APPLIED PHYSICS
(Question Bank)

Contents:

Hemanth Kumar Narsetti
(M. Sc, M. Ed, Ph. D)
Assistant Professor
Department of Physics

St. Peter`s Engineering College
Maisammaguda, Dhulapally
HYDERABAD-100

UNIT – I QUANTUM PHYSICS AND INTRODUCTION TO SOLIDS

1 MARK

Q.1 Write any **two** properties of matter waves?

Ans. The wavelength of matter waves is given by $\lambda = \frac{h}{mv}$

1) If heavier is the particle, smaller is the wavelength i.e. $\lambda \propto \frac{1}{m}$

2) If the velocity of the particle is small, greater is the wavelength i.e., $\lambda \propto \frac{1}{v}$.

3) If $v = 0$, $\lambda \rightarrow \infty$, this means if particle is at rest, wavelength cannot be determined.

4) If $v = \infty$, $\lambda \rightarrow 0$,this implies that when velocity of the particle is infinity wavelength cannot be determined.

5) Velocity of the matter waves is greater than the speed of light.

6) Matter waves are not physical (mechanical or electromagnetic waves) waves.

7) Matter waves are neither radiated nor absorbed.

8) Matter waves require medium.

Q.2 What is dual nature of matter and radiation?

Ans.

Either matter or radiation behaves like particles or waves depending on the situation. This is known as the dual nature of matter and radiation. This hypothesis is proposed by De- Broglie.

But it should be noted that particle nature or wave nature cannot be exhibited by either matter or radiation, simultaneously.

Q.3 Mention the types of symmetry in solids?

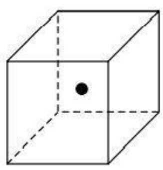
Ans.

The following are the types of symmetry in solids:

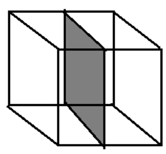
1) Center of symmetry or line of symmetry.

2) Translation symmetry or plane of symmetry.

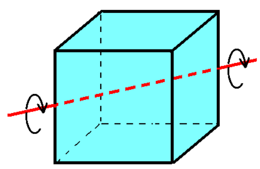
3) Rotational symmetry or axis of symmetry.



centre of symmetry



1) **Center of symmetry or point symmetry or line of symmetry**: "If an imaginary line is drawn through a point inside the crystal such that it intersects the faces of the crystal at equal distances on either side of the point, then the crystal is said to have center of symmetry".



2) **Translation Symmetry or Plane of Symmetry**: "An imaginary plane passing through the crystal which cuts the crystal into two equal parts such that one part is the mirror image of the other part."

3) **Axis of symmetry or rotational symmetry**: "An imaginary line through which when a crystal is rotated and if it appears more than once as it was in beginning in a complete rotation. Then the crystal is said to have rotational or axis of symmetry".

Q.4 Define photoelectric effect and write photo-electric equation (Einstein's photoelectric equation)?

Ans:

Photoelectric effect: "The phenomenon of ejection of electrons from a metal surface when a suitable frequency of light or radiation incident upon it is called as photoelectric effect"

The following mathematical expression is given by Einstein in order explain photoelectric emission phenomenon. Which is known as Einstein's photoelectric equation:

$$h\vartheta = \frac{1}{2}mv_{max}^2 + \emptyset$$

Where, $h\vartheta$ is the energy of incident photon, ϑ_{max} is the maximum velocity of object, $\emptyset$ is the work function of the metal surface.

The above equation can also be written as $h\vartheta = KE_{max} + \emptyset$

Q.5 Write the physical significance of wave function?

Ans.

The wave function Ψ has no direct physical meaning. As Ψ is complex wave function. $\Psi\Psi^* = |\Psi|^2$ represents the probability of finding the particle in a given volume. In mathematical form it is shown as follows:

$\Rightarrow \int_0^\infty |\Psi|^2\, dxdydz = 1$ which is called normalized function.

In other words, the square of the wavefunction gives the probability of finding the particle.

3 MARKS

Q.1 Write the difference between matter waves and electromagnetic waves?

Ans.

Matter Waves	Electromagnetic Waves
1. Matter waves are generated by both charged and uncharged particles.	1. Electromagnetic waves are generated by only accelerating charged particles.
2. Velocity of matter waves is not constant. It changes with the speed of particles.	2. The velocity of Electromagnetic waves is Constant.
3. Matter waves do not propagate in space. They require medium.	3. Electromagnetic waves propagates in space as well as in medium.
4. Matter waves are neither radiated nor absorbed in a medium.	4. Electromagnetic waves are either radiated or absorbed by the matter.

5. $\lambda = \frac{h}{p}$	5. $\lambda = \frac{c}{\vartheta}$
6. Velocity of matter waves is greater than the speed of light.	6. Velocity of Electromagnetic waves is equal to the speed of light in space or vacuum.

Q.2 Write the laws of photoelectric effect?

Ans.

1. The velocity of emitted electrons is independent of the intensity of incident light no matter how high or low the intensity is.

2. Photo electric current (or the number of photo electrons emitted per second) is proportional to the intensity of incident light.

3. For a given metal, there exists a certain minimum frequency of incident light, for which the electron emission takes place. This frequency is called 'threshold frequency'.

4. Photoelectron emission is an instantaneous process. So, there is no time lagging between the incidence of light and emission of electrons.

Q.3 Compute the work function of sodium metal if its threshold wavelength is 5040 Å ?

Ans.

Given data,

$$\lambda = 5040\text{Å} = 5040 \times 10^{-10} m$$

$$h = 6.625 \times 10^{-34} Js$$

$$C = 3 \times 10^{8} m/s$$

Work function, $\emptyset = \frac{hc}{\lambda} = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{5040 \times 10^{-10}}\ Joules$

$$= \frac{6.625 \times 10^{-34} \times 3x10^{8}}{5040 \times 10^{-10} \times 1.6 \times 10^{-10}}\ eV$$

$$\approx 2.46 eV$$

Q.4 Write the main postulates of Sommerfeld free electron theory of metals?

Ans.

Sommerfeld free e^- theory is also known as quantum free e^- theory. To solve the difficulties faced by the classical free e^- theory which was proposed by Drude-Lorentz, in 1928 Sommerfeld developed a theory based on quantum mechanics and Fermi-Dirac distribution statistics.

The following are the assumptions (postulates) of Sommerfeld quantum free e^- theory:

1) The free e^-s in a metal can have only discrete (quantized) energy values. Electrons are considered to be moving in a 3-D potential well.
2) The electrons (free) obey Pauli's exclusion principle. According to this, there cannot be more than 'two electrons' in any energy level. In other words, no two electrons have the same energy state as they have different quantum numbers.

3) The potential due to positive immobile ion cores is uniform throughout the crystal lattice which will be considered as zero for solving eigen (energy) values.
4) The force of attraction between the electrons and lattice ions, the repulsion between within the electrons is negligible.
5) The distribution of velocities, K.E among the free electrons obeys Fermi-Dirac statistics. The probability distribution function in FD statistics is given by:

$$f(E) = \frac{1}{e^{\frac{h\vartheta}{K_B T}} + 1}$$

Q.5 Explain Heisenberg's Uncertainty principle?

(here student is expected to write the statement of Heisenberg's uncertainty principle and one mathematical form)

Ans.

Matter waves are not physical waves. Matter waves are represented by a group of waves called "wave packet". If the width of wave packet is less, the wavelength cannot be determined, but the location of particle can be determined accurately. In the same way, if the width of wave packet is large the position of particle is uncertain. On the other hand, radiation (light) showed both particle property and wave nature.

Based on the above interpretations, Heisenberg formulated a principle known as Heisenberg's uncertainty principle.

According to the principle,

"It is impossible to determine the position and momentum of a particle simultaneously."

If Δx represents the uncertainty in the position of a particle and Δp represents the uncertainty in the momentum, then mathematically uncertainty principle is given as,

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

Where, h is the Plank's constant and h= 6.625×10^{-34} Js.

Δx and Δp are called conjugate physical parameters.

Similarly, if is ΔE the uncertainty in measurement of energy and Δt is the uncertainty in the measurement of time, then

$$\Delta E \Delta t \geq \frac{h}{4\pi}$$

And if ΔJ represents the uncertainty in angular momentum and $\Delta\theta$ represents uncertainty in the angular displacement then,

$$\Delta J \Delta\theta \geq \frac{h}{4\pi}$$

The significance of **HUP** is:

1) It helps us to understand why electrons cannot exist inside the nucleus and how do protons exist inside the nucleus.

2) It helps us to calculate the greatest velocity and largest frequency of radiation.
3) It helps us to understand dual nature of matter and radiation
4) It helps us to calculate the possible energies of α, β, γ radiations from nuclear decay.

5 MARKS

Q.1 Derive Schrodinger time independent waves equation (SWE)?

Ans.

Schrodinger wave equation is a fundamental equation in quantum mechanics which describes the dynamical behavior of microscopic particles such as $e^{-}s$, protons...etc. using certain boundary conditions like Newton's laws of motion used for macroscopic particles.

Consider a second order partial differentiation equation for the motion of plane wave along x-axis as is given by:

$$\frac{d^2y}{dt^2} = V^2 \frac{d^2y}{dx^2} \quad -(1)$$

Where 'y' is the displacement and 'V' is velocity. If Ψ is the displacement (amplitude) of the matter waves, then eqn. (1) becomes

$$\frac{d^2\Psi}{dt^2} = V^2 \frac{d^2\Psi}{dx^2} \quad -(2)$$

The solution of eqn. (2) is given by $\Psi = \psi_0 \sin(wt - kx) \quad -(3)$

ψ_0 - maximum amplitude of matter waves and $w = 2\pi v, k = \frac{2\pi}{\lambda}$

v - frequency of matter waves.

Differentiating eqn. (3) twice w.r.t time we get,

$$\frac{d^2\Psi}{dt^2} = -\Psi\, 4\pi^2 v^2$$

But, $v = \frac{V}{\lambda}$

$$\Rightarrow \frac{d^2\Psi}{dt^2} = -\Psi\, \frac{4\pi^2 V^2}{\lambda^2} - (4)$$

From eqn. (2) and (4)

$$V^2 \frac{d^2\Psi}{dt^2} = -\Psi\, \frac{4\pi^2 V^2}{\lambda^2}$$

$$\Rightarrow \frac{d^2\Psi}{dt^2} + \Psi\, \frac{4\pi^2}{\lambda^2} = 0$$

Now, let us use $\lambda = \frac{h}{p} = \frac{h}{mv}$

$$\Rightarrow \lambda^2 = \frac{h^2}{m^2 v^2}$$

Using the above,

$$\frac{d^2\Psi}{dx^2} + 4\pi^2\frac{m^2v^2}{h^2}\Psi = 0 \quad -(5)$$

Now, for an e −moving through a potential difference of V volts, the total energy E is given by,

E = P.E + K. E

$E = \text{V} + \frac{1}{2}mV^2$

$$E - \text{V} = \frac{1}{2}mV^2$$

$2(E - \text{V}) = mV^2$ (or) $2m(E - \text{V}) = m^2V^2 \quad -(6)$

Substituting (6) in (5) we get

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

(or) $\frac{d^2\Psi}{dt^2} + \frac{8m\pi^2}{h^2}(E - \text{V})\Psi = 0$

By letting $\hbar = \frac{h}{2\pi}$, we get

$\frac{d^2\Psi}{dt^2} + \frac{2m}{\hbar^2}(E - \text{V})\Psi = 0 \quad -(7)$

The above equation is known as time independent SWE in 1-D.

If e^- assumed to be moving through a constant potential field, then V can be taken as zero, i.e.,V= 0 . In this case taken e^- is simply to have only K.E and hence it is a free particle. The eqn. (7) becomes

$\frac{d^2\Psi}{dt^2} + \frac{2m}{\hbar^2}E\Psi = 0 \quad -(8)$

In 3-D,

$\frac{d^2\Psi}{dx^2} + \frac{d^2\Psi}{dy^2} + \frac{d^2\Psi}{dz^2} + \frac{2m}{\hbar^2}E\Psi = 0$

$\Rightarrow \nabla^2\Psi + \frac{2m}{\hbar^2}E\Psi = 0$

where, $\nabla^2\Psi = \frac{d^2\Psi}{dx^2} + \frac{d^2\Psi}{dy^2} + \frac{d^2\Psi}{dz^2}$

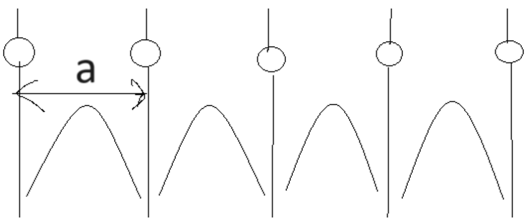
And $\nabla = \frac{d}{dx} + \frac{d}{dy} + \frac{d}{dz}$ is called Laplacian operator.

Q.2 Define periodic potential and write Schrodinger wave equation for a periodic potential function using block theorem. Derive an expression for effective mass of an electron.

Ans. (a) A potential field in a crystal lattice defined by the following function is called periodic potential.

$\text{V}(x) = \text{V}(x + na)$

Where, 'a' is the periodicity of the lattice and n is an integer.



For a periodic potential the SWE modifies as given below:

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

Where, $V(x) = V(x + na)$

The solution for above equation is of the form

$$\Psi(x) = \Psi_0\, e^{\pm ikx} U_k(x)$$

Where, $U_k(x) = U_k(x + a)$ and where, $U_k(x)$ is called the Bloch function.

Finally, the solution becomes

$$\Psi(x + a) = \Psi_0 e^{\pm ik(x+a)} U_k(x + a)$$

The above equation is known as **Bloch theorem**: *Bloch theorem is mathematical statement which explains the eigen value and eigen functions of an electron moving in periodic potential using boundary conditions.*

(b) Effective mass of an electron:

"The mass of an e^- in a periodic potential due to an applied external field is called effective mass."

If 'E' is an electric field applied, the acceleration of an e^- in the field is given by

$$a = \frac{eE}{m} \qquad -(1)$$

In case of periodic potential field, we can write eqn. (1) as,

$$a = \frac{eE}{m^*} \qquad -(2)$$

Where m^* is called effective mass of electron. We will derive an expression for effective mass as follows:

When an e^- moves through a periodic potential it moves with matter waves. Hence free e^- associates with wave packet. Then the group velocity is written as

$$v_g = \frac{dw}{dk} \qquad -(3)$$

But, $w = 2\pi v$

$\Rightarrow dw = 2\pi dv$

$$\Rightarrow v_g = \frac{2\pi dv}{dk}$$

Again, $\varepsilon = hv$

$$\Rightarrow \frac{d\varepsilon}{dk} = h\frac{dv}{dk}$$

$$\Rightarrow \frac{dv}{dk} = \frac{1}{h}\frac{d\varepsilon}{dk}$$

$$\Rightarrow v_g = \frac{2\pi}{h}\frac{d\varepsilon}{dk}$$

$$\Rightarrow dv_g = \frac{2\pi}{h} \frac{d^2\varepsilon}{dkdt}$$

$\Rightarrow dv_g = \frac{2\pi}{h}\left(\frac{d^2\varepsilon}{dk^2}\right)\frac{dk}{dt}$ $-(4)$ (by multiplying and dividing by dk)

Now, $p = \hbar k$

$$\Rightarrow \frac{dp}{dt} = \hbar\frac{dk}{dt}$$

$$\Rightarrow \frac{dk}{dt} = \frac{1}{\hbar}F \quad -(5) \qquad \left(\because \frac{dp}{dt} = F\right)$$

From (4) and (5)

$$\frac{dv_g}{dt} = \frac{2\pi}{h} \times \frac{1}{\hbar}F\left(\frac{d^2\varepsilon}{dk^2}\right)$$

$$\Rightarrow \frac{dv_g}{dt} = \frac{1}{\hbar^2}F\left(\frac{d^2\varepsilon}{dk^2}\right)$$

But, $\frac{dv_g}{dt} = a$ and $F = eE$

$$a = \frac{1}{\hbar^2}\left(\frac{d^2\varepsilon}{dk^2}\right)eE \quad -(6)$$

From eqn. (2) and (6)

$$\boldsymbol{m^* = \frac{\hbar^2}{\left(\frac{d^2\varepsilon}{dk^2}\right)} \quad -(7)}$$

Q.3 Derive an expression for De-Broglie's wavelength.

Ans. According to De-Broglie, material particles are associated with matter waves when they are in motion. The wavelength of matter waves is given by,

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

h- Plank's constant

p- linear momentum

Derivation:

(a) According to Einstein's mass energy relation, $E = mc^2$ $-(1)$

c -speed of light, m-mass

(b) According to Plank's quantum hypothesis, $E = hv$ -(2)

But $c = v\lambda$

$$\Rightarrow v = \frac{c}{\lambda} \quad -(3)$$

From (1) and (2) and (3) $\Rightarrow mc^2 = \frac{hc}{\lambda}$

$$\Rightarrow \lambda = \frac{h}{mc}$$

If, 'v' is the velocity of the particle, then $\lambda = \frac{h}{mv}$

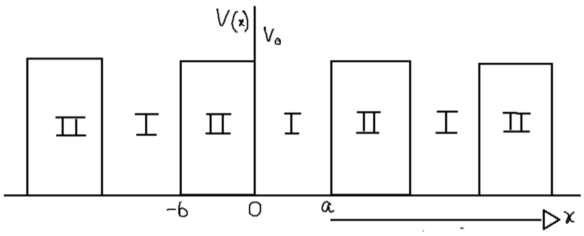
$$\therefore \lambda = \frac{h}{p}$$

Q.4 Explain Kronig-Penny model for the motion of electron in a crystal lattice. Also discuss the features of this model.

Ans. To determine allowed energy of electron in a periodic crystal lattice, Kronig and Penny suggested a simplified model in which periodic potential consists of rectangular alternate potential wells and potential barriers as shown in figure.

The periodicity of the lattice is considered as "a + b".

Here 'a' is the width of the potential well and 'b' is the width of the barrier.



(i) For $0 < x < a$, $V(x) = 0$ Region I
(ii) For $-b < x < 0$, $V(x) = V_0$ Region II

Applying SWEs in region I and II,

$$\frac{d^2\Psi}{dx^2} + \frac{2m}{\hbar^2}E\Psi = 0 \qquad (0 < x < a)$$

$$\frac{d^2\Psi}{dx^2} + \frac{2m}{\hbar^2}(E - V_0)\Psi = 0 \qquad (-b < x < 0)$$

Let, $\frac{2m}{\hbar^2}E = \alpha^2$ *and* $\frac{2m}{\hbar^2}(V_0 - E)\Psi = \beta^2$ as $V_0 > E$

The above equation can be written as

$$\frac{d^2\Psi}{dx^2} + \alpha^2\Psi = 0 \qquad -(1)\ (o < x < a)$$

$$\frac{d^2\Psi}{dx^2} - \beta^2\Psi = 0 \qquad -(2)\ (-b < x < 0)$$

From Bloch theorem, the solution of above equations become,

$$\Psi(x) = \Psi_o\, e^{\pm ikx}U_k(x)$$

Where, $U_k(x) = U_k(x + a)$

Solving equations (1) and (2) by applying boundary conditions, we get a final expression of the following form

$$P\frac{sin\alpha}{\alpha a}+cos\alpha a=\cos k\,a \quad -(3)$$

Where 'P' is called barrier strength and is given by

$$P=\frac{mV_0ab}{\hbar^2}\ and\ \alpha=\sqrt{\frac{8\pi^2mE}{h^2}}$$

The RHS of equation (3) varies between +1 and –1.LHS of equation (3) depends on barrier strength or scattering power.

The following graph is plotted between $P\frac{sin\alpha a}{\alpha a}+cos\alpha a$ and $\alpha a \quad for\ P=\frac{3}{2}\pi$.

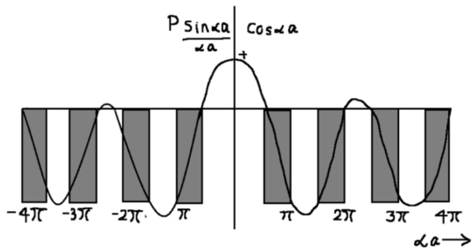
Inferences (features):

1) The energy spectrum of e^- in a periodic potential consists of alternated allowed energy regions called 'allowed bands' (shaded regions) and forbidden energy regions called 'forbidden bands' (unshared regions).
2) As αa increases the width of allowed bands increases and width of forbidden bands decreases.
3) If P is large, width of allowed band decreases and width of forbidden increases.
4) If $P\to\infty$, $\quad \frac{sin\alpha a}{\alpha a}=0$

$$\Rightarrow\ sin\alpha a=0$$

$$\alpha a\pm\frac{n^2\pi^2}{a^2}$$

$$\frac{8\pi^2mE}{h^2}=\frac{n^2\pi^2}{a^2}$$



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

This implies the energy of e^- are quantized not continuous.

For $n=1,\ E_n=E_1$

For $n=2,\ E_n=E_2$

So $E_2=4E_{1,}\ E_3=9E_{1,}\ E_4=16E_1$ … ….

5) If $P=0 \qquad cos\alpha a=\cos k\,a$

$$\alpha a=ka$$

$$\alpha=k$$

$$\alpha^2=k^2 \qquad \text{(or)}$$

$$\frac{2m}{\hbar^2}E=k^2$$

$$E=\frac{k^2\hbar^2}{2m}$$

But $p = k\hbar \quad \Rightarrow E = \frac{p^2}{2m}$

(or) $E = \frac{1}{2}mv^2$

Hence, in this situation electrons behave as free particles. This means binding energy of e^- tends to zero.

Q.5 Draw ***E-K*** diagram for an electron in a periodic potential lattice. From the graph explain Brillouin zones.

Ans. Brillouin zones are the boundaries that are marked by the values of propagation vector 'k' in which the electron can have allowed values without diffraction. Since 'k' is a vector, it has different values in different directions.

The relational between 'k' and 'E' of an electron in a periodic potential is given by

$$E = \frac{n^2h^2}{8ma^2} \qquad -(1)$$

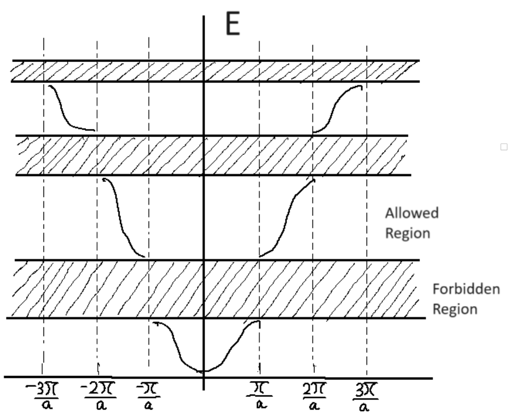
But $k = \pm\frac{n\pi}{a}$ (since $\alpha = k$) -(2)

From (1) and (2)

$$E = \frac{k^2h^2}{8m\pi^2} \qquad -(3)$$

A plot is made between the total energy 'E' and the wave vector 'k' for various values of k with

n = $\pm 1, \pm 2, \ldots$.



For $k = \pm\frac{n\pi}{a}$, the curve is a parabola with discontinues.

It is clear that the graph shows a discontinuity in the electron energy from $k = 0\ to\ \pm\frac{\pi}{a}$ and scatters.

The range of allowed energy values between $\frac{\pi}{a}$ and $-\frac{\pi}{a}$ is called ***first Brillouin zones.***

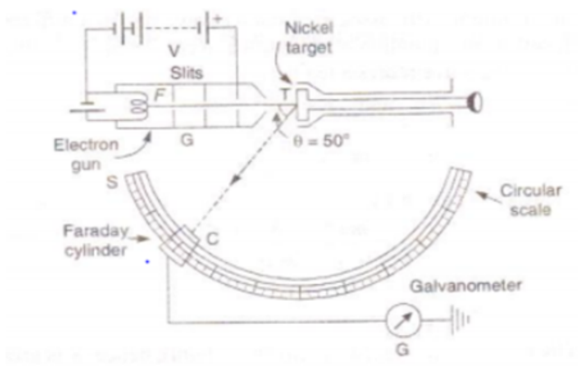
The range of allowed energy values from $\frac{\pi}{a}$ to $\frac{2\pi}{a}$ and then from $\frac{-\pi}{a}$ to $\frac{-2\pi}{a}$, is called ***second Brillouin zone*** and so on....

This implies an electron can go from B.Z. to another B.Z. when it is supplied with energy equal to the forbidden gap.

10 MARKS

Q.1 Describe the construction, working of Davisson Germer Experiment with the help of neat diagram.

Ans.



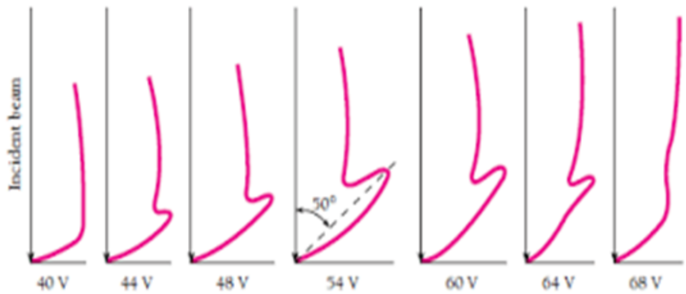
The figure shows the construction of Davisson-Germer Experiment for the proof of existence of matter waves.

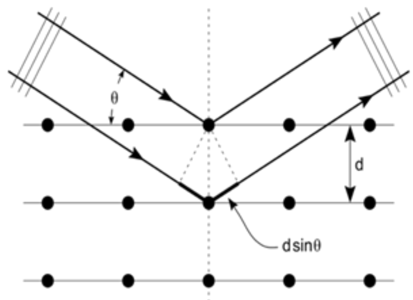
In the figure, a filament F is heated up by a Low-tension battery to emit $e^{-}s$ by thermionic emission. A high-tension battery is connected across the evacuated glass tube to accelerate the ejected electrons. Electrons travel through slits S1 and S2 in the form of fine pencil beam and incidence on the nickel (Ni) target. The angle theta (θ) of scattered $e^{-}s$ is measured with the help of circular scale. The intensity of scattered $e^{-}s$ is measured by means of ionization current caused in the Faraday cylinder (F_c) which can move on the circular scale and connected to a Galvanometer (G). In the experiment the angle of scattered $e^{-}s$ is observed to be between $29° - 80°$.

Observations:

1) By keeping the accelerating voltage (H.T) constant and angle (θ) of Ni target is fixed. The variation of ionized current is measured by moving Faraday cylinder over the circular scale.
2) Experiment is repeated by changing the value of accelerating potential and angle of target (θ), and current is noted.
3) It is observed that at $\boldsymbol{\theta} = \mathbf{50°}$, and at $\boldsymbol{44\ V}$ a bump begins to start, and the bump becomes larger at **54 V** indicating the maximum intensity of scattered electrons.
4) After 54V further increases in applied voltage the bump gradually disappeared.
5) The above observations showed that the variation of intensity of scattered $e^{-}s$ is in accordance with the diffraction pattern.
6) The wavelength of e^{-} beam is calculated as below

$$\lambda = \frac{12.26}{\sqrt{54}} \approx 1.67\text{Å}$$





Further, the electron wave nature is confirmed by Bragg's condition

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

for n = 1, d = 0.91Å (Ni target), $\theta' = 65$

$$\lambda \approx 1.65 \text{Å}$$

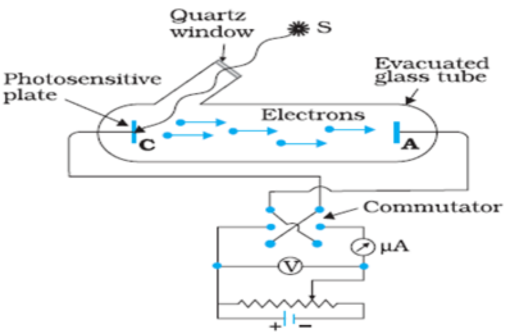
Where 'd' is interplanar spacing

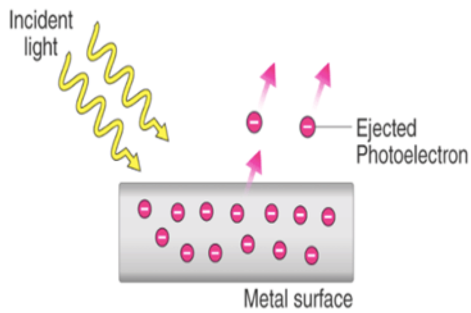
θ' – Glancing angle

Q.2 Define photoelectric effect. Explain experimental observations in photoelectric effect experiment.

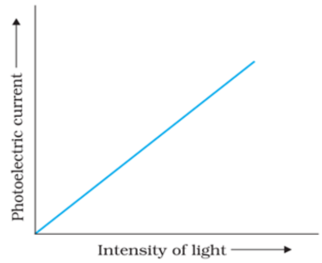
Ans. *"The emission of electrons from a metal surface when a suitable light or radiation incidence on the surface is called photoelectric effect."*

The figure shows the experimental arrangement for the demonstration of photoelectric effect.





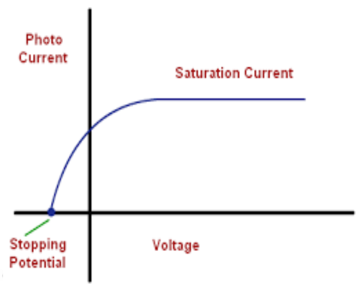
1) The cathode C is the photosensitive material and A is metallic anode.
2) When voltage is applied between cathode and anode ejected $e^{-}s$ reach anode.
3) The function of commutator is to reverse the direction of applied anode voltage when required.
4) Light or radiation is allowed to fall on cathode through a Quartz window.



Observations:

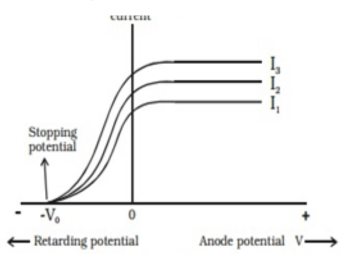
1) When intensity of incident light is increased, the photocurrent also increased.

2) At a constant intensity of light, when applied anode potential is increased the photo current becomes constant.



3) When anode potential is reversed w.r.t cathode, the photo current decreases and reaches a zero value at a particular reverse anode potential. This potential at which the photo current becomes zero is called stopping potential.

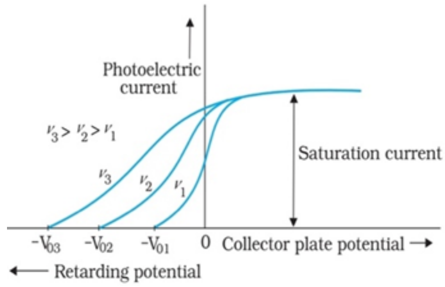
Stopping potential is independent of intensity of incident radiation.



4) At stopping potential, the K.E of electrons is maximum which is equal to work done.

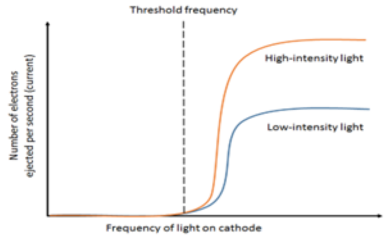
$$\Rightarrow \frac{1}{2}mv_{max}^2 = K.E_{max} = eV_0$$

5)When intensity of radiation and anode potential are kept constant by changing frequency of incident radiation photo current is measured. The following graph shows that the photo current is zero until a minimum frequency is reached above which the photocurrent increases and saturates.



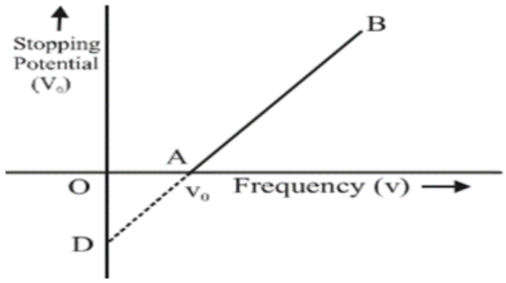
The minimum frequency of incident radiation at which the photoelectron emission takes place is called threshold frequency(ϑ_0).

6) By keeping intensity constant, frequency versus stopping potential is measured with photocurrent.



It is clear from the graph that as the frequency of incident radiation increases stopping potential increases. This means the K.E of electrons is a function of incident radiation frequency.

7)When frequency vs stopping potential is plotted, a straight-line interest the x-axis which represents threshold frequency (ϑ_0).



From the above experimental observations Einstein derived photoelectric equation:

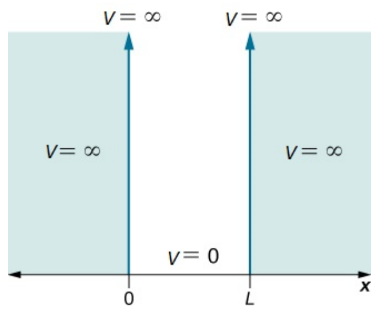
$$h\vartheta = \frac{1}{2}mv_{max}^2 + \emptyset$$

Where $\emptyset$ is work function of the given metal.

Q.3 Discuss the eigen values and eigen functions for an electron moving in an infinite square well potential box.

Ans.

Consider a $e^{-}s$ moving along x-axis in an infinite square well potential as shown in figure. When an electron reaches the wall, it experiences an abrupt force and moves back and forth between the walls.



L- length of the potential box

Boundary conditions,

V(x) = 0   0 < x < L

V(x) = ∞ $x \leq 0, x \geq L$

Applying SWE,

$$\frac{d^2\Psi}{dx^2} + \frac{2mE}{\hbar^2}\Psi = 0 \quad 0 < x < L \qquad -(1)$$

$$\frac{d^2\Psi}{dx^2} + k^2\Psi = 0 \quad where\ k = \frac{2mE}{\hbar^2} \qquad -(2)$$

The solution of the above equation is given as,

$$\Psi(x) = A\sin k\,x + B\ \cos k\,x \qquad -(3)$$

Determination of constant B

(a) At x = 0 $\Psi(x) = 0$

At x = L $\Psi(x) = 0$

This gives $B = 0$

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

$$kL = n\pi$$

$$\Rightarrow k = \frac{n\pi}{L} (n = 1,2,3 \dots)$$

$\Rightarrow \frac{2mE}{\hbar^2} = \left(\frac{n\pi}{L}\right)^2$ (or) $E = \frac{n^2h^2}{8mL^2}$

In general, $\boldsymbol{E_n = \frac{n^2h^2}{8mL^2}}$

For n = 1, $E_1 = \frac{h^2}{8mL^2}$

For n = 2, $E_2 = \frac{4h^2}{8mL^2}$

$\Rightarrow E_2 = 4E_1,$

$Similarly,\ E_3 = 9E_1 \dots\dots etc\dots.$ This means the energies of electron are quantized or discrete.

Determination of constant A

When, $B = 0$

$$\Psi(x) = A \sin\left(\frac{n\pi x}{L}\right)$$

The constant 'A' is determined by using normalized conditions

$\int_0^L |\Psi(x)|^2\, dx = \int \left\{A^2 \sin^2\left(\frac{n\pi x}{L}\right)\right\}^2 dx = 1$

$$\Rightarrow A^2 \int_0^L \sin^2\left(\frac{n\pi x}{L}\right) dx = 1$$

$$\Rightarrow A^2 \int_0^L \left(\frac{1 - \cos^2\left(\frac{n\pi x}{L}\right)}{2}\right) dx = 1$$

$$\Rightarrow \frac{A^2}{2} \left| x - \frac{L}{2\pi x} \text{Sin } \frac{2x\pi x}{L} \right|_0^L = 1$$

The second term in the bracket is zero at x = 0 and x = L.

$\Rightarrow \frac{A^2}{2} L = 1$ (or)

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

The above equation represents the eigen(wave) function for an e' in the potential box.

Evaluation of eigen functions.

Case 1: n = 1 $\quad \Psi_1 = \sqrt{\frac{2}{L}}\,\text{Sin}\,\frac{n\pi x}{L}$

At x = 0, x = L $\quad \Psi_1 = 0$

At x = 0, x = L $\quad \Psi_1^2 = 0$

At x = L/2 $\quad \Psi_1 = $ max

At x = L/2 $\quad \Psi_1^2 = $ max

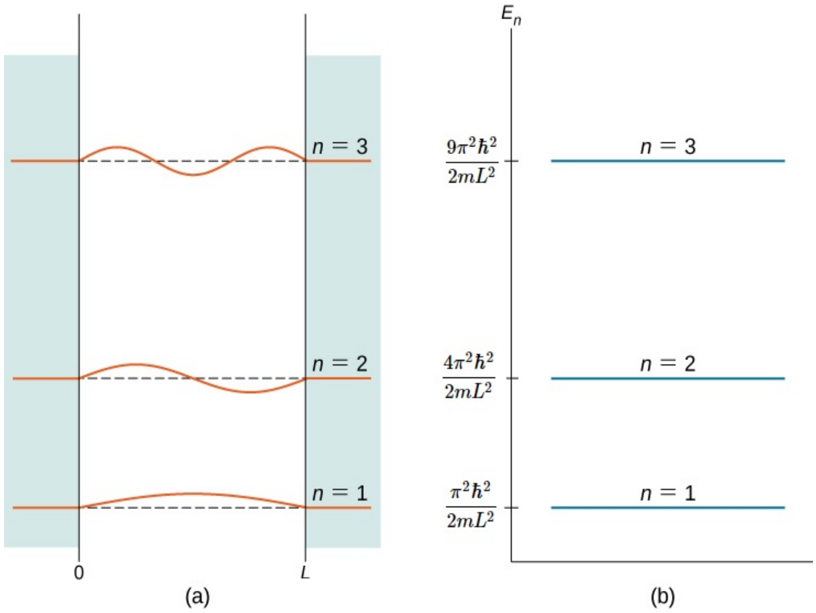
Case 2: n = 2, $\Psi_2 = \sqrt{\frac{2}{L}}\,\text{Sin}\,\frac{2n\pi x}{L}$

At x = 0, x = $\frac{L}{2}$, x = L $\quad \Psi_2 = 0$

At x = 0, x = $\frac{L}{2}$, x = L $\quad \Psi_2^2 = 0$

At x = $\frac{L}{4}$, x = $\frac{3L}{4}$ $\quad \Psi_2 = $ max

And at x = $\frac{L}{4}$, x = $\frac{3L}{4}$ $\quad \Psi_2^2 = $ max



Case 3: n = 3, $\Psi_3 = \sqrt{\frac{2}{L}}\,\text{Sin}\,\frac{3n\pi x}{L}$

At x = 0, x = $\frac{L}{3}$, x = $\frac{3L}{4}$, x = L $\quad \Psi_3 = 0$

At x = 0, x = $\frac{L}{3}$, x = $\frac{3L}{4}$, x = L $\quad \Psi_3^2 = 0$

At x = $\frac{L}{6}$, x = $\frac{L}{2}$, x = $\frac{5L}{6}$ $\quad \Psi_3 = $ max

At x = $\frac{L}{6}$, x = $\frac{L}{2}$, x = $\frac{5L}{6}$ $\quad \Psi_3^2 = $ max.

The above results are depicted in the adjacent figures.

Unit – II Semiconductor Physics and Devices

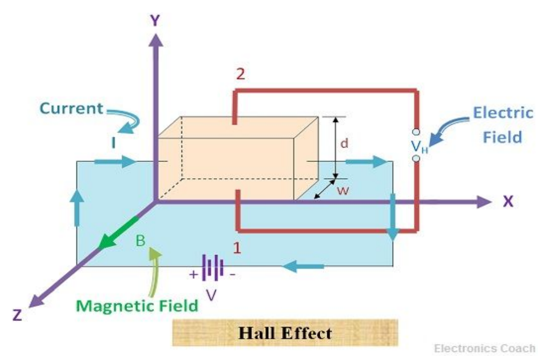
Q.1. What is Fermi level?

Ans. ***The highest energy level occupied by the electrons in a conductor or semiconductor at absolute zero temperature (0 K) is called as Fermi energy level and the corresponding energy of electron is called Fermi energy and is denoted by*** $\boldsymbol{E_F}$.

In other words, at 0 K all the energy levels below Fermi level are completely occupied by the electrons whereas, all the energy levels above Fermi level are completely empty.
Above 0 K when temperature gradually increases, electrons starts occupying energy levels above E_F and contribute electric current.
Note: Fermi energy level is the reference energy level for electrons in a conductor or semiconductor, similar to the gravitational potential energy of the macroscopic bodies at the surface of the earth which we consider as zero, but truly not zero.

Q.2. What is Hall effect?

Ans. ***When a rectangular block of metal or semiconductor carrying a current I, is placed in a transverse magnetic field B, a potential difference*** V_H ***is induced across the opposite faces in a direction perpendicular to both magnetic field and electric current is called Hall effect. This phenomenon is known as Hall Effect.***



The Hall effect is the combined effect of electrical force and Lorentz force (magnetic force) on moving electrons in the material under static conditions.

The potential difference developed is called *Hall voltage*.

Q.3. What are the examples of extrinsic semiconductor?

Ans. Both *n*-type and *p*-type semiconductors are the examples of extrinsic semiconductors.

When a pure semiconductor or intrinsic semiconductor such as Si or Ge is doped with pentavalent atoms such as P, Sb, Bi.. it becomes as *n*-type semiconductor. In the same way, when a pure or intrinsic semiconductor such as Si or Ge is doped with trivalent atoms like Al, Ga, B … it becomes as *p*-type semiconductor.

The advantage of making pure (intrinsic) semiconductor as impure (extrinsic) semiconductor is to increase the electrical conductivity from intrinsic state.

Q.4. What are applications of photodiodes? (Note: Write any two or three in the exam)

Ans. Photodiodes are used as

1. The current generated by photodiodes is directly proportional to the illumination. So they can be used to detect electrical signals as photodetectors.
2. Photodiodes are used in detection circuits. For example, to detect fire and smoke in buildings.
3. Photodiodes are used in solar cell panels to convert light into electrical energy.
4. In our houses, compact disc players, televisions, and remote controls also have inbuilt photodetectors.
5. In the medical field, photodetectors detect computed tomography, analyse samples and monitor blood gas.
6. Photodiodes are used in street lights and camera light meters.
7. Photodiodes are also used for lightning regulation and optical communication systems because their response time is significantly less than other dies.
8. Photodiodes are also used for security purposes, especially in burglar alarms. In these alarms, current flows until the radiation exposure are not disturbed. Then, as someone enters the security system and stops the falling of radiation on the device, the alarm starts producing sounds.
9. Photodiodes are used in logic circuits, character recognition circuits, and automotive devices.

Q.5. List any three applications of BJT.

Ans. A npn-device or pnp-device is known as transistor. It is also called bipolar junction transistor (BJT). The following are the applications of transistor.
1. It is used in logic circuits
2. It is used as amplifier
3. It is used as a multivibrator
4. It is used in electron switches
5. It is used in switching circuits.

3 MARKS

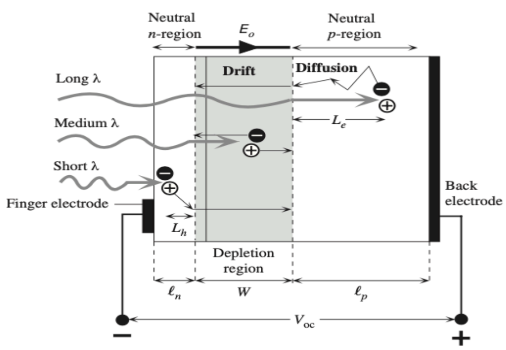
Q.1. Explain the working principle of a solar cell?

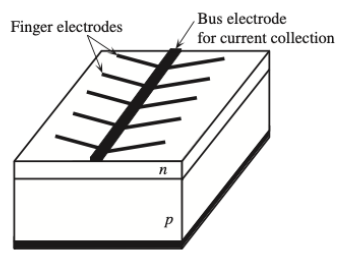
Ans. A solar cell is semiconductor device, basically a *pn-junction* diode, also known as photovoltaic cell, which converts sun light energy into electrical energy.

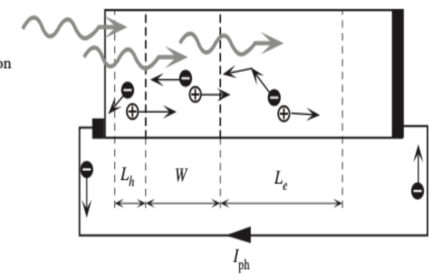
Common materials for solar cells are Si, GaAs, InAs, and CdAs. Among all these materials most common is Silicon. The maximum theoretical efficiency of a solar cell depends on ***band gap***. For Si it is about 22%. Efficiency tells that how effectively the sun light energy is converted into electrical energy.

1. Solar cells are made with indirect band-gap semiconductors.
2. The band-gap is manipulated in such way that all the photons of sun light are absorbed in the depletion region.
3. Due to this, electron-hole pairs (EHPs) are created in the depletion region.

4. Built in electric field make the electrons move towards the edge of *n*-region and holes move towards the edge of *p*-region and establish a potential difference across the barrier. It should be noted that solar cell is neither connected in forward bias nor in reverse bias.
5. The accumulations of electrons and holes on the two sides of the junction gives rise to voltage called open-circuit voltage **(V_{OC})**.
6. When a load resistance is connected, excess electrons in the *n*-side travel around the external circuit called short-circuit current **(I_{SC}).**
7. The open-circuit voltage is typically 0.6 V and short-circuit current is typically 40 mA/cm^2.

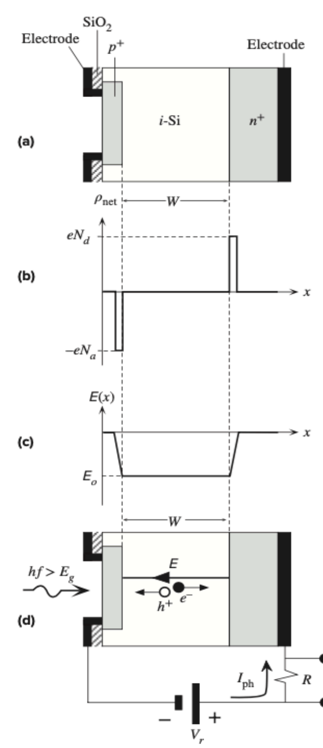






Q.2. Illustrate or explain the working principle of a PIN diode with suitable diagrams?

Ans. **Construction**



PIN diode is an example of photodetector. The construction of PIN diode is as follows:

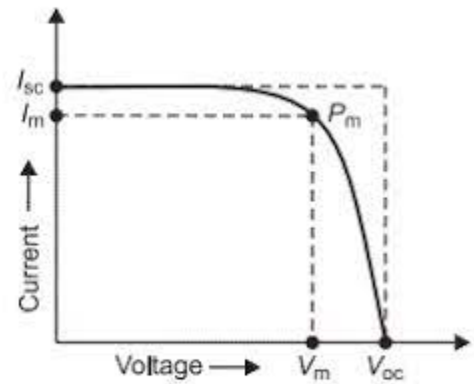
1. It consists of heavily doped thin p^+, a practically wider intrinsic region denoted as i, and heavily doped n^+-region of width greater than p^+ region.
2. During the formation, acceptor ions on the p^+ side and donor ions on the n^+ side appear like in pn-junction diode.
3. The junction barrier mostly extends into the intrinsic region from the edges of p^+ and n^+ regions as it is undoped.
4. Figure shows: *(a)* idealised p-i-n diode as photodiode, *(b)* the net space charge across the diode, *(c)* the built-in potential E_0 and *(d)* the diode under reverse bias.
5. The built in potential is uniform in contrast to normal pn-junction diode. It is similar to electric filed between the plates of parallel plate capacitor.

Working

1. Under no bias, if W is the width of depletion region then, $E_0 = {}^{V_0}/_{W}$
2. The photon absorption takes place in intrinsic (i) region and EHPs are created.
3. Under reverse bias, these EHPs drift across the barrier and constitute photocurrent as shown in figure *d* which can be measured across a load resistance *R*.

4. As the reverse bias voltage increases, depletion region increases and more photons can be allowed to enter into the diode intrinsic region which increases photocurrent.
5. The measure of photocurrent is the measure of incident light intensity. Which is the desired function of a photodetector.
6. Measurement of photocurrent detects the type of radiation incident on the diode.

Q.3. Explain V-I characteristics of a solar cell?



Ans. A solar cell, that convert the energy of light directly into electricity.

The graph shows the current-voltage (I-V) characteristics of a typical Silicon PV cell operation under normal condition. The power delivered by a solar cell is the product of current and voltage ($P = V \times I$).

1. With the solar cell open-circuited that is not connected to any load the current will be at in minimum (zero) and the voltage across the cell is at its maximum knows as the solar cells open circuits voltage (V_{oc}).
2. When the solar cell is short circuited, that is the positive and negative terminals connected together, the voltage across falls to minimum (zero) but the current flowing out of the cell reaches its maximum, known as the solar cells short circuit current (I_{sc}).
3. The solar cell is characterised by fill-factor which determines its efficiency and is given by

$$FF = \frac{V_m \times I_m}{V_{OC} \times I_{sc}}$$

Where $V_m \times I_m$ is called ***maximum usable power*** or obtainable power and $V_{OC} \times I_{sc}$ is called ideal power.

Q.4. How would you describe intrinsic and extrinsic semiconductor?

Ans.

S. No	Intrinsic Semiconductor	Extrinsic semiconductor
1	It is the pure form of semiconductor	It is the impure form of a semiconductor
2	The number of electrons and holes are equal and does not depend on temperature	The number of holes and electrons are no equal and depends on temperature
3	The electrical conductivity is very low.	The electrical conductivity is very high
4	The fermi level does not depend on temperature.	The fermi level depends on impurity concentration and temperature.
5	The fermi level lies exactly middle of bottom of CB and top of VB	The fermi level may shifts towards the top of VB or towards the bottom of CB
6	Acts as insulator at 0K	Conducts electricity even at 0K.
7	There are no types of intrinsic semiconductors	These are classified as n-type and p-type
8	The band gap is fixed and cannot be manipulated.	The band gap is not fixed and can be manipulated by doping process.

Q.5. What is the working principle of light emitting diode (LED)?

Ans.

Principle: ***Light emitting diodes are semiconductor diodes which converts electrically energy into light energy under forward bias.***

The energy of emitted light is approximately equal to the band gap of the semiconductor. The wavelength of emitted is calculated by the following relation:

$$E_g = h\vartheta$$

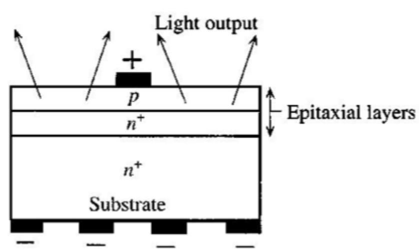
$$\Rightarrow \ E_g = h\frac{c}{\lambda}$$

$$\Rightarrow \lambda = \frac{hc}{E_g} = \frac{1.24}{E_g(eV)}\ \mu m$$

Construction

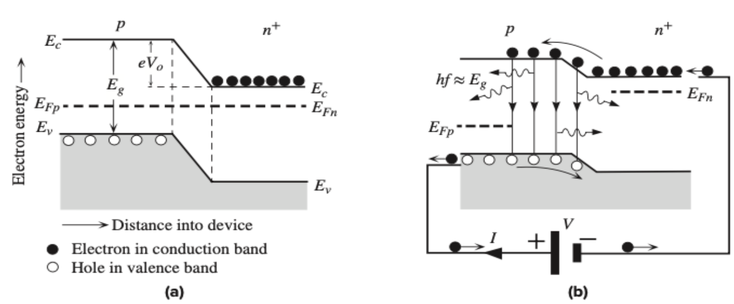
1. LED is a direct band gap semiconductor diode such as GaAs, which emits visible light when forward biased.
2. LED works on the basic principle called as *"direct recombination"*.
3. The construction of LED is as shown in figure.
4. In LED, n-region is heavily doped (n^+) whereas p-region is lightly doped (p).
5. In the growth process initially a heavily doped n-region (n^+) is grown on a heavily doped thick n^+ **substrate** (GaAs or GaP). Then a p-type lightly doped region is grown on to the heavily doped n^+region.

Symbol:



Working

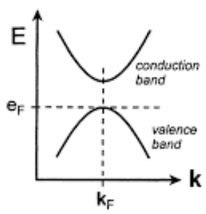
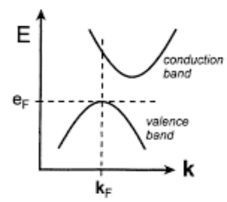
1. The following diagram shows the energy band structure of LED before and after biasing.
2. Under no bias voltage, fermi levels in both regions coincide.
3. With forward bias V, barrier region decreases and direct recombination of EHPs around the junction in the p-side leads to photon emission.



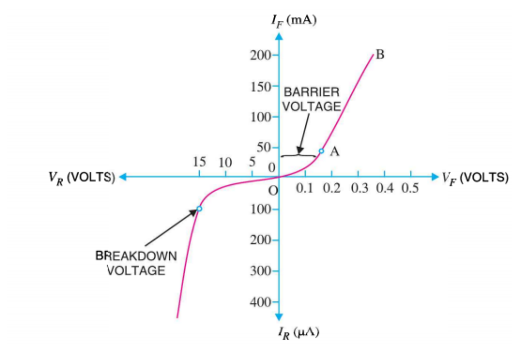
5 MARKS

Q.1. Distinguish between direct and indirect band gap semiconductors?

Ans.

Direct band gap semiconductors	Indirect band gap semiconductors
1. 	1. 
2. The bottom of CB lies just above the top of VB.	2. The bottom of CB does not lie above the top of VB.
3. The bottom of CB and the top of VB occur at the same momentum	3. The bottom of CB and top of VB occur at two different momentum values.
4. When electron makes a downward transition it undergoes only change in energy. The is no change in momentum	4. When electron makes a downward transition it needs to undergo change in energy as well as momentum.
5. The compound semiconductor such as GaAs are direct gap semiconductor.	5. All elemental semiconductors as Si, Ge are indirect gap semiconductor
6. These direct gap semiconductors are used in LED and semiconductor laser.	6. Not useful for LED and semiconductor laser.
7. Transitions form from CB to VB leads to light emission (photons)	7. Transitions from CB to VB leads to heat emission (phonons).

Q.2. Explain V-I characteristics of ***pn***-junction diode?



Ans. The following graph shows ***I-V*** charcteristics of a typical *pn-junction* diode.

The following table explains the differences between forward bias and reverse bias.

Forward bias	*Reverse bias*
1. As Forward bias voltage is increased, depletion layer width reduces.	1. As reverse bias voltage is increased, depletion layer width increases.
2. When Forward bias voltage is equal to barrier voltage, the depletion layer vanishes and majority carriers can cross the junction.	2. Majority carriers cannot cross the junction as repulsive force increases.

3. Current is due to majority charge carriers mainly	3. Current is due to minority carriers can be obtained which is negligible.
4. As we increase the forward voltate, forward current increases and diode becomes as normal conductor	4. When reverse bias voltage is increased minority charge carriers accelerate and create new EHPs by breaking covalent bonds.
5. There is no break down voltage in the faorwrad bias	5. The number of electrons in the depletion layer suddenly gets multiplied which leads to breakdown voltage.

Q.3. Discuss about the avalanche photodiode?

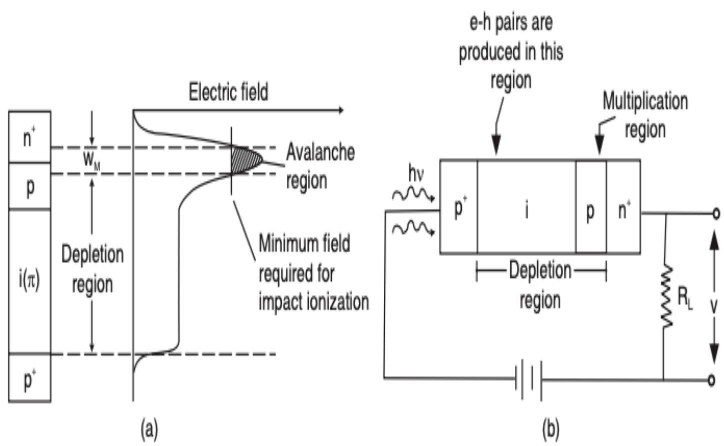
Ans.

The avalanche photodiode was invented by Japanese engineer Jun-ichi Nishizawa in 1952.

1. Avalanche photodiode is more sophisticated than *pin* diode.
2. It has an internal gain mechanism by avalanche break down effect like in avalanche diode.
3. Photocurrent is amplified internally by avalanche mechanism.
4. It is very useful in low light detection.

Construction

1. The diagram shows the construction of APD. It consists of four regions in series:
2. A thin $p^+, i(\pi), p\ and\ a\ thin\ n^+$ regions. The $p - region$ is lightly doped and the intrinsic region is free from charge carriers.
3. The p^+, and n^+ regions are heavily doped and have low resistance.
4. The p^+ region acts as anode and n^+ region acts as cathode.



Working

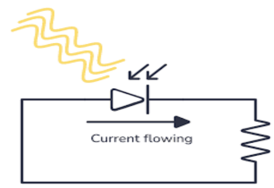
1. Avalanche photodiode is always connected in reverse bias. It has high reverse bias voltage (break down voltage) about 100-200V.
2. External photons enter from p^+ region and travels across the diode material. Most of the light passes into intrinsic region and creates EHPs.
3. Due to high reverse voltage, a high electric field is set up across the diode. This high reverse field increases the kinetic energy of EHPs which can break down the covalent bond in the p-region and generates new EHPs.
4. This process takes place in the geometric progression by the impact ionization.
5. The avalanche effect is carried by the electrons. The holes generated in the intrinsic region drift towards p^+ electrode and do not take part in the multiplication process.

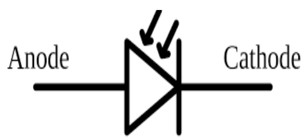
6. The electrons generated travel form p-region to n^+ region and constitute photo current. In this way APD is said to be acting as photo-detector.
7. Avalance photodiodes are high sensitive, high speed semiconductor "Light" detector.
8. These are swept out of the depletion region quickly due to the low transit time.
9. The current senstivity is increases from 30 to 100 times due to its avalanche operation.

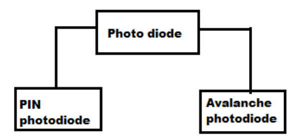
Q.4. What do you mean by photodiode?

Ans.

1. A photodiode is a pn-junction diode which is used to detect the intensinty of incident light.
2. PIN diode and avalnche photodiode are the examples.
3. When light is absorbed in the depeltion region, EHPs are generated and estalblish photo current.
4. Photodiode is one kind of detection that can able to convert the optical signal into electric signals.
5. Photodiode is a *pn*-junction diode operated in reverse bias.

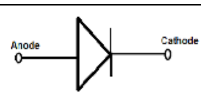
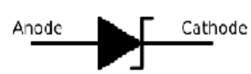


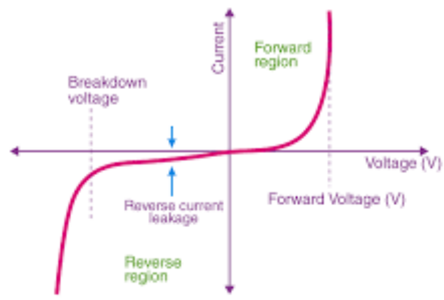
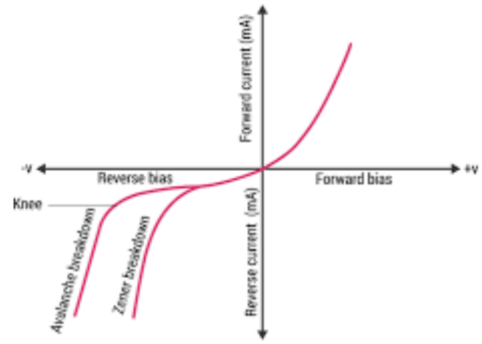
Symbol: 



Q.5. Explain advantages of Zener diode over pn- junction diode?

Ans.

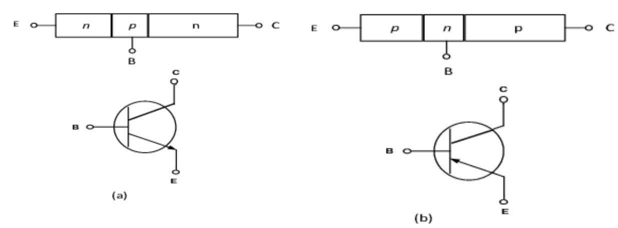
Parameter	*pn*-Junction Diode	Zener Diode
Defination	It is a semiconductor diode which conducts only in one direction, i.e, in forward direction.	The diode which allows the current to flow in both the direction i.e., forward and reverse, such type of diode is known as the Zener diode.
Symbol		
Reverse current effect	Damage the junction and not reversible	Do not damage the junction and is reversible
Doping level	Low	High
Breakdown	Occurs in high reverse voltage	Occurs in lower reverse voltage
Ohms law	Obey at high FB voltages	Do not obey
Application	For rectification, means converting dc into ac.	Voltage stabilizer, motor protection and wave shapping.

V-I characteristics		

10 MARKS

Q.1. With the help of schematic diagrams, explain the principle of operation of BJT?

Ans. A bipolar junction transistor (BJT) consists of three different doped regions, assumed to be formed by connecting two pn-junction diodes back to Back.
There are two barrier junctions namely EB junction and EC junction.
a) *npn*- transistor
b) *pnp*- transistor



1. *Emitter region*- This is usually a heavily doped region. The emitter emits the carriers into the base.
2. *Base region*-This is lightly doped region the base region is also physically thin so that carriers can pass through with minimal recombination.
3. *Collector region*: The collector region has a larger width that the other two regions since charged is accumulated here from the base.

BJT Operation modes:

The transistor con be operated in three modes:
- Active region- In this region BJT worked as a amplifier.
- Cut-off- BJT works as a switching circuit.
- Saturation region- BJT works as a switching circuit.

Active region:

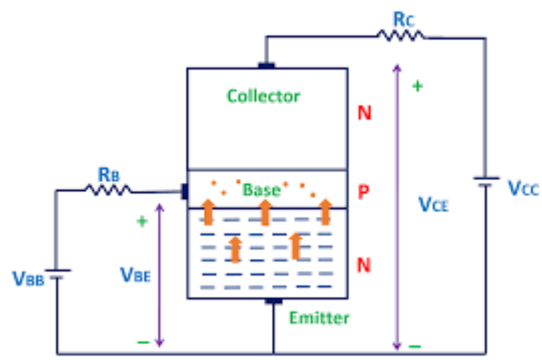
In Active region, Emitter-Base junction in forward biasing and collector-base junction in reverse biasing condition.
In this biasing condition, the BJT worked or act as amplifier.

Cut-off region:

Both the junctions are reverse biased in cut-off mode.

We know that in reverse bias condition, no current flows through the device. Hence no current flows through the transistor. Therefore, the transistor is in off-state and act like an open switch.

Saturation Region:



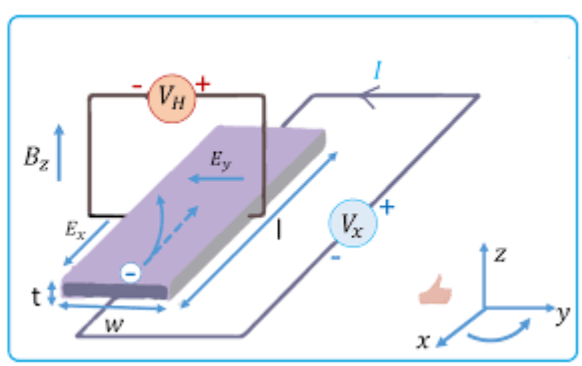
Both the junctions are forward biased.
The transistor in saturation node will be in on state and acts like a closed switch.

Working principle of BJT:

By using KCL
We can observe the mathematical equation,
$I_B + I_C = I_E$ - (1)
The base current is very less as compared to emitter and collector current
$I_E \approx I_C$
$I_C = \propto I_E$ - (2)
$\propto$-defines, what fraction of the emitter current is flowing through the collector terminal.
Put (2) and (1) $\Rightarrow I_B + \propto I_E = I_E$
$\Rightarrow I_B = (1-\propto) I_E$
$\Rightarrow I_B = (1-\propto)\frac{I_C}{\propto}$
$\Rightarrow I_C = \frac{\propto}{(1-\propto)} I_B$
$\Rightarrow I_C = \beta I_B$
Where, $\beta = \frac{\propto}{(1-\propto)}$
Where β is the application factor.

Q.2. Describe the Hall effect and derive the Hall coefficient?

Ans.



If a metal or semiconductor carrying a current (I), is placed in a transverse magnetic field (B), an electric field (E_H) or voltage is induced in the direction perpendicular to both the direction of current and magnetic field. This phenomenon is called on Hall effect. The electric field produced is called as Hall field (E_H).

The current through the metal (or) semiconductor is given by

$$I = nevA \qquad -(1)$$

Where n - concentration of electrons
A - area of cross section of the plate

e - charge of the electron
v - average drift velocity of electrons

At equilibrium,

Electric force on electrons = Magnetic force on electrons (Lorentz force)

$eE_H = evB \qquad -(2)$

$\frac{V_H}{w} = vB \quad since \ E_H = \frac{V_H}{w}$ (Since E_H acts along E_y in figure)

$$V_H = vBd$$

$$V_H = \frac{IBw}{neA}$$

$$V_H = \frac{IBw}{neWt} \qquad -(3)$$

$$V_H = R_H \frac{BI}{W}$$

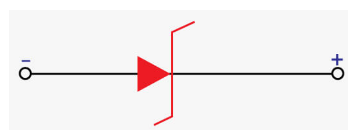
where $\quad R_H = \frac{1}{ne}$ called *Hall Coefficient*

Importance/ Significance of Hall effect is that if helps:

1. To determine carrier concentration (n).
2. To determine type of the semiconductor.
3. To determine mobility (μ) of the charge carriers.

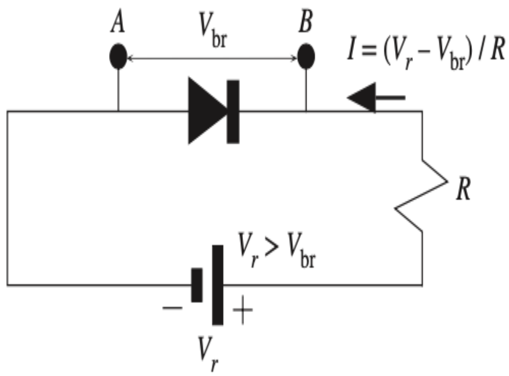
Q.3. Discuss about the working, I-V characteristics of Zener diode?

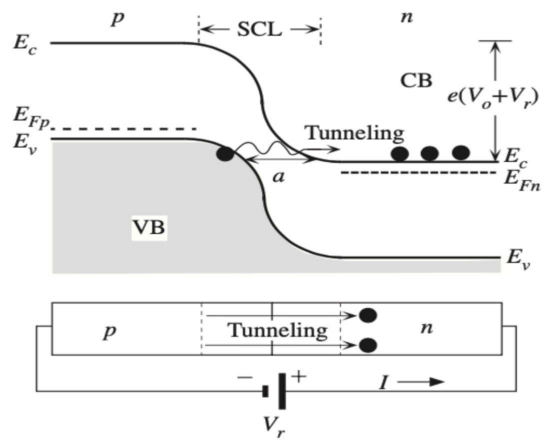
Ans.



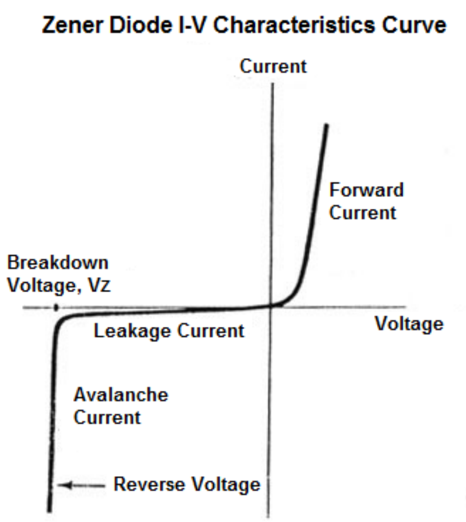
1. Zener diode is a *pn*-junction diode made specifically to have heavily doped p-region and n-regions.
2. Due to this a narrow depletion regions forms. Hence barrier field becomes very high across the junction.
3. This implies a reverse voltage causes a large electric field which is strong enough to rupture covalent bonds of host atoms and produce electron hole pairs (EHPs). Hence this leads a large reverse current.
4. In terms of energy band diagram, the energy levels on n-side much lowers down to the energy levels on p-side.
5. The top of valence band E_V on p-side will be slightly above the bottom of conduction band E_C on n-side.
6. At sufficient reverse bias (typically < 10V), electrons in the VB on p-side can *tunnel* through the barrier and occupy the empty available energy levels in the CB on n-side. This tunneling effect is called ***Zener effect*** which is a quantum mechanical effect.

7. The reverse voltage V_r at which the reverse current suddenly increases is ***Zener breakdown voltage***.





I - V characteristics of a Zener diode



1. The forward bias characteristics are similar to normal pn-junction diode.
2. In the reverse bias condition, due to tunnelling Phenomenon a sudden increase in current takes place.
3. The reverse voltage at which sudden increase in current happens is called *reverse break down voltage.*
4. Under reverse breakdown voltage, the diode operation is reversible.
5. Therefore, a Zener diode is mainly used as voltage regulator

UNIT-3- Dielectrics, Magnetic materials and Superconductivity
1 Mark

Q.1. Define piezo electricity with example?

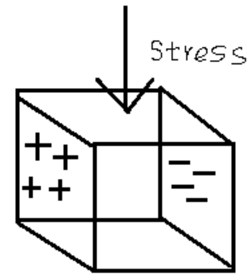
Ans. The material which gets polarized when subjected to mechanical stress is known as piezo electric material and the property is known as piezo electric effect.

$P = d\sigma$

Where, P = polarization

d = piezo electric coefficient

σ = stress applied



Quartz, Barium titanite ($BaTio_3$) are examples of piezo electric material. When stress is applied on these materials, they get polarized.

Q.2. Define Ferroelectricity with examples?

Ans. The dielectric materials which are having spontaneous polarization in the absence of electric field are called ferroelectric materials. The phenomenon of possessing spontaneous polarization in the absence of external electric field is called ferroelectricity.
Barium titanate, Lithium niobate and lithium tantalate are examples of some ferroelectric materials.

Q.3. Interpret or mention the classification of dielectric polarization?

Ans. Polarization in dielectrics occurs due to several mechanisms. When the dielectrics is placed inside dc electric field, four kinds of polarization occur
(1) Electronic polarization
(2) Ionic polarization
(3) Orientational polarization
(4) Space charge polarization

Q.4. Summarize any three applications of superconductors?

Ans. There are several applications of superconductors which are given as follows

(1) Magnetic Levitation: -It means a super conducting material can be suspended in air against the repulsive force from a permanent magnet. Magnetic levitation effect can be used for high-speed transportation

(2) Super conductors are used to generate very high magnetic field of order 150 tesla

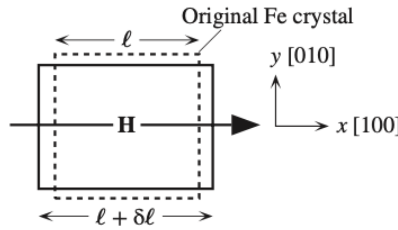
(3) Superconductors are used as fast electrical switching applications.

(4) Super conductors are also used to form SQUID (Super conducting Quantum interferences devices) sensor.

(5) Super conductors are also used to perform logic and storage function in computer.

Q.5. What is magnetostriction?

Ans. When a ferro magnetic material is subjected to an external magnetic field, it experiences a change in shape or size. The property of changing the dimension of material due to presence of magnetic field is known as magnetostriction.

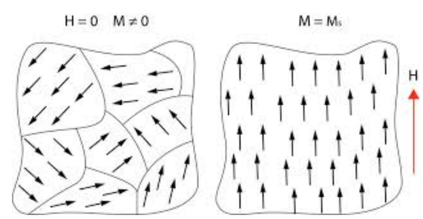


3 Marks

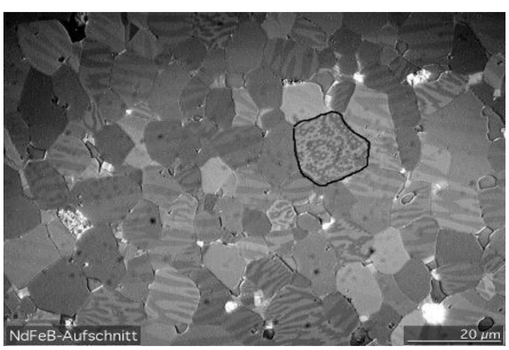
Q.1. Distinguish between soft and hard magnetic materials

Soft magnetic material	Hard magnetic material
1)Soft magnetic materials are those which can be easily magnetized and demagnetized	1) Hard magnetic materials are those which are difficult to magnetize and demagnetize
2)Soft magnetic materials possess a low hysteresis loop area. Hence these are having low hysteresis loss.	2) Hard magnetic materials have high or wide hysteresis loop area. Thus, they have higher hysteresis loss.
3) These materials have low value of coercivity and retentivity.	3)These materials have high values of coercivity and retentivity.
4) These materials have large values of permeability and susceptibility.	4) These materials have small values of permeability and susceptibility.
5) E.g.: Fe-Si alloy	5) E.g.: Fe-Ni-Al alloy with Co doping.

Q.2. Explain ferromagnetism based on domain theory or explain domain theory of ferromagnetism?

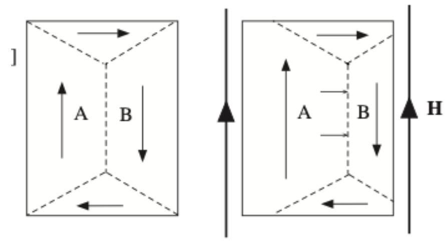


Ans. According to Wiess (1807), a virgin specimen of ferromagnetic material consists of a number of spontaneously magnetizing regions known as domains. In each domain there will be $10^{12} – 10^{18}$ atomic magnetic dipoles whose dipole moment vectors align parallel to each other in the same direction. The size o domain varies between 10^{-4} to 10^{-6} m. Each domain is separated by a boundary called *domain wall* or *Bloch wall.* The formation of domains in ferromagnetic substances is explained on the basis of quantum mechanics. The main reason behind the formation of domains is due exchange interactions of adjacent spins of electrons in an atom.



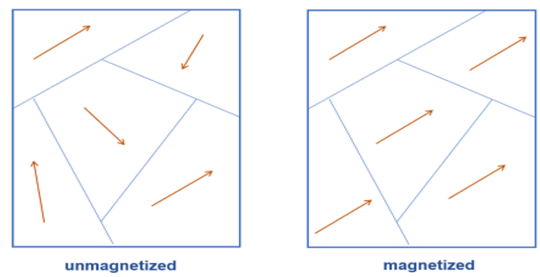
Microcrystalline grains within a piece of $Nd_2Fe_{14}B$ (the alloy used in neodymium magnets) with magnetic domains made visible with a Kerr microscope. The domains are the light and dark stripes visible within each grain. The outlined grain has its magneto crystalline axis almost vertical, so the domains are seen end-on. (Not for exam)

1) In the absence of external magnetic field, each domain spontaneous magnetized and align randomly. Thus, the resultant magnetization of the ferromagnetic specimen is zero.
2) When an external magnetic field is applied, the net magnetization in the direction of external magnetic field arises in the material. This happens in two ways:
a) By motion of domain walls: -
When field is gradually increased, in the low magnetic field regions this mechanism takes place. The size of the domains whose magnetization is in favorable to the direction of external magnetic field increases by the movement of domain walls. And the size of the domains which are unfavorable to the external field direction shrink in size.



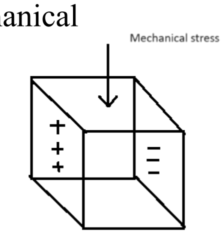
b) By rotation of domains: -
When applied field is strong or at higher magnetic fields, rotation of domains of magnetization occurs along the applied field direction.

But when the field is switched off or reversed to zero field, the reorientation of domains does not take place to initial condition and ferromagnetic substance possess finite magnetization which is known as spontaneous magnetization.



Q.3. Explain piezo electric materials and mention their application?

Ans. The material which can be polarized when subjected to mechanical stress are known as piezo electric materials.
The polarization occurred in the material is directly proportional to the applied mechanical stress.



$P = d\sigma$

P = polarization

d = piezoelectric coefficient

σ = applied mechanical stress

Electric field is generated in the piezo electric material perpendicular to the applied field.

Examples: Quartz, Barium titanate are good examples of piezo electric materials

Applications: -

i) These materials are used to convert mechanical energy into electrical energy by means of piezoelectric effect.

ii) Piezoelectric materials are used in filter, resonator circuit

iii) These materials are used for transducer applications.

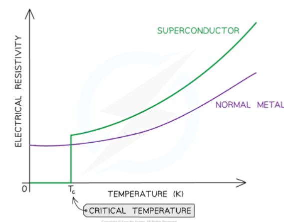
Q.4. Define superconductivity. Graphically represent how resistance of super conductor varies from normal conductor and explain the dependence of superconductivity on applied magnetic field?

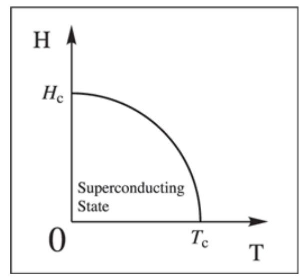
Ans. When certain metals and alloys are cooled to a very low temperature, their electrical resistance decreases. But at a certain temperature called critical temperature, their resistance falls sharply and becomes zero

.

The disappearance of electrical resistance at or below finite extremely low temperature is known as super conductivity and temperature at which resistances become zero is known as critical temperature (T_c).

*The superconducting behavior depends on the intensity of applied magnetic field. If the magnetic field intensity increases to a critical value, the super conducting behavior is lost, and material makes transition to normal state. The value of critical magnetic field decreases with increase in temperature.





Q.5. Define multiferroic materials and classify the different types of multiferroic materials with examples?

Ans. Multiferroic materials are those materials which exhibit more than one ferroic property in the same phase.

The ferric properties may be following:

i) Ferromagnetic

ii) Anti ferro magnetic

iii) Ferrimagnetic

iv) Ferro electric

v) Ferro elasticity

Depending on the origin of ferroic behavior of materials multiferroic are classified into two categories.

i)Type-1 Multi ferroic

ii)Type-2 Multiferroic

i)Type-I Multiferroic: - Type-1 multiferroic are those materials, whose both the ferroic behavior are having different origins.

$BiFeO_3$ is a type-1 multiferroic, where ferroelectricity occurs due to loan pair in Bi atom and unpaired electron in Fe gives rise to anti ferromagnetism

ii)Type-II Multiferroic: -

Type –II multiferroic are those, where ferroelectricity is generated in specific magnetic ordering and called as magnetism –driven multiferroic

Ex: - $TbMnO_3$ and $TbMnO_5$ are examples of type-II multiferroic.

5 Marks

Q.1. Define polarization? Explain different types of polarization vector is defined as electric dipole moment per unit volume.

Ans. $p = \frac{\mu}{V}$

μ = dipole moment

P = polarization

V = volume

There are four kinds of polarization

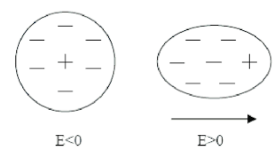
i) Electronic polarization

ii) Ionic polarization

iii) Orientational polarization

iv) Space charge polarization

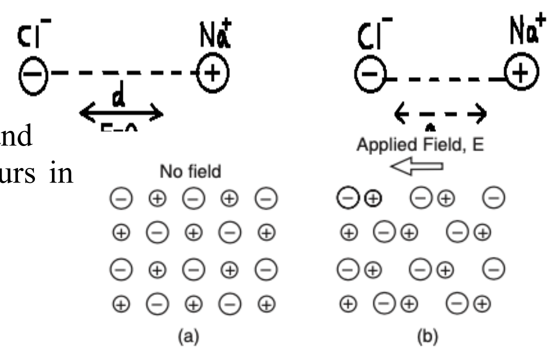
Electronic polarization



When an atom is placed in an electric field, the positively charged nucleus and negatively charged electrons are shifted in opposite direction to the applied field and the atom is said to be polarized. It is called electronic polarization.
Here $\mu = \alpha_e E$

Where $\alpha_e = 4\pi\epsilon_0 R^3$
R-radius of the nucleus. It is independent of temperature.

Ionic polarization:
The ionic polarization occurs due to displacement of cation and anion in opposite directions. When field is applied it occurs in ionic compounds.



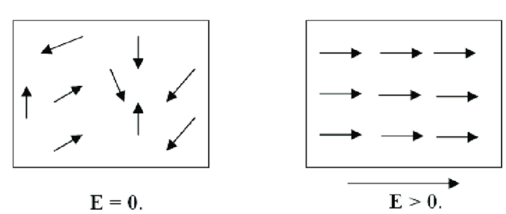
$$\alpha_i = \frac{\mu}{E} = \frac{e^2}{w_0^2}\left(\frac{1}{M} + \frac{1}{m}\right)$$

ω_0= natural frequency of vibration
M, m = masses of ions

Orientational polarization: -
It occurs in molecules having permanent dipole moment when electric field is applied, dipoles themselves align along the applied field direction and the net polarization occurs.

$$\alpha_0 = \frac{\mu^2}{3kT}$$

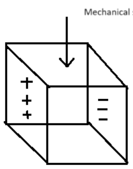
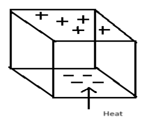
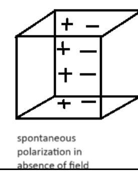
*Orientational polarizability depends on temperature i.e. inversely proportional absolute temperature.



Space charge polarization: -
It occurs due to accumulation of charges at electrodes or at the interface of multiphase material space charge polarization is very small as compared to other polarization.

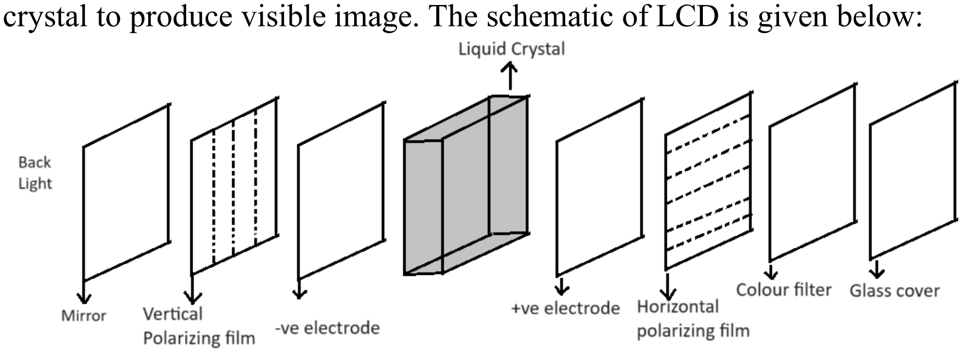
Q.2. Differentiate between ferro, piezo and pyro electric properties.

Ans.

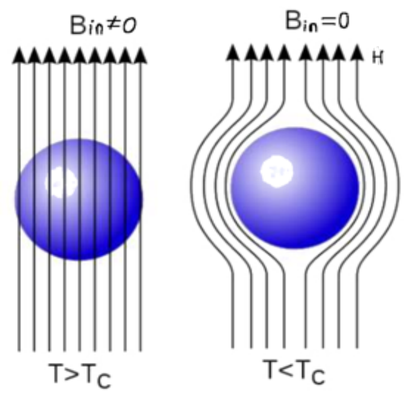
Piezo electric	Pyro electric	Ferro electric
1)Piezo electric materials get polarized when mechanical stress is applied.  	1) Pyro electric materials get polarized when thermal stress is applied.  	1)Ferro electric materials are those material which exhibit spontaneous polarization in the absence of electric field. 
2)A material should have non-Centro symmetrical non-polar to be piezoelectric.	2)A material should be non-centrosymmetric and non-polar to be pyro electric.	2)A material has to be piezo electric and pyroelectric to be ferro electric
3)E.g.: -Quartz crystal, ADP	3)E.g.: -Quartz crystal ADP	3)E.g.: Lithium niobate, Barium titanate.
4)Acts like transducers generate ultrasonic waves.	4)Used in IR defectors image tubes.	4)Used in ultrasonic transducers, pressure transducers.
5) presence of piezo electric effect P = dσ d = piezo electric coefficient	5) presence of pyro electric effect $\lambda = \frac{dP}{dT}$ λ = pyroelectric coefficient	5) presence of ferro electric effect. $\varepsilon = \frac{c}{T - T_c}$ ε = ferroelectric coefficient

Q.3. How does liquid crystal display work?
Or Explain the working principle of LCD?

Ans. Liquid crystal display is a combination of two state matter, the solid and liquid LCD uses liquid crystal to produce visible image. The schematic of LCD is given below:



i) The LCD works on the principle of blocking light. LCD needs external florescent lamp or CRT to produce backlight which is unpolarized.
ii)The unpolarized light pass through vertical polarizer and becomes vertically polarized.
iii)Liquid crystal generally twists the light by 90° . But when electric current is applied across the electrode. The molecule of liquid crystal tends to be untwisted and can't rotate the light.
iv)The portion of vertically polarized light which passes through the liquid crystal is blocked by horizontal filter and particular portion appears dark in the screen. In this way the image is produced on this screen.



Q.4. What is Meissner's effect. Show that a super conduction material exhibits diamagnetic behaviors using this effect and state any three applications of superconductors?

Ans. The phenomenon of expulsion of external magnetic field lines by a superconducting material in its super conducting state is called Meissner effect.
As for super conductor B = 0, (By Meissner effect)

$$\mu(M+H)=0$$

$$(M+H)=0$$

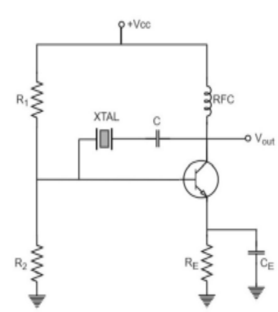
$$M=-H$$

$$\frac{M}{H}=-1$$

As $\boldsymbol{X_m}$ **= -1** for superconductor it behaves as a perfect diamagnetic substance.
Applications: -
1) Superconducting material can be suspended in air against the repulsive force from a permanent magnet. This effect is called magnetic levitation. This effect is used for high-speed transportation.
2) Superconductors are used to generate a very high magnetic field of order of 50T.
3) Super-conductors are used as fast electrical switch elements and electric generators.
4) Superconducting wires can be used in transformers to avoid power loss due to heating.

Q.5 Explain the working of crystal oscillator and interpret the expression for resonant frequency along with necessary circuit diagram.

Ans. We know when a quartz crystal is subjected to an external electric field it undergoes physical strain. This is known as piezo-electric effect.
Crystal oscillator works on this principle of inverse piezo electrical effect, in which an ac voltage is applied across the quartz crystal causes it to vibrate as its natural frequency.



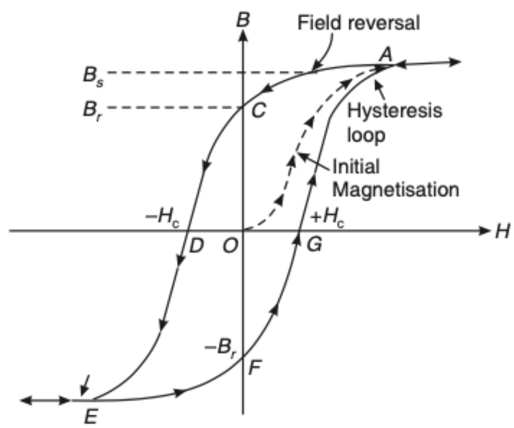
Circuit diagram and working: -
i)The resistances R_1, R_2 *and* R_e provide biasing stabilization to the circuit
ii) Capacitor C_e bypasses ac component and isolates R_e to avoid voltage drop.
iii) Radio frequency choke (RFC) provides dc collector load and prevents any ac signal from entering the power supply, when V_{cc} is switched on.
iv)The crystal in the circuit acts as LCR tank circuit which generate oscillation wave form at

180° phases.
v)The crystal is connected in series with transistor such that it will provide positive feedback at the base of transistor.
vi)The transistor will amplify the signal and provide an output of oscillation of 360° phase.
Resonant frequency: -
When the series capacitance C_s with series inductance L_s , the crystal impedance will be least, and amount of feedback is largest. The series resonant frequency for the above crystal oscillator is given by

$$F_r = \frac{1}{2\pi\sqrt{L_s C_s}}$$

10 MARKS

Q.1. Explain the hysteresis curve of ferromagnetic material based on domain theory of ferromagnetism.

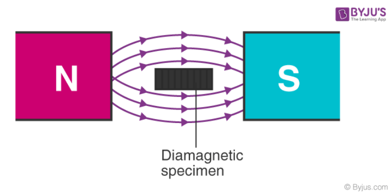


Ans. The hysteresis of ferromagnetic material refers to the lagging of magnetization behind the applied magnetic field. The figure shows the hysteresis loop of a ferromagnetic material when magnetized.
i) When a weak magnetic field is applied to the ferromagnetic material, the domains that are aligned parallel to the applied field grow at the expense of domain having opposite orientation. Thus, results in small magnetization. Such displacement of domain boundary is reversible by the removal of field.
ii) When the field becomes stronger, domains rotates along applied magnetic field. This process is represented by OA in the M.H curve. It is irreversible in nature.
iii) If further the magnetic field is increased all the magnetic dipoles in the domains will align themselves along the applied magnetic field and magnetization becomes maximum this is called saturated magnetization (B_s).
iv) On decreasing the field, the magnetization doesn't follow the same path because the aligned domains do not retrace their random states of orientation.
v) There exists some non-zero magnetization even after removal of magnetic field. This magnetization is called remanent magnetization or remanence (B_r). This is represented in the curve along AC.
vi) The magnetization can be reduced to zero by applying a reverse magnetic field known as coercive field or coercivity (Hc) at C.
vii) If further reverse magnetic field is increased then magnetization occurs similar to this positive magnetic field but in reverse direction along CDEFGA. In this way a loop is formed known as hysteresis loop.
viii) The hysteresis loss is represented by the area of loop which is defined as the energy loss during complete cycle of magnetization for ferromagnetic material.
ix) Based on area of hysteresis loop, magnetic material is divided into soft and hard magnetic material.

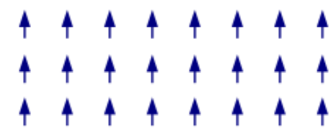
Q.2. Classify the different magnetic properties of materials?

Ans. The magnetic properties of materials are classified into five categories.
i) Diamagnetism ii) Ferromagnetism iii) Para magnetism iv) Anti Ferromagnetism v) Ferrimagnetism

i) **Diamagnetism**: -



(a) Diamagnetism is a very weak effect and is observed in solids which do not contain any permanent magnetic moment.
(b)An electron moving around the nucleus results in magnetic moment. Due to different orientation of various orbit of atoms, the net magnetization is zero in diamagnetic materials
(c)When diamagnetic material is placed in the magnetic field, it repels the magnetic lines of force.
(d)Magnetic susceptibility is independent of temperature and applied magnetic field
(e)Relative permeability is slightly less than ‘1’



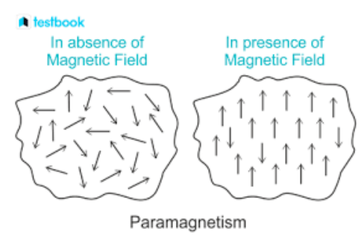
ii) **Ferromagnetism**: -

a) Ferromagnetism is associated with ferromagnetic material. Ferromagnetic materials exhibit magnetic moment in the absence of applied magnetic field below curse temperature (Tc).
b) The magnetization existing in ferromagnetic material in the absence of magnetic field is called spontaneous magnetization.
c) Ferromagnetism materials acquire large magnetization in presence of weak magnetic field.
d)When placed in magnetic field, it allows the lines of forces to pass through it.
e) Magnetic susceptibility (χ_{ferro}) is large and inversely proportional to temperature.

$$\chi_{ferro} = \frac{C}{T - T_c} (T_c = Critical\, temperature, C = curie\ const.)$$

f) spin alignments are parallel.

iii)**Para magnetism**

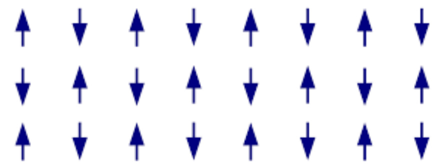


(a) Each electron in an orbit has magnetic moment. In the absence of magnetic field, these moments are randomly oriented and there is no magnetization.

When external magnetic field is applied, these dipoles align themselves along applied field and dipole moment is induced. The induced dipole moment is proportional to the applied field and is a source of Para magnetism.
(b) Paramagnetic material possesses permanent magnetic dipole moment.
(c) When placed in this magnetic field, it attracts the magnetic lines of force and allows them to pass through it.
(d) Paramagnetic susceptibility is positive and inversely proportional to temperature.

$$X_{para} = \frac{C}{T} \quad C = curie's\ const.$$

iv) **Anti ferromagnetism**

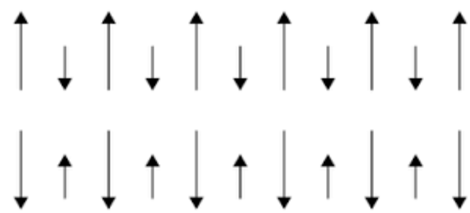


When the distance between interacting atoms is small, the exchange forces produce anti parallel alignment of electron spin in neighboring atom. If the spins are equal in magnitude and have opposite alignment, then it is called anti ferromagnetism.
*The susceptibility is positive and vary with temperature as follows

$$X_{Anti} = \frac{C}{T + T_N} \qquad T_N = neel\ temperature$$

*Anti ferro magnetism occurs below Neel temperature

v) Ferrimagnetism: -



It is a special kind of anti-ferromagnetism. If the neighboring spins are opposite and unequal, then it is called ferrimagnetism.

*The susceptibility is positive and ferrimagnetism occurs below Curie temperature.

Q.3 Describe the differences between Type-I and Type-II superconductor?

Ans.

Type – I	Type – II
These super conductors exhibit single critical magnetic field.	Theses super conductors contains two critical magnetic fields.
These are completely diamagnetic.	These are not completely diamagnetic.
These are also referred to as Low-temperature Superconductors.	These are also referred to as High-temperature Superconductors.
The critical temperature is typically ranges from 0K to 10K.	The critical temperature is typically greater than 10K.
These typically have a Low critical magnetic field which ranges from 0.0000049 to 1T.	These typically have a High critical magnetic field which is typically greater than 1T.
These perfectly obey the Meissner effect.	These partially obey the Meissner effect.

Type – I	Type – II
These are also termed as soft superconductors.	These are also termed hard superconductors.
There is not existence of mixed state.	There is an existence of mixed state.
There is no effect of slight impurity on superconductivity of type – I superconductors.	There is great effect of slight impurity on superconductivity of type – II superconductors.
These generally consist of pure metals.	These consist of alloys and complex oxides of ceramics.
The transition from a superconducting state to a normal state happens very quickly and sharply due to the external magnetic field.	The transition from a superconducting state to a normal state due to the external magnetic field is gradually but not sharp and abrupt .
Examples: Hg, Pb, Zn, etc.	Examples: NbTi, Nb3Sn, etc.

UNIT-4 NANOPHYSICS AND NANOTECHNOLOGY

1 MARKS

Q.1. What is Nano material?

Ans. A material composed of nanoparticles of size between 1 nm to 100 nm is called nanomaterial. Nanomaterial may be in the form of tubes, rods, spherical particles or fibers. They may be usually prepared as particles, colloidal solutions and thin films on substrates.

Nanomaterial is defined as the "material with any external dimension in the nanoscale or having internal structure or surface structure in the nanoscale i.e., length range approximately from 1 nm to 100 nm"

Q.2.What is nanotechnology?

Ans. Nanotechnology is the design, characterization, production and application of structure devices and systems by controlling shape and size at the nano meter scale.

Q.3. What is nanoscale?

Ans. The materials are converted into 1-100 *nm* range or 10^{-9} m is called nanoscale.

Q.4. Mention the examples of one- dimensional nanoparticles?

Ans. The examples of one-dimensional nanostructures like fibers, rods, tubes, wires, belts and rings.

Q.5. What is nanoscience?

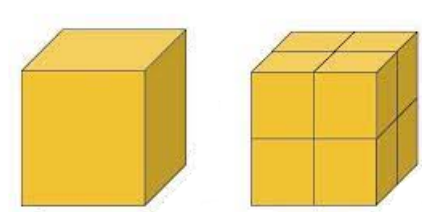
Ans. Nanoscience is the study of phenomena and manipulation of materials with atoms, molecules at the nanometer scale, where properties differ significantly from those at bulk scale.

3 MARKS

Q.1. Discuss surface to volume for a nanoparticle ratio with an example?

Or why nanoparticles show different physical and chemical properties from bulk?

Ans. **Reason 1**: Nanomaterials have a relatively larger surface area when compared to the volume.



Ex: For a sphere of radius r, the surface area and its volume can be given as

Surface area= $4\pi r^3$

Volume: $\frac{4}{3}\pi r^3$

Now surface area to volume ratio= $\frac{4\pi r^2}{\frac{4}{3}\pi r^3} = \frac{3}{r}$

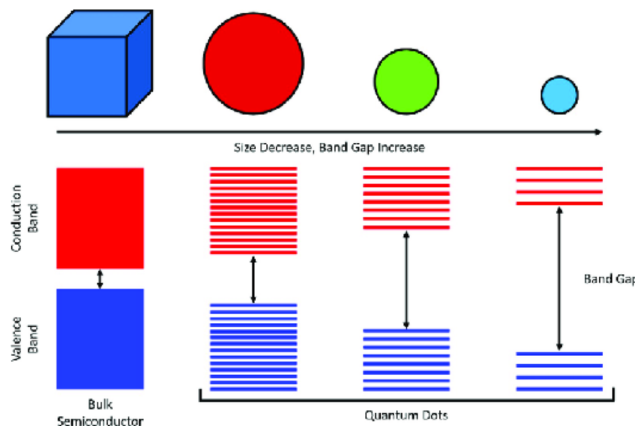
Thus, we find that when the given volume is divided into smaller parts, surface area increases.

area = 6× $1m^2$

= $6m^2$

area = 6× $(^1/_2)m^2 \times 8$

= $12m^2$



Single box ratio

$\frac{6m^2}{1m^3} = \frac{6}{m}$

smaller boxes ratio

$\frac{12m^2}{1m^3} = \frac{12}{m}$

Reason 2: Quantum confinement

As the particle size decreases quantum mechanical effects comes into play. It implies that we need to apply quantum mechanics to understand the change in physical properties of nanoparticles.

Q.2. Explain Quantum Confinement

Ans. When the dimensions of a particle are or space concerned with a particle are reduced to the order of de-Broglie wave length the energy levels of particles like electrons and holes change. This effect is called as Quantum Confinement.

Due to this, the physical properties of material particles from bulk to nano changes significantly.

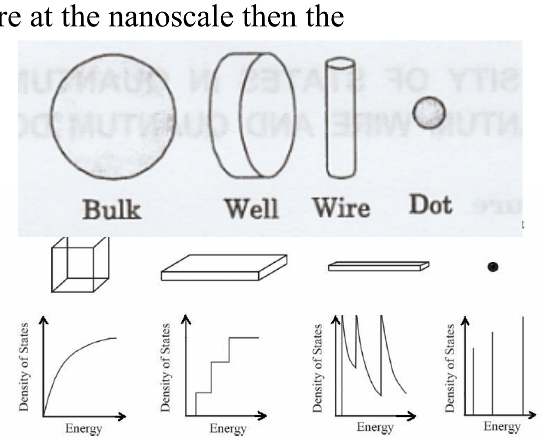
Quantum confinement is also understood by the following

Quantum Wires: If a nanostructure one dimension is at the nanoscale and other two dimensions remain at the bulk scale then the nanostructure is called quantum wire.

Quantum Wells: If a nanostructure two dimension are at the nanoscale and other one dimension remain at the bulk scale then the nanostructure is called quantum well.

Quantum Dots: If a nanostructure whose all dimensions are at the nanoscale then the nanostructure is called quantum dot.

Note: If the bulk structure is spherical then cylindrical form, disc form and dot referred to quantum wire, quantum well and quantum dot respectively.

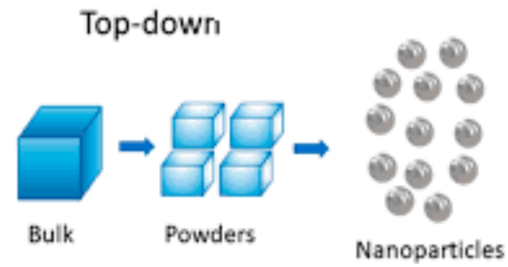


In the figure adjacent, the graphs represents how energy of the nanoparticles changes from continuous to discrete from bulk to nanoscale.

Q.3. Discuss the top-down approach?

Ans. In the top - down approach the fabrication of bulk materials is broken into nano sized particles. In this process there is no control over the size and the morphology of particles.

Some common methods of top- down approach are:

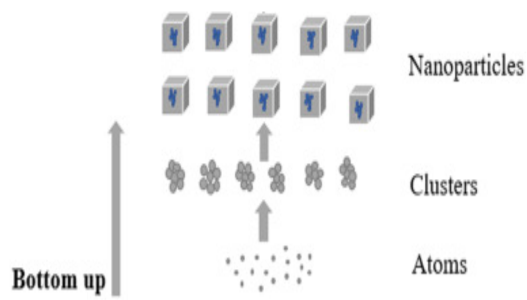


1) Ball milling method
2) Plasma arc
3) Laser sputtering
4) Vapor deposition method

Q.4. Discuss the bottom - up approach?

Ans. Bottom up approach refers to the building up of a material from the bottom i.e. atom by atom, molecule by molecule (or) cluster by cluster.

Colloidal dispensing is a good example used of bottom-up approach in the synthesis of nano particles.



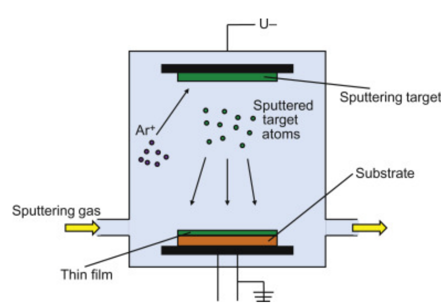
There are different methods used for the synthesis:

1) Sol-gel method
2) Colloidal method
3) Electro deposition
4) Solution phase reductions

Q.5. Explain the physical vapor deposition (PVD)?

Ans. Physical vapor decomposition is fundamentally a vaporization cooling technique involving transfer of material in an atomic level.

PVD is a process by which a thin film of material is deposited on a substrate according to following steps.



1) The material to be deposited is converted into vapor by physical means.

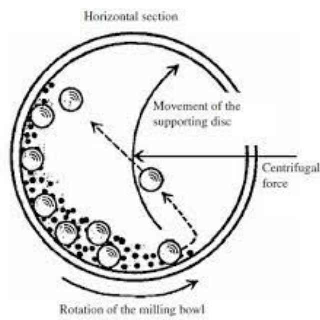
2) The vapor is transported across a region of low pressure from its source to the substrate.

3) Vapor undergoes condensation on the substrate to form the thin films.

5 MARKS

Q.1. Discuss the Ball milling method briefly?

Ans. Ball milling is a method of production of nano materials by the process of a mechanic crunching. The mills are equipped with grinding media composed of Wolfram Carbide (or) steel. Small balls inside a drum-like cavity are rotated at high speeds and by gravity actions, they settle on a solid layer where they are crushed into nanocrystals.



The following are the various types of Ball milling methods:

1) Attrition ball mill

2) Vibrating ball mill

3) Planetary ball mill

4) Low and high energy ball mill

1) Attrition Ball milling:

The milling procedure takes place by a stirring action of agitator which had a vertical rotator central shaft with horizontal arms. The rotation speed was later increased to 500 rpm. The milling temperature will be in control.

2) Vibrating Ball milling:

It is used for production of amorphous alloys. The changes of powder and milling tools are agitated in the perpendicular direction at very high speed (1200 rpm).

3) Planetary Ball Mill:

Planetary ball mills are smaller than common ball mills and mainly used in laboratories for grinding samples materials down to very small size. A planetary Ball mill consists of at least one grinding jar.

4) Low and high energy Ball milling:

The low energy Ball mill method

Run at speeds between 60 and 90 percent of critical speed.

High energy Ball mill method:

In high energy Ball milling method chemical processing is a novel and cost-effective method of producing a wide range of nano powders. It involves the use of a high energy ball mill to initiate chemical reactions and structural changes.

Q.2. Write the applications of nanoparticles?

Ans.

1) Automotive Industry: Light weight construction, painting (or) base coat, catalyst,

2) Chemical Industry: Fillers, adhesives, magnetic fluids as coating etc.

3) Engineering: Lubricant free bearing, wear protection for tools and machines like scratch resistant coatings.

4)Electronic industry: Data memory, displays (like OLED), laser diodes, glass fibers, optical switch conductive coatings etc.

5) Medicine: Drug delivery system, active agents, medical rapid test, anti-microbial agents, anti microbial coatings, agents in cancer therapy.

6) Energy storage: Fuel cells, solar cells, batteries, capacitors, magnetic refrigeration etc.

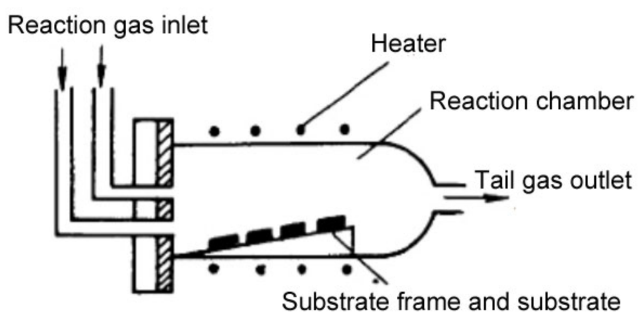
7) Cosmetics: Sun protection creams, lip sticks, skin creams, tooth pastes etc.

Q.3. Discuss the chemical vapor deposition (CVD) method briefly?

Ans. Nanoparticles are deposited from the gas phase. Materials are heated to form a gas and then allowed to deposit on solid surface usually under vacuum condition.

The deposition may be either physical (or) chemical. In deposition by chemical reaction new product is formed. Nano powder of oxides and carbides of metals can be formed, if vapor of carbon (or) oxygen are present with the metal.

These materials include Si, carbon fiber, carbon nano fibers, filaments, carbon nano tubes, SiO2, tungsten, silicon carbide.



Construction:

Figure shows basic construction of CVD method.

Working:

A material often a metal is evaporated from a heated metallic source into a chamber which has been previously evacuated to about 10-7 torrent back filled with inert gas to a low pressure.

The metal vapor cools through colliding with the inert gas atoms, becomes supersaturated and then nucleates homogenously, the particle size is usually in range 1-100nm and can be controlled by varying the inert gas pressure.

The particles are collected and may be compacted to produce a dense nano materials.

The process of chemical vapor decomposition, the substrate material at the wafer surface but also in gas phase in the reactor's atmosphere.

Reactions that take place at the substrate are known as heterogeneous reactions. Reactions that take place in the gas phase are known as homogeneous reactions.

Advantages:

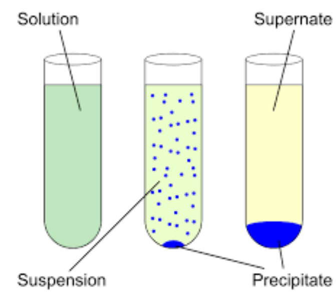
1) The increased yield of nanoparticles.

2) A wider range of ceramics including nitrides and carbides.

3) More complex oxides such as BaTiO3.

Q.4. Discuss the chemical precipitation method with heat illustration?

Ans. Removal of metal ions from solution by changing the solution composition, thus causing the metal ions to form insoluble metal complexities called chemical precipitation.



Chemical precipitation:

1) Heavy metal removal

- Hydroxide precipitation (OH^-)
- Sulphide precipitation (S^-)
- Carbonate precipitation (CO_3^{2-})

2) Phosphorus removal

- Phosphate precipitation (PO_4^{2-})

3) Hydroxide precipitation

Add lime (or) sodium hydroxide (NaOH) to water stream to precipitate heavy metals in the form of metal hydroxides

$$Cd^{2+} + Ca(OH)_2 \rightarrow Cd(OH_2) \downarrow + Ca^{2+}$$

CaO in the form of slurry (Ca $(OH)_2$) while NaOH in the form of solution.

NaOH is easier to handle but is very corrosive will form floc and settle in clarifier.

4) Sulphide precipitation

Use of sulphide in the form of FeS, Na_2,NaHS. Better metal removal as sulphide salt has low solubility limit.

$$Cu^{2+} + FeS \rightarrow CuS \downarrow + Fe^{2+}$$

Limitations can produce H_2S(g) at low pH

$$2H^+ + FeS \rightarrow H_2S + Fe^{2+}$$

At low pH reaction will proceed to the right. Thus, require pH>8 for safe sulphide precipitation.

Applications:

1) Removal of metals from waste stream Ex: plating and polishing operations, mining, steel manufacturing, electronics manufacturing including arsenic, barium, chromium, lead.

2) Treatment of hard water removal of Mg^{2+} & Ca^{2+}

3) Phosphorus removal

4) Making pigment

5) Removal salts from water in water treatment.

Q.5. Discuss the Sol-Gel method briefly?

Ans. Sol-Gel is a chemical process used to make ceramics and glass materials in the form of the films, fibers (or) powders.

A sol is a colloidal (or) molecular suspension of solid particles of ions in a solvent. The colloids in which molecules of size ranging from 20nm to 100nm.

A gel is a semi-rigid mass that forms when the solvent from the sol begins to evaporate and the particles or ions left behind begins to join together in a continuous network.

The sol-gel process usually consists of 4 steps:

1) The desired colloidal particles once disposed in a liquid to form a sol.

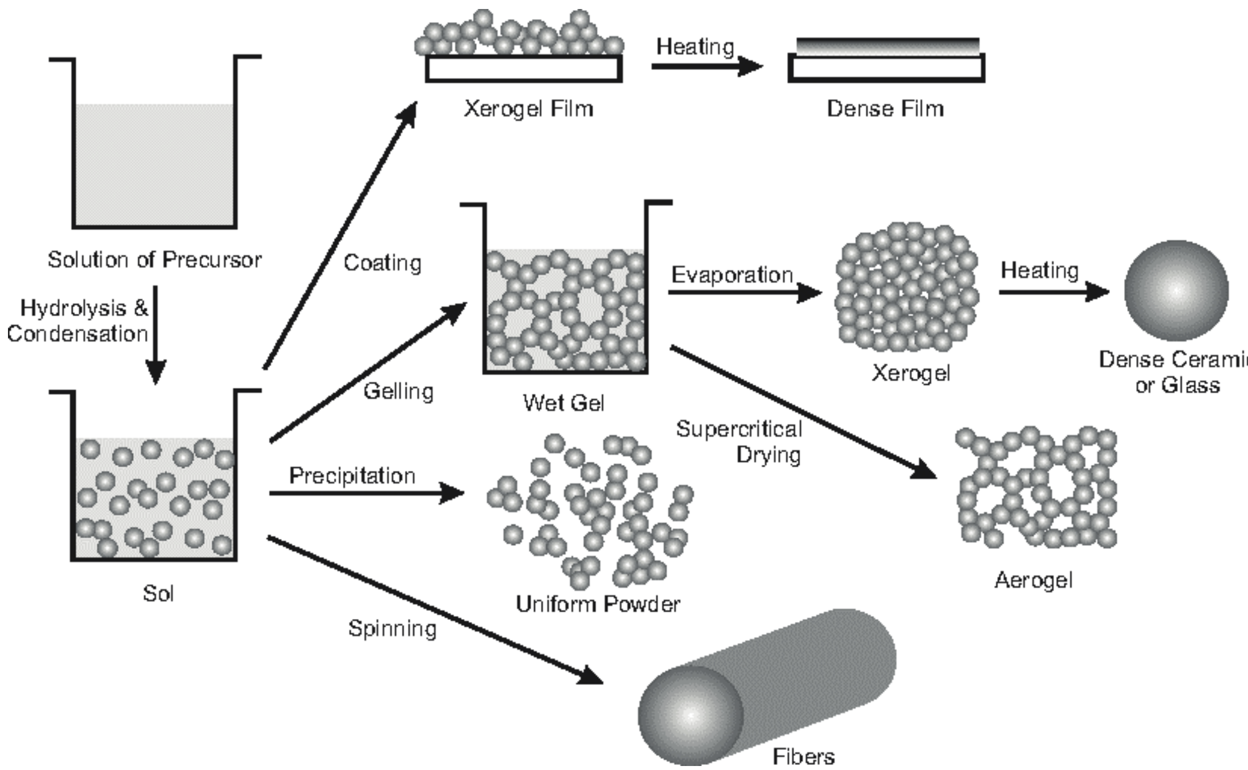
2) The deposition of sol solution produces the coatings on the substrates by spraying, dipping (or) spinning.

3) The particles in sol are polymerized through the removal of the stabilizing components and produce a gel in a state of a continuous coating.

4) The final heat treatments pyrolyze the remaining organic (or) inorganic components from an amorphous (or) crystalline coating.

The sol-gel approach is easy and cheap low temperature technique that allows for the fine control on the product chemical composition like organic dyes and rare earth metals, can be introduced in the sol and end up in the final product finally dispensed.

The following diagram represents the sol-gel preparation method of nanoparticles.



10 MARKS

Q.1. Discuss the XRD (X-ray diffraction) technique for characterizing the nano materials

Ans. XRD is a very important experimental technique that has long been used to address all issues related to the crystal structure of solid including lattice constants and geometry, identification of unknown materials orientation of poly crystalline defects, stress etc in XRD, a collimated beam of x-rays with a wave length typically ranging from 0.7 to $2A°$ is incident on a specimen according to Bragg's law:

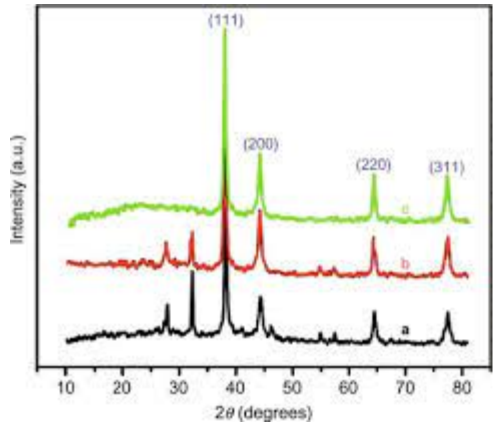
$$\lambda = 2d\, sin\theta$$

When d is the spacing between atomic planes in the crystalline phase and λ is the x-rays is measured as a function of the diffraction angle 2θ and the specimen orientation. This diffraction pattern is used to identify the specimen crystalline phases and to measure its structural properties.

XRD is non-destructive and does not require elaborate sample preparation, which partly explains the wide range of XRD method in materials characterized.

It there is no in homogeneous strain, the crystalline size D, can be estimated from the peak width with the Scherer's formula,

$$D = \frac{k\lambda}{Bcos\theta_B}$$



Where λ is the X-rays wave length, B is the full width of height maximum (FWHM) of a diffraction peak, θ_B diffraction angle, K is the Scherr's constant of the order of unity for usual crystal. Similarly, the film thickness of optional and highly textured thin film can also be estimated with XRD.

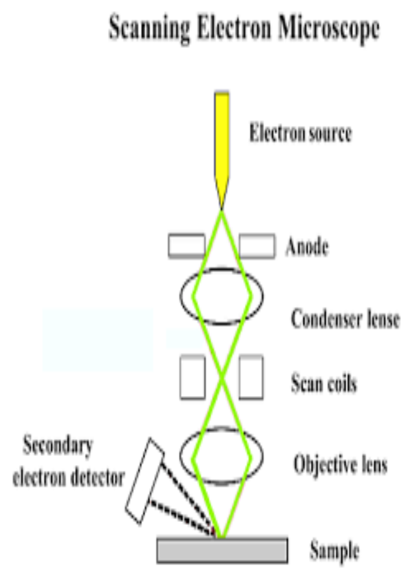
Advantages:

The possibility of synthesizing non-metallic, inorganic materials like glasses, glass ceramics(or) ceramic materials at very low temperature.

Disadvantages:

Controlling the growth of the particle is difficult.

Q.2. Discuss the scanning electron microscope (SEM)



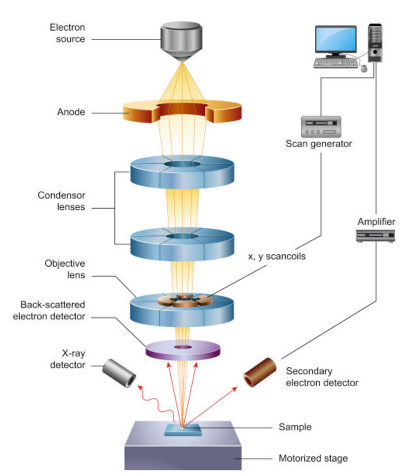
Ans. ***Principle:*** A scanning electron microscope is a type of electron microscope that images a sample by scanning with a high energy beam of electrons in a scan pattern.

Construction: The electrons interact with the atoms that make up the samples production signals that contain information about the samples surface topography, composition and other properties.

Working:

1) The electrons gas produced a stream of monochromatic electrons.

2) The electron stream is condensed by the final condensations. It works in conjunction with the condenser aperture to eliminate the high angle electrons from the beam.



3) The second condensation lens forms the electrons into a thin light coherent beam.

4) Objective aperture further eliminates high angle electrons from the beam.

5) A set of coils acting as electro static lens scans and sweeps the beam in a grid fashion. The beam will be on points for a period of

time determined by the scan speed. Dwell time is usually in micro second range.

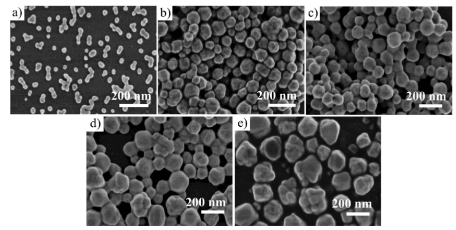
6) The objective lens focuses the scanning beam onto the part of the specimen.

7) When the beam strikes the sample, interaction occurs. Before the beam to the next Dwell point the various interactions count the number of interactions and display is determined by the interaction number. More interaction gives a brighter pixel.

8) This process is repeated until the grid scan is finished and then repeated. The entire pattern can be scanned 30 times per second.

Applications:

1. Topography
2. Morphology
3. Composition
4. Crystallographic information



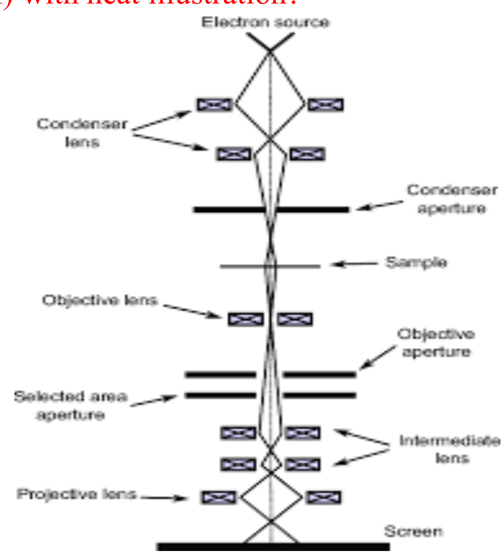
SEM images of gold (Au)nanoparticles

(not for exam)

Q.3. Discuss the Transmission Electron Microscope (TEM) with neat illustration?

Ans. ***Principle:***

The transmission electron microscopic (TEM) forms an image by accelerating a beam of electrons that pass through the specimen.



Working:

In TEM electrons are accelerated to 100 KeV or higher (up to 1mev), projected onto a thin specimen (less than 200nm) by means of the condenser lens system, penetrate the sample thickness either un deflected or deflected.

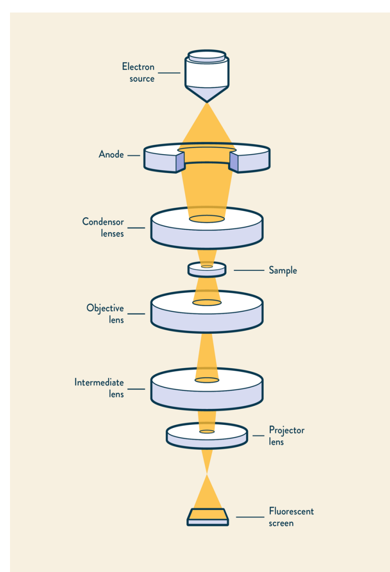
Construction:

1) The electron gun produces a stream of monochromatic electron.

2) This stream is focused to a small coherent beam by the first and second condense lens.

3) The condensed aperture knocks off high angle electrons.

4) The beam strikes the specimen.



5) The transmitted portion if focused by the objective lens into an image.

6) Objective aperture enhances the contract by blocking out high- angle diffraction of electrons by an ordered arrangement of atoms in the sample.

7) Intermediate and projector lenses enlarge the image.

8) The beam strikes the phosphorus screen and image is formed on the screen.

Advantages:

The TEM offers are the high magnification ranging from 50 to 10^6 and its ability to provide both image and diffraction information from a single sample.

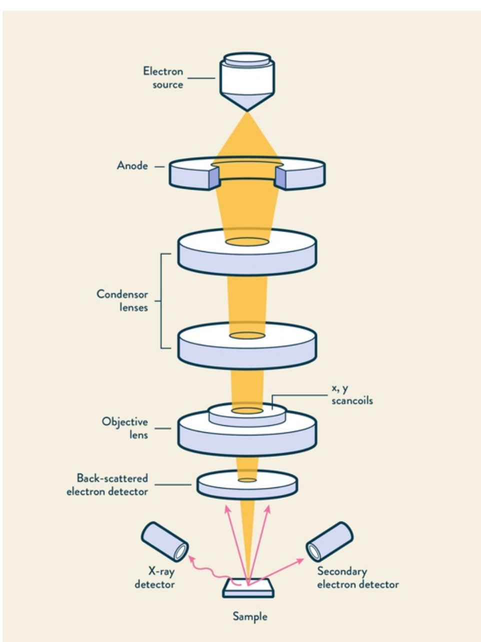
Applications:

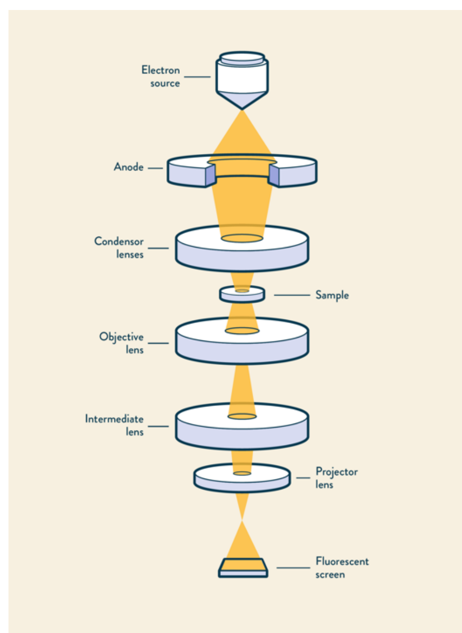
1) Morphology: The size, shape and arrangement of particles as well as their relationship to one another on the scale of atomic diameters.

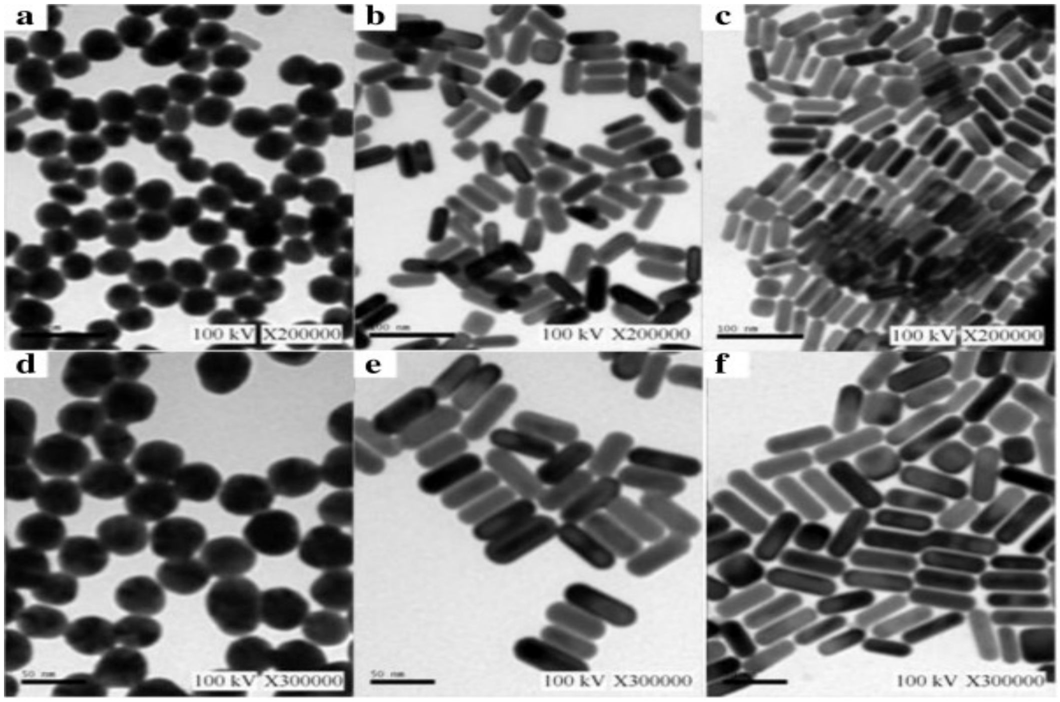
2) Crystallographic information: The arrangement of atoms in the specimen and their degree of order, detection of atomic scale defects a few nano meters in diameter.

3) Compositional Information: The elements and compounds the sample is composed of and their relative ratios.

SEM vs TEM (not for exam)







TEM images of gold nanoparticles in a solution (not for exam)

UNIT-5 LASERS AND FIBER OPTICS

1 MARK

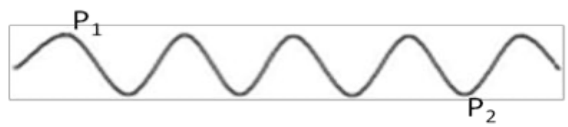
Q.1. Define population inversion?

Ans. The process making of number of atoms in the excited state is much greater than the number of atoms in the ground state is known as population inversion.
i.e. $N_1 > N_2$ to $N_2 > N_1$
where, $N_{1\rightarrow}$ population of lower energy level or ground state,
$N_{2\rightarrow}$ population of higher energy level or excited state.

Q.2. Define coherence.

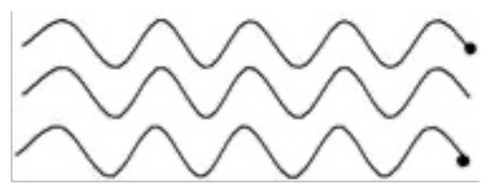
Ans. Two or more waves either mechanical waves or electromagnetic waves are said to be coherent if the have identical wave properties like phase, amplitude, frequency and velocity. There are two types of coherence.

(a) **Temporal coherence**:



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

(b) Spatial Coherence (Transverse Coherence)



The predictable correlation of amplitude and phase at one point on the one wave train w. r . t. another point on a second wave, then the waves are said to be spatial coherence (or transverse coherence). Two waves are said to be coherent when the waves must have same phase & amplitude.

Q.3. Mention any four applications of Lasers

Ans.
1) Lasers are used in medical field as endoscope.
2) Lasers are used in communication.
3) Lasers are used in industry
4) Lasers are used in computers.

Q.4. Define numerical aperture (NA)?

Ans. Numerical aperture determines the light gathering ability of the fiber. It is a measure of amount of light that can be accepted by a fiber. NA depends only on the reflective indices of the core and cladding materials. A large NA implies that a fiber will accept large amount of light from the source.

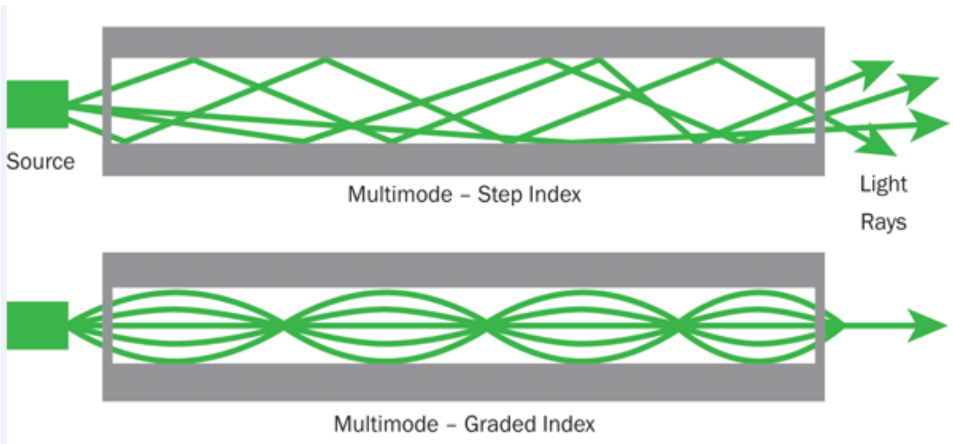
Numerical aperture is function of acceptance angle. Where the acceptance angle is defined as the maximum angle of incident light ray with the fiber axis for which the light ray successfully travels through the optical fiber. It is given by

$$NA = Sin\theta_a$$

Or $$Sin\theta_a = \sqrt{n_1{}^2 - n_2{}^2}$$

Q.5. Sketch the ray propagation in multimode step index and multimode graded index optical fiber.

Ans.
Practice the figures in adjacent.



3 MARKS

Q.1. Write the difference between spontaneous emission and stimulated emission?

Ans.

Spontaneous emission	Stimulated emission
1) Polychromatic radiation	1) Monochromatic radiation
2) Less intensity	2) High intensity
3) Less directionality	3) High directional
4) No coherence	4) Highly coherence
5) Spontaneous emission takes place when excited atoms make transitions to lower energy level voluntarily without any external stimulation.	5) Stimulates emission takes place when a photon of energy equal to $h\vartheta = E_2 - E_1$ stimulates an excited atom to make transition to lower energy level.
6) Only one photon per one transition emits.	6) Two photons will be emitted per one transition
7) Emitted light is un polarized	7) Emitted light is highly polarized

Q.2. Explain pumping? Classify the types of pumping?

Ans. The method of raising the particles from lower energy state to higher energy state is called pumping.

There are different methods of pumping the energy to create population inversion. They are

<u>Optical pumping</u>:

In this method, light is used to supply energy to the laser medium. An external light source like xenon flash lamp is used to produce more electrons in the higher energy level of the laser medium.

Electrical discharge:

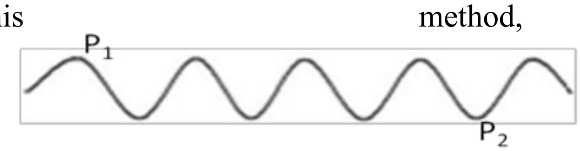
In this method of pumping, electrical discharge acts the pump source (or) energy source. A high voltage electric discharge is passed through the laser medium (or) gas.

Chemical Reaction:

If an atom(or) molecules is produced through some chemical reaction and remains in an excited state at the time of production, then it can be used for pumping.

Thermal pumping:

In the pumping, heat acts as the pump source. In this method, population inversion is achieved by supplying heat into the laser medium.



Q.3. Discuss spatial coherence and temporal coherence?

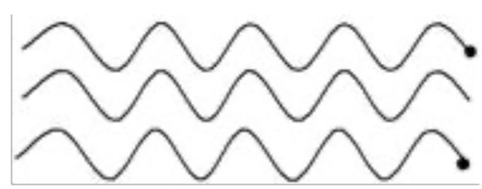
Ans: Two waves either mechanical waves or EM waves are said to be coherent if they have identical wave properties such as phase, amplitude, frequency and speed in space. There are two types of coherence for waves:

(c) **Temporal coherence**:

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

(d) Spatial Coherence (Transverse Coherence)

The predictable correlation of amplitude and phase at one point on the one wave train w. r. t. another point on a second wave, then the waves are said to be spatial coherence (or transverse coherence). Two waves are said to be coherent when the waves must have same phase & amplitude.



Q.4. How will you classify the optical fibers?

Ans. Optical fibers are classified into three major categories:

1. The types of material used
2. The number of modes
3. The refractive index profile

Optical fibers are based on materials

Glass fibers:

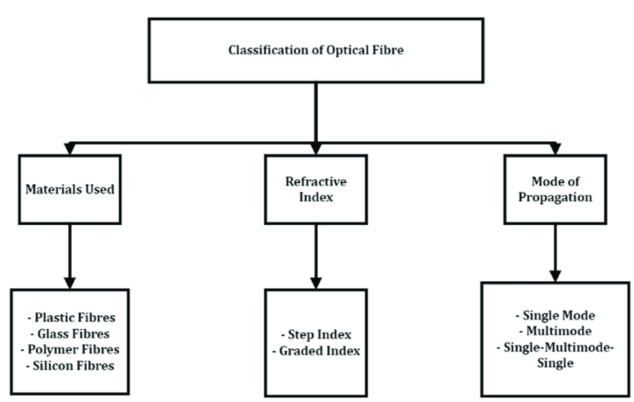
Examples:

Core: SiO2 cladding: SiO2

Core: GeO2-SiO2 cladding: SiO2

Plastic fiber:

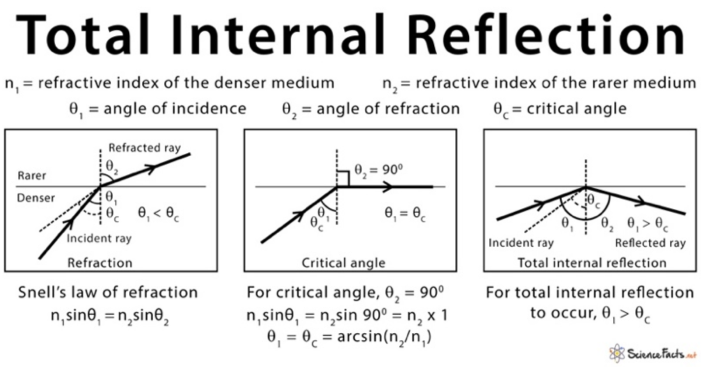
Example:core: Polymethyl methacrylate cladding: co-polymer



core: Polystyrene cladding: Methyl methacrylate
Based on the number of modes:
1) Single mode fiber (SMF)
2) Multimode fiber (MMF)
Based on the refractive index profile
1) Step index fiber (SIF)
2) Graded index fiber (GRIN)

Q.5. Explain total internal reflection?

Ans. The phenomenon in which when a light travels from denser medium to rarer medium, the ray reflects back into the denser medium for which the angle of incidence is greater than an angle called critical angle, at the denser and rarer medium boundary, is called total internal reflection.



Consider a light ray entering from denser medium to rarer medium as shown in the figure.
Let θ_i , θ_r are the angle incidence and angle of refraction respectively

If n_1, n_2 are the refractive indices of the denser and rarer medium, then applying Snell`s law we get,
$n_1 Sin\theta_i = n_2 Sin\theta_r$
At $\theta_i = \theta_c$, $\theta_r = 90$

$$\Longrightarrow Sin\ \theta_c = \frac{n_2}{n_1}$$

If $n_1 = \mu(R.I\ of\ the\ denser\ medium)$ and $n_2 = 1(R.I\ of\ air)$

$$Sin\ \theta_c = \frac{1}{\mu}$$

5 MARKS

Q.1. What are the characteristics of laser?

Ans. The four characteristics of laser radiation over conventional light sources are:
1) Laser is highly directional
2) Highly monochromatic
3) Highly coherent

4) Highly intensity

Highly Monochromatic: The bandwidth of ordinary light is about 1000A°. The bandwidth of laser light is about 10A°. The narrow band width of laser light is about 10A°.The narrow band width of laser light is called high monochromacity.

The spread of the wavelength about the wavelength of maximum intensity is band width. Laser light source. Because of this monochromaticity large energy can be concentrated into an external small band width.

High directionality: In conventional light source photons will travel in random directions. Therefore, these light sources emit light in all directions on the other hand, in laser all photons will travels in same direction. Therefore, laser emits light only in one direction. This is called directionality of laser light. The width of laser beam is extremely narrow. Hence, a laser beam can travel to long distances without spreading.

In an ordinary light travel a distance of 2 km it spreads to about 2 km in diameter on the other hand, if a laser light travels a distance of 2 km, it spreads to diameter less than 2cm.

Coherence: Laser beam is spatially and temporarily coherent.

Spatial Coherence: If wave maintains a constant phase difference or in phase at two different points on the wave overtime 't', then the wave is said to have spatial coherence. For He-Ne laser coherence length is about 600 km for ordinary light coherence length about 3 Cm.

Temporal Coherence: It refers to the correlation between light fields at different times at a point on the wave. If there is no change in phase over time 't' at a point. On the wave then it is said to be coherent temporally doing that time. For laser source temporal coherence time is 2×10^{-3} sec where as ordinary source temporal coherence time is 10^{-10} sec.

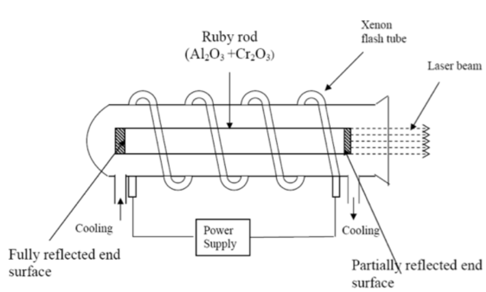
Brightness (or) High Intensity: Laser are bright and intense light sources because of coherence and directionality. Intensity of a wave is the energy per unit time flowing through a unit area. The light from ordinary source spreads out uniformly in all directions and form spherical wave fronts around it.

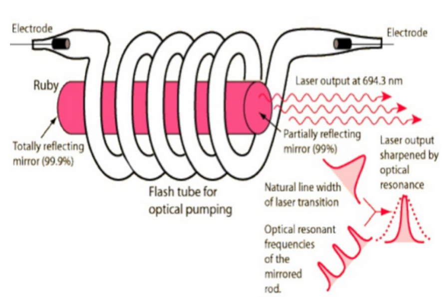
Q.2. Demonstrate construction and working of Ruby laser?

Ans. The Ruby laser is first constructed and demonstrated in 1960 by T. H. Maiman.

Characteristics: Ruby rod ($Al_3O_3 + 0.05\%\ Cr_2O_3$)

Active Element: Cr^{3+}

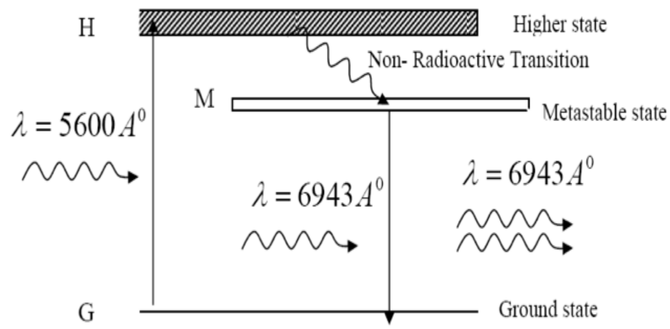




Energy source: Xenon flash lamp

Resonant cavity: The ends of the ruby rod are polished to satisfy the optical resonator cavity condition.

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



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

Working:

The energy level diagram of chromium ions is shown in figure. The chromium ions get excitation into higher energy levels by absorbing of $5600A^0$ of wave length radiation. The excited chromium ions stay in the level H for short interval of time (10^{-8} Sec). After their life time most of the chromium ions are de-excited from H to G and a few chromium ions are de-excited from H to M.

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

Due to the continuous working of flash lamp, the chromium ions are excited to higher state H and returned to M level. After few milli seconds the level M is more populated than the level G and hence the desired population inversion is achieved. The state of population inversion is not a stable one. The process of spontaneous transition is very high. When the excited chromium ion passes spontaneously from H to M it emits one photon of wave length 6943A . The photon reflects back and forth by the silver ends and until it stimulates an excited chromium ion in M state and it to emit fresh photon in phase with the earlier photon. The process is repeated again and again until the laser beam intensity is reached to a sufficient value. When the photon beam becomes sufficient intense, it emerges through the partially silvered end of the rod. The wave length $6943A^0$ is in the red region of the visible spectrum.

Draw backs of ruby laser

- The laser requires high pumping power

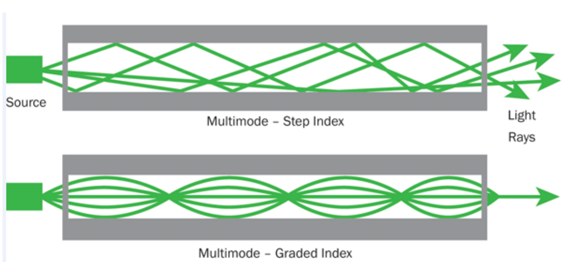
- The efficiency of ruby laser is very small
- It is a pulse laser

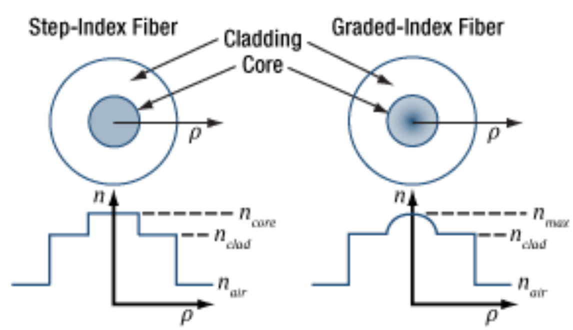
Uses of ruby laser

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

Q.3. Describe the structure of different types of optical fibers with ray paths?

Ans. The different types of optical fibers and their ray paths are:
1) Single mode step index fiber: A single mode step index fiber consists of is very thin core of uniform refractive index lower than that of case. The refractive index abruptly changes at the case cladding boundary light travels along a side path, i.e. along the axis only. So, zero modes is supported by single mode fiber.
2) Multimode step index fiber: A multimode step index fiber consists of a case of uniform refractive index surrounded by cladding of refractive index abruptly changes at the core cladding boundary. The core is of large diameter. Light follows zigzag paths inside the fiber, many such zigzag paths of propagation are permitted in multimode fiber. The numerical aperture of a multi mode fiber is larger as the core diameter of the fiber is large.
3) Graded index fiber: GRIN fiber is one in which refractive index varies radially, decreasing continuously in a parabolic manner from the maximum value of n1, at the center of the core to a constant value of n2, at the core cladding interface
In graded index, light rays travel at different speeds in different parts of the fiber because the



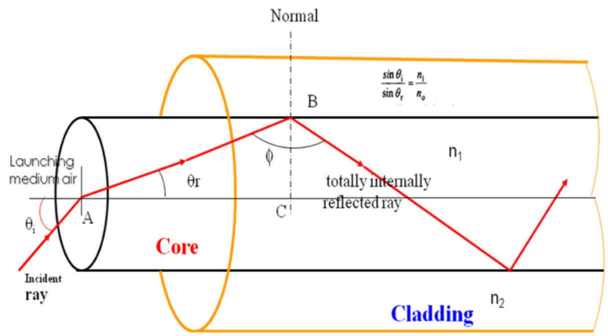


refractive index varies throughout the fiber. Near the outer edge, the refractive index is lower. As a result, rays near the outer edge travel faster than the rays at the center of the core. Because of these rays arrive at the end of the fiber at approximately the same time. In effect light rays arrive at the end of the fibers are continuously refocused as they travel down the fiber. All rays take the same amount of time in traversing the fiber, this leads to small pulse dispersion.

Q.4. Derive an expression for the Numerical aperture of an optical fiber.

Consider a small portion of an optical fiber as shown in above figure. Let n_0, n_1, n_2 are the refractive indices of air, core and cladding regions respectively.

Let θ_i be the angle of incident light ray with the axis of the fiber entering in to the core.
θ_r be the angle of refraction of light ray with the axis of fiber after entering into the core.
φ be the angle of incidence if the refracted ray at the interface of core and cladding.



Appling Snell`s law at the air-core interface

$n_0 Sin\theta_i = n_1 Sin\theta_r$
But from $\Delta ABC, \theta_r = 90^0 - \varphi$
$\Longrightarrow n_0 Sin\theta_i = n_1 Sin(90^0 - \varphi)$
For $\theta_i = \theta_a, \varphi = \theta_c$
Where θ_c is critical angle and θ_a angle of acceptance.

$\Longrightarrow n_0 Sin\theta_a = n_1 Sin(90^0 - \theta_c)$

$\Longrightarrow n_0 Sin\theta_a = n_1 Cos(\theta_c)$
But form the total internal reflection, $Sin\ \theta_c = \frac{n_2}{n_1}$
$\Longrightarrow n_0 Sin\theta_a = n_1 Cos(\theta_c) = n_1\sqrt{1 - Sin^2\theta_c}$

$$\Longrightarrow n_0 Sin\theta_a = n_1\sqrt{1 - \left(\frac{n_2}{n_1}\right)^2}$$

$$n_0 Sin\theta_a = \sqrt{n_1^2 - n_2^2}$$

For $n_0 = 1$, we get

$$Sin\theta_a = \sqrt{n_1^2 - n_2^2}$$

Where $Sin\theta_a = NA$

Therefore numerical aperture, $\boldsymbol{NA} = \sqrt{\boldsymbol{n_1^2 - n_2^2}}$

Q.5. Write the important applications of optical fibers

The application and uses of optical fibre can be seen in:

- Medical Industry
- Communication
- Defence
- Industries

- Broadcasting
- Lighting and Decorations
- Mechanical Inspections

The application of optical fibres in various fields is given below:

Optical Fibres uses in Medical industry

Because of its extremely thin and flexible nature, it is used in various instruments to view internal body parts by inserting into hollow spaces in the body. It is used as lasers during surgeries, endoscopy, microscopy and biomedical research.

Optical Fibres used in Communication

In the communication system, telecommunication has major uses of optical fibre cables for transmitting and receiving purposes. It is used in various networking fields and even increases the speed and accuracy of the transmission data. Compared to copper wires, fibre optics cables are lighter, more flexible and carry more data.

Optical Fibres used in Defence Purpose

Fibre optics are used for data transmission in high-level data security fields of military and aerospace applications. These are used in wirings in aircraft, hydrophones for SONARs and Seismic applications.

Optical Fibres are used in Industries

These fibres are used for imaging in hard-to-reach places such as they are used for safety measures and lighting purposes in automobiles both in the interior and exterior. They transmit information at lightning speed and are used in airbags and traction control. They are also used for research and testing purposes in industries.

Optical Fibres used for Broadcasting

These cables are used to transmit high-definition television signals which have greater bandwidth and speed. Optical Fibre is cheaper compared to the same quantity of copper wires. Broadcasting companies use optical fibres for wiring HDTV, CATV, video-on-demand and many applications.

Uses of Optical Fibre for Lightening and Decorations

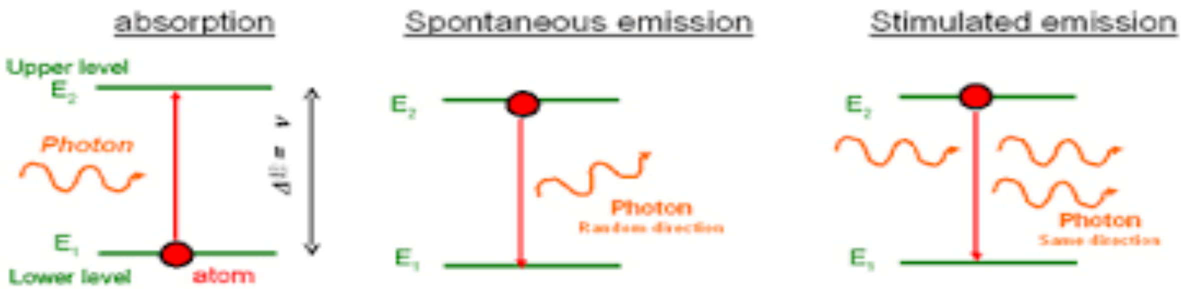
By now, we got a fair idea of what is optical fibre and it also gives an attractive, economical and easy way to illuminate the area and that is why it is widely used in decorations and Christmas trees.

Optical Fibres used in Mechanical Inspections

On-site inspection engineers use optical fibres to detect damages and faults which are at hard-to-reach places. Even plumbers use optical fibres for the inspection of pipes.

10 MARKS

Q.1. Explain the interaction of radiation with matter. Derive the relation between Einstein coefficient?



Ans. In 1916, Albert Einstein proposed that are three processes occurring in the formation of an atomic spectral line. The three processes are referred to as spontaneous emission, stimulated emission and absorption.

Let us consider N1 and N2 be the population in the energy levels of energies E1 and E2 respectively in a system of atoms at a thermal equilibrium of temperature.

Upward transition:

Stimulated absorption: Absorption is the process by which a photon is absorbed by the atom, causing an electron to jump from a lower energy level E1 to a higher one E. The absorption rate is directly propositional to N1 and $\rho(\vartheta)$.

⟹Rate of stimulated absorption = B_{12}N1 $\rho(\vartheta)$.-------(1)

***Downward Transition**:*

(a) Spontaneous emission : is the process by which an electron spontaneously decays from E2 to E1.

Spontaneous emission directly proportional to N2 only and not depends on the incident radiation density.

Therefore, rate of spontaneous emission = $A_{21}N_2$------(2)

(b)Stimulated Emission:

Stimulated emission is the process in which an external spontaneously emitted photon initiates excited atom to undergo downward transition which causes emission of two coherent photons.

The rate of stimulated emission depends on number of atoms in the excited state and on incident radiation density $\rho(\vartheta)$.

⟹Rate of stimulated absorption = B_{21}N2 $\rho(\vartheta)$.-------(1)

Where, B_{12}, A_{21}, B_{21} are called Einstein's coefficients.

Under thermal equilibrium ,

Absorption= spontaneous emission + stimulated emission ----- (4)

$\Longrightarrow B_{12}\mathrm{N1}\,\rho(\vartheta) = A_{21}N_2 + B_{21}\mathrm{N2}\,\rho(\vartheta)$

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

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

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

Divide with $B_{21}N_2$ in numerator and denominator in right side of the above equation

$$\rho(\upsilon) = \frac{A_{21}N_2/_{B_{21}N_2}}{(B_{12}N_1 - B_{21}N_2)/_{B_{21}N_2}} = \frac{A_{21}/_{B_{21}}}{\frac{B_{12}N_1}{B_{21}N_2} - 1} \qquad (1)$$

$$\rho(\upsilon) = \frac{A_{21}N_2/_{B_{21}N_2}}{(B_{12}N_1 - B_{21}N_2)/_{B_{21}N_2}} = \frac{A_{21}/_{B_{21}}}{\frac{B_{12}}{B_{21}}e^{(E_2-E_1)}/_{KT} - 1} \qquad (2)$$

From Maxwell Boltzmann distribution law

$$\frac{N_1}{N_2} = e^{(E_2-E_1)}/_{KT}$$

From Planck's law, the radiation density

$$\rho(\upsilon) = \frac{8\pi h\upsilon^3/C^3}{e^{(E_2-E_1)/kT} - 1} \qquad (3)$$

Comparing the two equations (2) and (3) we get

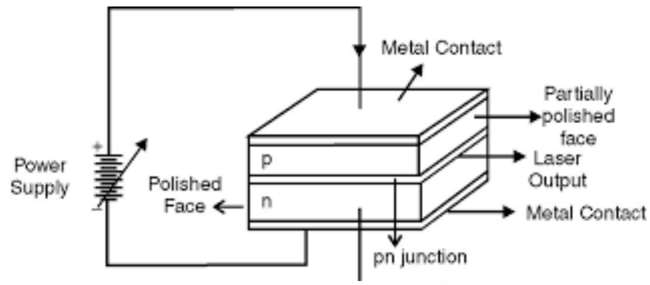
$$\frac{A_{21}}{B_{21}} = \frac{8\pi\, h\upsilon^3}{C^3} \qquad \text{and} \qquad \frac{B_{12}}{B_{21}} = 1$$

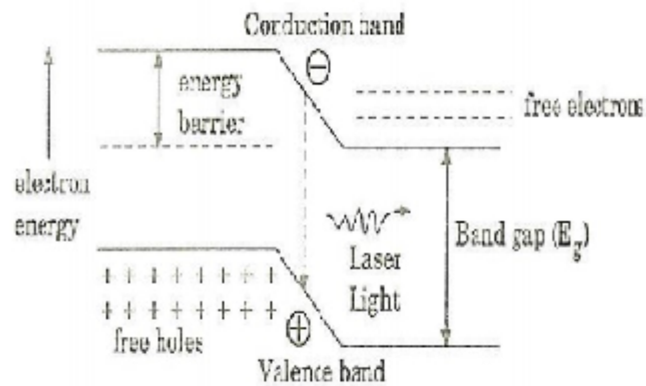
Q.2. Explain construction and working of a semiconductor laser?

Ans. Semiconductor lasers also known as quantum well lasers are smallest, cheapest can be produced in mass, and easily scalable. They are basically p-n junction diode, which produces light of certain wavelength by recombination of charge carriers when forward biased, very similar to the light-emitting-diodes. LEDs possess spontaneous emission, while laser diodes emit radiation by stimulated emission.

Principle:

In the case direct gap semiconductors there is a large possibility for direct recombination of hole and electron emitting a photon. GaAs is a direct band gap(1.4ev). Semiconductor and hence it is used to make lasers and light emitting diodes. The wavelengths of the emitted light depend on the band gap of the material.





Construction:

The P+ and N+ regions of the diode are obtained by heavily doped p and n regions of GaAs. The thickness of p-n junction layer is very narrow at the junction. The side walls are well polished and parallel to each other. Since the refractive index of GaAs is high, the reflectance at the material air inference is sufficiently large so that external mirrors are not necessary to produce multiple reflections.

The p-n junction is forward biased by connecting positive terminal to p-type and negative terminal to n-type.

Working:

The population inversion can be obtained by injecting electrons and holes into the junction from the n-region and p-region by means of forward bias voltage. When the forward bias is not connected, no electron and holes present in the depletion region. When a small forward bias voltage is given to the p-n junction then small number of electrons and holes will injected into the depletion regions from respective regions. When relatively a large current of the order of $10^4 A/cm^2$ is passed through the junction then large number of electrons and holes will be injected into the depletion region as shown in above fig. Then the direct recombination processes take place between holes and electrons in the depletion region and release the protons.

Further, emitted photons increase the rate of recombination. Thus, more number of the photons produced having same phase and frequency of the induced photons.

The wavelength of the emitted radiation depends on the energy band gap of GaAs semiconductor is 1.4 eV then it emits laser light of wavelength 8600A°.

$$\lambda = \frac{hc}{Eg} = \frac{6.625 \times 10^{-34} \times 3 \times 10^{8}}{1.44} = 8.626A°$$

Q.3. Discuss the various factors contributing to attenuation in optical fibers.

Ans. Attenuation refers to the loss of optical signal strength while propagating through an optical fiber. As we know that when light travels through a medium, the intensity of light decreases with distance exponentially. The following equation gives the relation of optical absorption by a medium called Beer-Lambert`s law.

$I(x) = I_0 e^{-\mu x}$

$I(x)$ is the intensity of light at any distance *x* along *x-axis,* I_0 is the intensity of light at *x = 0* and μ is called medium absorption coefficient. Here the absorption of light by the medium depends on the nature of the medium.

In similar way, when a ray of light propagates through an optical fiber it suffers attenuation by various factors. The following equation gives the optical loss in an optical fiber.

$$\alpha = -\frac{10}{L} log_{10}\left(\frac{P_0}{P_i}\right) \; dB/_{km}$$

L- distance in kilometres, $P_{0,} and \; P_i$ are the output and input powers of the optical signals.
The factors which are responsible for optical power loss are divided into two broad categories.
(a) Internal (intrinsic) factors and
(b) External (extrinsic) factors

Intrinsic factors:

Material Absorption:

Contaminants in the fiber, like water molecules, contribute to absorption loss. Water molecules trapped in the glass of the optical fiber can absorb light around 1300 nm and 2.94 µm. This attenuation is undesirable as it affects telecom signals and lasers operating in the same region.

Silica naturally contains hydroxyl ions (OH-) that absorb light in the NIR-IR spectrum.

Scattering:

Scattering is the process by which some or all of the optical power is transferred into another mode. It occurs when light encounters a change in the refractive index of the medium. This can be caused by irregularities in refractive index of the fiber, impurities, particulates, or bubbles; or intrinsic, caused by fluctuations in the glass density, fiber axis direction composition, geometry or phase state. There are two main types:

- Rayleigh scattering: Rayleigh scattering contributes to up to ≈ 90% of total light attenuation in optical fibers. It is a form of elastic scattering that occurs when light interacts with particles that are much smaller than the wavelength of the incident light, such as random inhomogeneities in the glass lattice. Thus Rayleigh scattering is inversely proportional to the fourth power of the wavelength of light and becomes significant at shorter wavelengths comparable to size of the structures in the glass.
- Mie scattering: Mie scattering is a type of scattering that occurs when light interacts with particles that are comparable in size to the wavelength of the incident light, such as inhomogeneities in the fiber core or cladding or external contaminants.

Dispersion:

Dispersion refers to the distortion or spreading of an optical signal as it propagates along the fiber length. There are three main types: chromatic, modal and polarization mode dispersion. The total dispersion in SM fibers comprises contributions from the chromatic and polarization dispersion whilst in MM fibers there is also the additional modal dispersion.

Chromatic Dispersion (CD):

This occurs because different spectral components of the optical signal in the optical fiber travel at different speeds. In figure different wavelengths are represented by the red , green and blue lines.

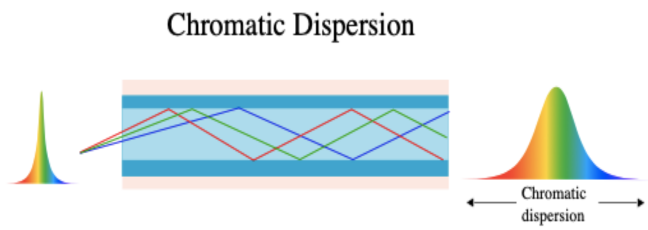


Figure : Chromatic dispersion along the optical fiber occurs due to the different wavelengths of light traveling at different speeds.

Modal Dispersion(MD):

This is due to the fact that when more modes of propagation of light travels through an optical fiber, they differ in optical path lengths.

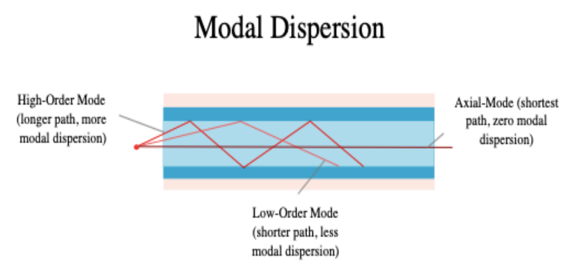
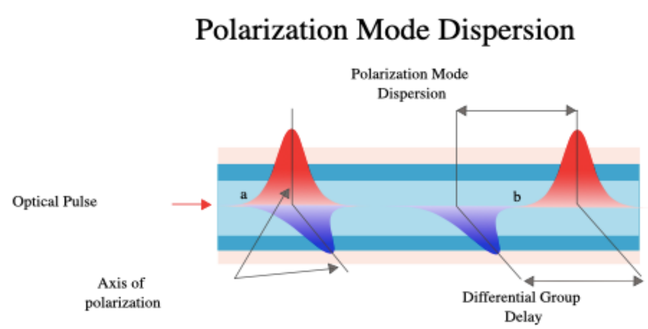


Figure: Modal dispersion leads to pulse spreading in multi-mode fibers.

Polarization mode dispersion (PMD):

The change in state of polarization of light ray by which the optical signal spreads is known as polarization mode dispersion. This arises due to the asymmetry in core region, stress induced birefringence, interference and other imperfections.



Extrinsic Factors

Extrinsic losses are related with all the components in addition to the fiber optic cable. Extrinsic losses occur at the interfaces between fiber components and can significantly affect the overall system performance. Depending on the loss mechanism, these extrinsic losses are described as either insertion loss or return loss.

- Imperfect End Face Geometry: If the end faces are not precisely cleaved, polished, or aligned, it can lead to increased reflection and scattering, causing higher insertion and return losses.
- Connector Quality: High-quality connectors are engineered to minimize reflections and maintain accurate alignment, reducing losses.
- Alignment Tolerance: Misalignment between the fibers being connected may cause some of the light to miss the core of the receiving fiber, leading to insertion loss. Similarly, misalignment can cause increased return loss due to higher levels of reflection.

- Fiber Mismatch: When connecting two fibers with different core sizes or numerical apertures, a mismatch can occur, resulting in increased insertion and return losses.
- Fiber Core Concentricity: The concentricity of the fiber core with the cladding is crucial for minimizing insertion loss. Any eccentricity can lead to light escaping from the core and contributing to insertion loss.
- Fiber Cladding Modes: In multimode fibers, higher-order modes can couple to the core during splicing or connecting, contributing to increased loss.
- Surface Contamination: Dust, dirt, or other contaminants on the fiber end faces can cause additional reflection and scattering, resulting in higher insertion and return losses.
- Mechanical Stress: Excessive bending or tension on the fiber can cause increased insertion and return losses due to micro bending effects and stress-induced reflections. Bending causes light to leak out of the fiber, resulting in loss of the original signal. There are bend insensitive fibers used to reduce the bending induced-losses.
- Wavelength and Polarity: The wavelengths of light used and the fiber's polarity can also impact insertion and return losses in certain types of components.