated by using any one of the following approaches.
- **Bottom up:** Materials and devices are built from molecular components which assemble chemically using principles of molecular recognition.(Refers to build up Nano material from bottom i.e. atom by atom, cluster by cluster)



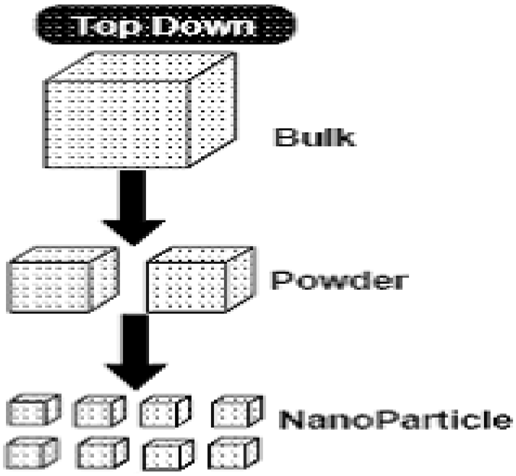
Example: Sol-Gel process

Sol-Gel process:

- This is an example for Bottom-Up approach comes under chemical method.
- In solutions, molecules of Nanometer size are dispersed and move randomly, hence the solutions are clear.

- In colloids, the molecules of size ranging from 20µm to 100µm are suspended in a solvent.
- When mixed with a liquid, colloids look cloudy or even milky. A colloid that suspended in a liquid is called a “Sol”. A suspension that keeps its shape is called a “Gel”.
- Thus “Sol-Gel”s are suspensions of colloids in liquids that keep their shape.
- “Sol-Gel” formation occurs in different stages like a) Hydrolysis b) condensation
- c) Growth of particles d) Agglomeration of particles.
- The rate of hydrolysis and condensation reactions are depends on various factors such as pH, temperature, molar reaction, catalyst and process of drying.
- Under proper conditions, fine Nano particles are produced.

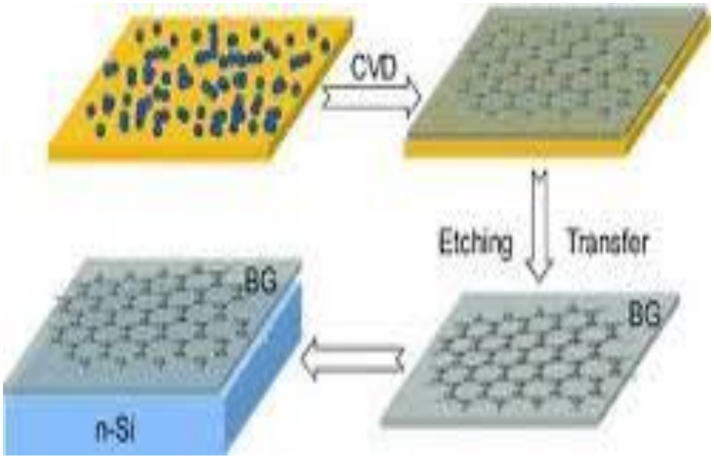
Top down: Nano objects are constructed from larger entities without atomic level control. (Refers to slicing or successive cutting of Bulk material in to Nano sized particles.)



Example: Chemical Vapor Deposition (CVD)

Chemical Vapor Deposition (CVD):

- This is an example for Top-Down approach comes under Physical method.
- In this method, Nano particles are deposited from gas phase. Materials are heated to form a gas and then allowed to deposit on a solid surface, usually under vaccum condition.
- This deposition may be either physical/chemical.
- In deposition by chemical reaction new product is formed. Production of pure metal powders is also possible using this method.
- CVD can also be used to grow surfaces. The object to be coated is placed inside the chemical vapour and may react with substrate atoms.
- Then the atoms or molecules grow on the surface of the substrate depends on alignment of atoms or molecules of the substrates.



- Under these two approaches any one of the three following methods will be employed for material fabrication.

1. Chemical Methods:

- Sol-gel processes
- Chemical combustion
- Spray pyrolysis

2. Mechanical Methods:

- Grinding
- Milling
- Mechanical alloying

3. Physical Methods:

- Electrical wire explosion method
- Chemical vapour deposition
- Laser ablation

3. Explain the different properties of Nano materials based on surface to volume ratio (Or) Explain the difference in properties of a material on Nano and in bulk scale.

- Nano materials have properties that are different from those of bulk materials. This is due to increase in surface to volume ratio and the change in inter planar spacing. Nano materials properties are depend on their size & structure.
- Starting from bulk, the first effect of reducing particle size is to create more surface sites i.e. surface to volume ratio increases. As a result inter atomic spacing decreases with size and change in surface pressure shows effect on material properties.
- Then the properties such as physical, chemical, Optical, Electrical, Magnetic and Mechanical properties are changed with size.

i) Physical Properties:

- The first effect of reducing particle size is to create more surface sites i.e., surface to volume ratio increases. This changes the surface pressure and results a change in the inter particle spacing.
- As a result, the thermodynamic properties may change for example melting point decreases with size.

ii) Chemical Properties:

- Increase in surface to volume ratio & variations in geometry have a strong effect on catalytic properties i.e., increases the chemical activity of the material

- Due to increase in chemical activity, Nano-materials can be used as catalyst.
- Nano materials contains small particles may be useful in hydrogen storage devices in metals.

iii) <u>Optical Properties:</u>

- Depending upon the particle site, different colours are seen i.e., Gold Nano spheres of 100 nm appears orange in colour while 50 nm Nano spheres appears green in colour.
- The linear and non linear optical properties of materials can change with its size i.e., Nano crystalline systems have novel optical properties.

iv) <u>Electrical Properties:</u>

- The change in electrical properties in Nano materials is electrical conductivity increases with reduction in particle size.

v) <u>Magnetic Properties:</u>

- The strength of the magnet, coercively and saturation magnetization values increases with decrease in the grain size.
- Small particles are more magnetic than the bulk material.

vi) <u>Mechanical Properties:</u>

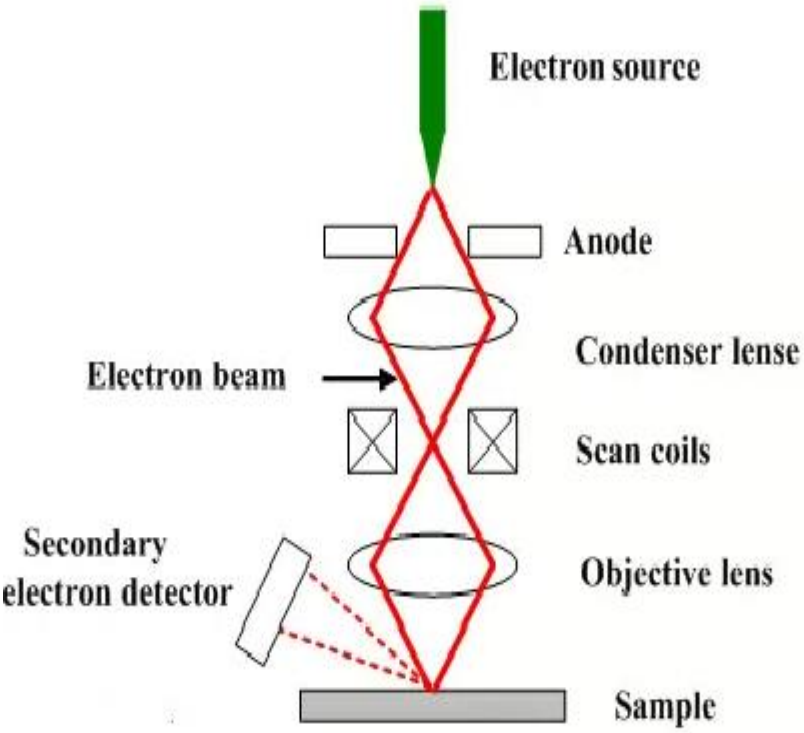
- Materials made up of with small grains have more strength.
- Because of the Nano size, many of the mechanical properties such as hardness, elastic modules, scratch resistance, fatigue strength are modified.
- Super plasticity is achieved with help of Nano technology (i.e. poly crystalline materials exhibit very large texture deformations without necking or fracture).

5. Explain SEM and EDAX techniques for characterization of Nano materials.

<u>Scanning electron Microscopy (SEM):</u>

- The image of the sample in SEM is produced by scanning the sample with a focused electron beam and detecting the secondary/back scattered electrons.
- When electron beam is incident on surface of bulk material, scattered electrons carries information.
- When electron beam is incident on surface of Nano material, the electrons are transmitted then such electrons are utilized for sample analysis. This technique is known as Transmission electron Microscopy (TEM).

Scanning Electron Microscope



Working:

- Electron source produces a stream of monochromatic electrons.
- Electrons are attracted and travel through anode there by attains directionality.
- Condenser lens eliminates high angled electrons from the beam so electron beam becomes thin and coherent.
- A set of coils acts as electro static lens, scans and weeps the beam in grid fashion and allowed to pass through objective lens in wide way.
- Then such a beam of electrons strikes the sample, interaction takes place in smooth way and this process is displayed on CRT.
- This process is repeated several times i.e. 30times/Sec to get accurate results.

Applications: SEM gives useful information on

1. **Topography:** Surface features of the object.
2. **Morphology:** Shape, Size and arrangement of particles.
3. **Composition:** Composition and their relative ratio.
4. **Crystallographic Information:** Arrangement of atoms and their order.

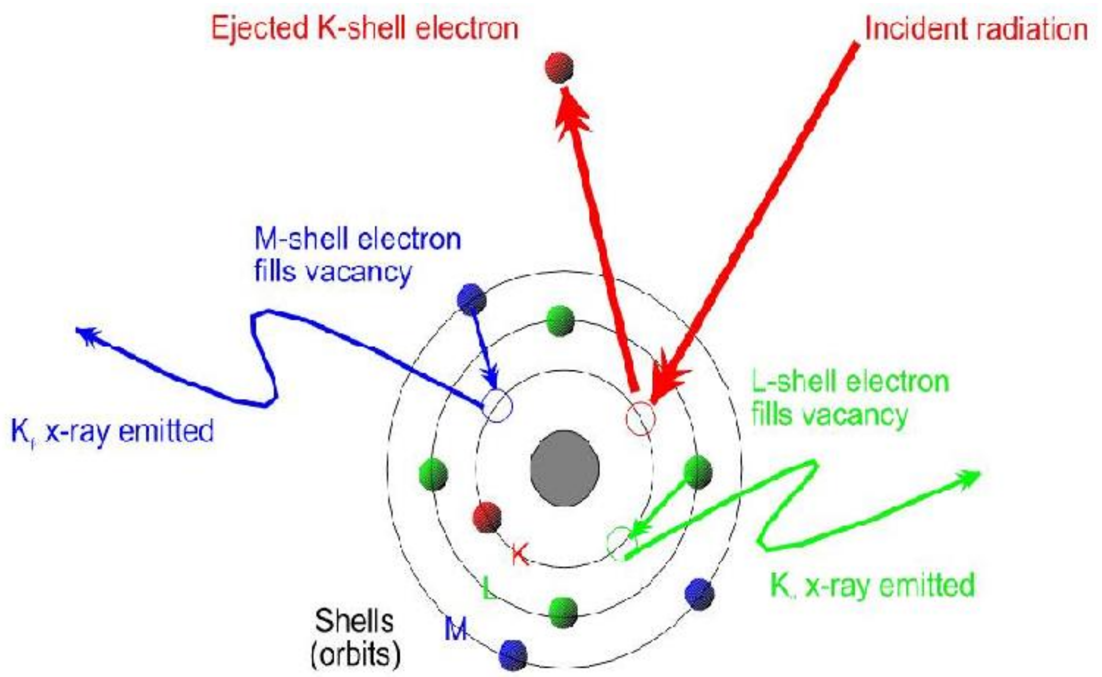
Energy Dispersive X-Ray analysis (EDAX/EDX) :

- This technique is used for identifying the Elemental composition of the sample.
- EDX system works an integrated feature of SEM.

Principle:

- During EDX analysis, the sample is bombarded with electron beam inside the SEM. The bombarded electrons collide with the specimen atoms and show the alignment of the sample in the form of spectrum.
- The spectrum intensity depends on energy and speed of the electrons used for collision with the sample.
- During the collisions between electrons and sample atom own electrons, some of the inner shell electrons are ejected and those places are occupied by outer electrons.

- Thus the transfer of outer electrons gives some of its energy by emitting an X-ray.
- The sample EDX spectrum is shown in figure.



- Then SEM/TEM technique is used for complete analysis.

Applications of EDX:

1. Classification of materials.
2. Structural analysis
3. Composition investigation.
4. Failure and defect analysis.
5. Identification of corrosion and oxidation problems.
6. Examination of surface Morphology.