PVP 23

Code: 23BS1103

I B.Tech - I Semester – Regular / Supplementary Examinations - DECEMBER 2024

ENGINEERING PHYSICS

Duration: 3 hours Max. Marks: 70

Note: 1. This question paper contains two Parts A and B.
2. Part-A contains 10 short answer questions. Each Question carries 2 Marks.
3. Part-B contains 5 essay questions with an internal choice from each unit. Each Question carries 10 marks.
4. All parts of Question paper must be answered in one place.

BL – Blooms Level CO – Course Outcome

PART – A

		BL	CO
1. a)	Interpret Principle of Stimulated Emission.	L2	CO1
b)	Define Total Internal Reflection and mention its applications.	L1	CO1
c)	Explain Atomic Packing fraction.	L2	CO1
d)	Identify and mention Lattice parameters of Cubic crystal structure.	L1	CO1
e)	Outline Ionic Polarisation.	L2	CO1
f)	Show the relation between B, H and M.	L2	CO1
g)	Explain the Concept of Heisenberg Uncertainty Principle.	L4	CO5
h)	List out postulates of Classical Free Electron Theory.	L2	CO1
i)	Illustrate Donor energy level in N type Semiconductors.	L4	CO4
j)	Define Drift current.	L1	CO1

PART – B

			BL	CO	Max. Marks
		UNIT-I			
2	a)	Describe construction and working of He-Ne Gas LASER.	L3	CO2	6 M
	b)	Explain Population inversion and Pumping Mechanisms.	L4	CO4	4 M
		OR			
3	a)	Illustrate various types of Optical Fibers.	L3	CO2	6 M
	b)	Calculate Acceptance angle, If light is launched in to fiber through air with core refractive index 1.70 and cladding refractive index 1.67.	L4	CO4	4 M
		UNIT-II			
4	a)	Analyze the SCC is loosely packed compared to BCC, FCC Cubical Structures.	L4	CO5	6 M
	b)	Derive the equation of separation between Successive (hkl) Planes.	L3	CO3	4 M
		OR			
5	a)	Demonstrate Laue Diffraction Method for determination of crystal Structure.	L3	CO3	6 M
	b)	Derive the Bragg's relation between Interplanar separation and wavelength of X Ray Diffraction.	L4	CO5	4 M
		UNIT-III			
6	a)	Explain concept of Frequency dependence of Polarisation.	L3	CO3	4 M
	b)	Calculate Ionic Polarisability in a Dielectric Material.	L4	CO5	6 M
		OR			
7	a)	Illustrate concept of Hysteresis in Ferromagnetic Materials.	L3	CO3	5 M
	b)	Classify Ferro magnetic Materials.	L4	CO5	5 M
		UNIT-IV			
8	a)	Explain Significance of wave function and Derive Schrodinger Time Independent wave Equation.	L3	CO3	6 M
	b)	Calculate Energy levels in Ground state and First Excited state when electron is bound in 1-D Infinite well of width 10^{-10} m.	L4	CO5	4 M
		OR			
9	a)	Explain Electrical Conductivity based on Quantum free Electron Theory.	L3	CO3	6 M
	b)	Discuss about Fermi Energy.	L4	CO5	4 M
		UNIT-V			
10	a)	Distinguish between P-Type and N-Type Extrinsic Semiconductors.	L4	CO4	4 M
	b)	Calculate Carrier Concentration of Electrons in Intrinsic Semiconductors.	L3	CO2	6 M
		OR			
11	a)	Calculate Carrier Concentration in P-Type extrinsic Semiconductors.	L3	CO2	6 M
	b)	Illustrate formation of Energy Bands according to origin of Band theory.	L4	CO4	4 M

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I B. Tech –I Semester Regular Examination-Dec-2024

ENGINEERING PHYSICS

SCHEME OF VALUATION

PART-A

1.			
	a)	Principle of stimulated Emission	2 M
	b)	(i) Total internal reflection definition	1 M
		(ii) Applications	1 M
	c)	Packing Fraction definition	2 M
	d)	Lattice parameters of Simple cubic.	2M
	e)	Ionic Polarization	2 M
	f)	Relation between B, H and M	2M
	g)	Statement of Heisenberg's Uncertainty Principle	2M
	h)	Any two postulates of Classical Theory	2M
	i)	Donor energy level in N-type	2M
	j)	Drift current definition	2M

PART-B

2.	(a) Diagram		2 M
	Construction		1 M
	Working		2M
	Energy Level Diagram		1M
	(b) Population Inversion definition		2 M
	List of pumping Mechanisms		2 M
3.	(a) Classification of optical Fibres		2M
	Illustration		2M
	Explanation		2M
	(b) Numerical		4 M
	Formula –	1 M	
	Substitution of parameters-	1 M	
	Calculation-	1 M	
	Answer -	1 M	
4.	(a) Packing fraction of SC		2 M
	Packing fraction of BCC		2M
	Packing fraction of FCC		2M
	(b) Definition		1 M
	Diagram		1 M
	Derivation		2 M

5. (a) Diagram		1 M
Description		2 M
Working-		3 M
(b) Diagram of crystal lattice		1M
Derivation with explanation		3 M
6. (a) Frequency dependence polarization graph		2 M
Explanation of graph		2 M
(b) Diagram		1M
Derivation with explanation		5M
7. (a) Hysteresis curve -		3 M
Explanation of curve		2 M
(b) Any four differences of soft and hard magnetic Materials.		5 M
8. (a) significance of wave function		1 M
Schrodinger's time independent Wave Equation		5M
(b) Numerical		4 M
Formula –	1M	
Substitution of parameters-	1M	
Calculation-	1M	
Answer -	1M	
9. (a) Quantum free electron theory (Derivation of electrical conductivity)		6 M
(b) Definition of Fermi energy		2 M
10. (a) any four Differences of P-type & N-type semiconductors		4 M
(b) Derivation of no. of electrons in conduction band		6 M
11. (a) Derivation of Carrier conc. in P-type		6 M
(b) Explanation of origin of energy bands		2M
Energy bands illustrations (Conductors, semiconductors, insulators)		2 M

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I B. Tech –I Semester Regular Examination-Dec-2024
ENGINEERING PHYSICS

SCHEME OF VALUATION
ANSWER KEY

PART-A

1.

a) Stimulated emission is the process by which an excited atom, ion, or molecule emits a photon when stimulated by an external photon of the same energy, when the population inversion is achieved. **2M**

b) Total Internal Reflection (TIR) is the phenomenon in which a light ray traveling through a medium with a higher refractive index is completely reflected back into the medium when it strikes the boundary with a medium of lower refractive index at an angle greater than the critical angle. **2 M**

Any one Application**:** fiber optic communications, Optical Sensors, Reflecting Periscopes.

c) Atomic Packing Fraction: It is the ratio of volume occupied by the atoms in an unit cell (v) to the total volume of the unit cell (V).It is also known as packing fraction. **2M**

d) Lattice parameters of simple cubic $a = b = c$; $\alpha = \beta = \gamma = 90^0$ **2 M**

e) **Ionic Polarization:** **2M**

Ionic polarization is a type of polarization occurs in materials due to the relative displacement of positively charged ions (cations) and negatively charged ions (anions) under the influence of an external electric field.

f) **Relation between B,H,M** **2 M**

The magn. moment per unit volume developed inside a solid is called Magnetization. [M].

The total flux density $B = B_0 + B_I$

$$B = \mu_0 H + \mu_0 M$$
$$= \mu_0 (H + M)$$

$B_0 = \mu_0 H$ → the magn. flux density due to magnetizing field.

$B_I = \mu_0 M$ → flux density due to the Magnetization of the material.

g) Heisenberg's Uncertainty Principle: **2M**

It is impossible to determine precisely and simultaneously the values of both the Momentum and position of the electron

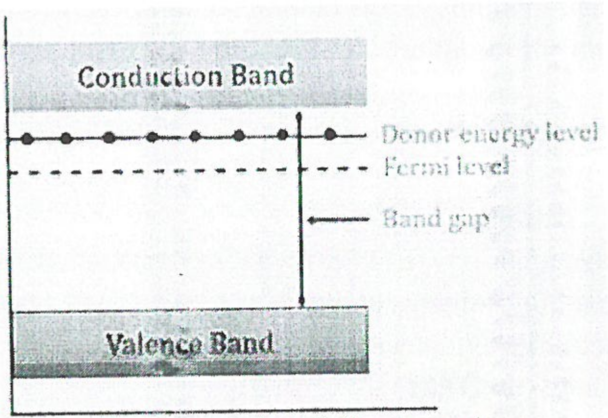
$$\Delta x \,.\, \Delta p \geq \frac{h}{4\pi}$$

h) Postulates of Classical Free Electron theory. (any two) **2M**

1. In conductors (Metals) there are large number of free electrons moving freely within the metal.
2. The free electrons are assumed to behave like gas molecules, obeying the laws of kinetic theory of gases. The mean kinetic energy of a free electron is equal to that of a gas molecule at the same temperature.
3. Electric conduction is due to motion of free electrons only. The positive ion cores are at fixed positions. The free electrons undergo collisions with the ion cores.
4. The electric field due to the ion cores is constant throughout the metal. The repulsion between the electrons is negligible.

i) Donor energy level in N-type semiconductor.

In a N-type semiconductor donor energy level is just below the conduction band.



Energy level diagram of N type semiconductor

j). Drift Current definition **2M**

When an electric field E is applied across a semi conductor, every charge carrier experience a force due to electric field and drifts in the direction of the force. Thus, a charge carrier acquires an average velocity which is called the drift velocity and it gives rise to the drift current.

The total current due to the holes and electrons in the presence of applied electric field is called as drift current.

$$J_{drift} = n_i\, e(\mu_e + \mu_h)E$$

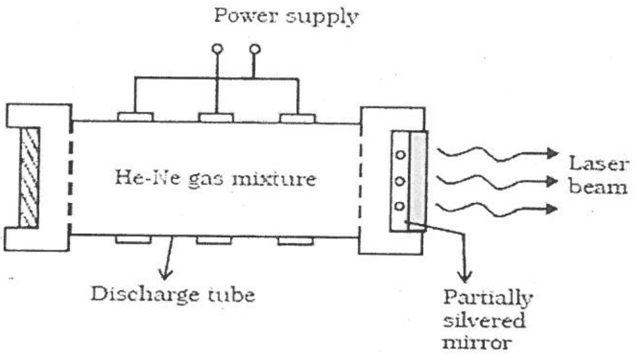
PART-B

2. (a) HELIUM-NEON GAS LASER: 6M

This was designed by Ali Javan in the year 1961. It is a four level laser system. Using He-Ne gas laser, a continuous laser beam can be produced.

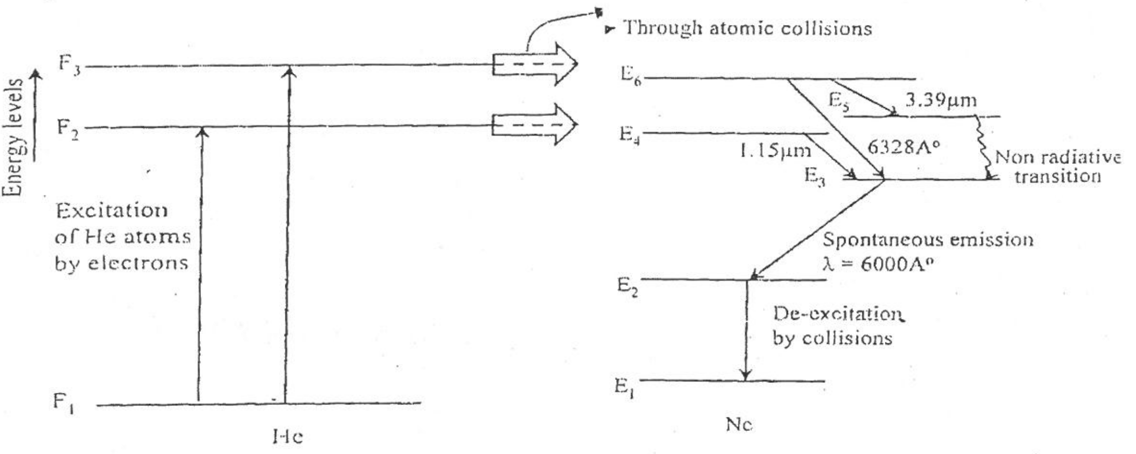
CONSTRUCTION:

It consists of a long cylindrical gas discharge tube. Its length is about 100cm and diameter will be 1to 1.5cm. The tube is filled with a mixture of He and Ne gas in mixture as in the ratio 10:1. Brewster windows made up of quartz are sealed to the tube at both ends, One of the mirror acts as perfect reflector and other as partial reflector. About 10,000 volts is needed to ionize the gas.



Working:

When a voltage of 10,000 V is applied between the electrodes, the electrons are accelerated. The accelerated electrons collide with Helium atoms and excite them to higher energy levels F_2 and F_3.



When He atoms in levels F_2 and F_3 collide with Neon atoms in the ground level E_1, an Exchange of energy takes place. This results in the excitation of atoms (Ne) to the levels E_4 and E_6 . Due to continuous discharge, more Neon atoms are excited to the levels E_4 and E_6. This creates population inversion between E_4 (E_6) and the lower energy level E_3 (E_5). The stimulated emissions from $E_6 \rightarrow E_5$, $E_4 \rightarrow E_3$, $E_6 \rightarrow E_3$ levels leads to wavelengths 3.39 μm, 1.15 μm and $6328A^0$. The Neon atoms undergo transition from E_2 to E_1 in the form of fast decay by spontaneous emission. The Neon atoms are returned E_1 by non-radiative diffusion and collision process. The continuous Laser output can be obtained from He-Ne Laser. He-Ne lasers are useful in making holograms and interferrometric experiments.

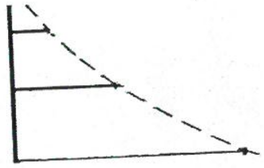
2 M

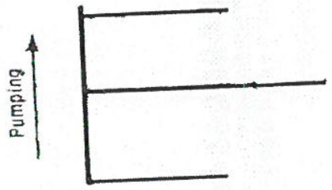
2. (b) (i) Population Inversion definition

Usually the number of atoms in the ground state (N_1) is larger than the number of atoms in the higher energy state (N_2) i.e., $N_1>N_2$. The process of making $\mathbf{N_2>N_1}$ is called **Population Inversion**. This population inversion can be achieved by supply sufficient energy to the active medium.

$$\frac{N_2}{N_1} = \exp\left(\frac{-E}{K_B T}\right) \qquad E = E_2 - E_1$$

The process of achieving population inversion is known as **Pumping.**





2M

(ii). List of pumping Mechanisms

1. Optical Pumping
2. Electric Discharge
3. Atomic Collisions
4. Direct Conversion
5. Chemical Reaction

The various methods to achieve population inversion are optical pumping:

The most common method of pumping is **optical pumping.**

If **'υ'** is the frequency of external source falls on the system, some atoms will jump to 3.

Some atoms return to state 2. After certain time, the condition $\mathbf{N_2>N_1}$ achieved.

By the incident radiation $h\upsilon$, stimulation emission takes place from state 2 to 1.

The Laser material is placed inside Xenon flash lamp. Flash light supply sufficient energy and electrons are pumped from state 1 to state 3. It is used in solid state lasers.

Electric Discharge:

This method of pumping is employed in gaseous ion laser.

The active medium is kept in a discharge tube and excited by an electric field.

The accelerated electrons collide with atoms ionize them and raise them to the higher energy levels. Ex: Argon gas laser

Atomic Collisions:

In this pumping method one type of atoms collide with another type of atoms. This Provides population inversion. Ex: He-Ne Laser.

Direct Conversion:

Here electrical energy is converted on to radiant energy. Population inversion is achieved by forward bias. It is used in LED and Laser diodes.

Chemical Reaction:

This method of pumping used in CO_2 Laser. Here Hydrogen combines with Fluorine that generates heat energy to achieve population inversion.

3. (a) Illustration of types of optical fibers 6 M

Based on the **refractive index of the core**, optical fibers are divided in to two types.

(i) Step-index optical fibers (SI)
(ii) Graded-index optical fibers (GI)

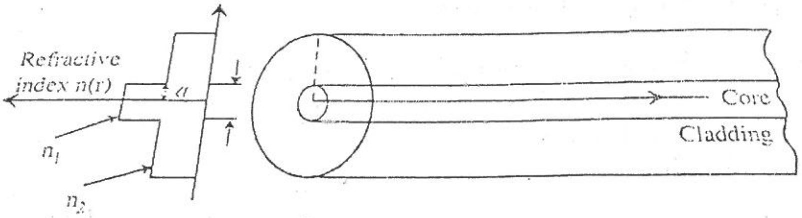
When a light ray is launched at one end, the light propagates through the fiber core in different paths. Each path is called as a **mode**. Depending on the mode of propagation, step-index fibers are divided in to two types. They are single mode and multimode step-index optical fibers.

STEP-INDEX OPTICAL FIBERS:

In these optical fibers, the refractive index is **uniform** throughout the core and undergoes a **step Change** at the core-cladding interface. The number of modes that a fiber allows depends on the diameter of the core. Since the index profile is in the form of a **step**, these fibers are called step-index fibers. Depending on the mode of propagation, step-index fibers are classified in to two types.

SINGLE MODE STEP-INDEX OPTICAL FIBERS:

The refractive index is **uniform** throughout the core. It has very small core diameter about 8 to 10 μm. And cladding diameter is 60to70 μm. Only **one path** is available for the propagation of light. The transmission of light is due to **Total Internal Reflection**. The difference between n_1 and n_2 is very small. It has **low** Numerical Aperture. These are mainly used in **Submarine** cable system.



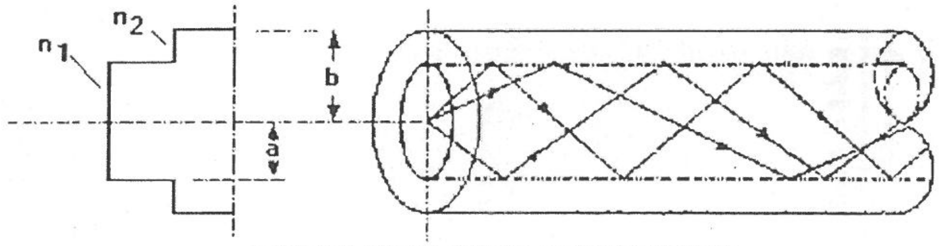
MULTIMODE STEP-INDEX OPTICAL FIBERS:

The refractive index is **uniform** throughout the core. It has large core diameter about 50 to 200 μm. And cladding diameter is 100 to250 μm. **Many paths** are available for the propagation of light.

The transmission of light is due to **Total Internal Reflection.**

The difference between n_1 and n_2 is more. It has **large** Numerical Aperture.

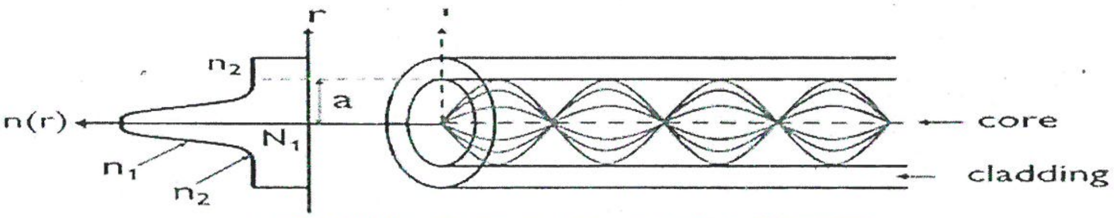
These are mainly used in **Data Link** system.



MULTIMODE STEP-INDEX FIBER

GRADED INDEX OPTICAL FIBERS:

The refractive index of the core is **not uniform** and varies radially. The refractive index is **maximum** along the axis and **decreases** radially as they move towards the cladding.



Ray Transmission in Multimode Graded Index Fiber

Because of varying refractive index across the core, the light rays are bend and converge repeatedly at points along the cable. This is called **Self Focusing** effect. The propagation of light rays is due to continuous **refraction** in the core. The light rays propagating in the form of **helical rays**. These have moderate Transmission loss.

3. (b) Numerical 4 M

Formula –	1 M
Substitution of parameters-	1 M
Calculation-	1 M
Answer -	1 M

Solution: The refractive index of the core $n_1 = 1.70$

The refractive index of clad $n_2 = 1.60$

The refractive index of air $n_0 = 1$

Acceptance angle $\theta_A = \sqrt{(n_1{}^2 - n_2{}^2)}$

$= \sqrt{1.7^2 - 1.6^2)}$

$= \sqrt{2.89 - 2.56)}$

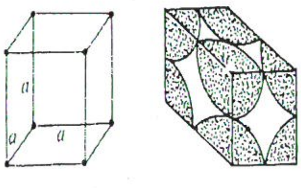
Acceptance angle $\theta_A = \sqrt{0.33} = 0.5745°$

4. (a) SCC is most loosely packed of all three structures 6 M

Structure and Packing Fraction Of Simple Cubic:

The simplest and easiest structure is simple cubic structure. There are 8 corner atoms situated at the eight corners of the unit cell. The corner atoms touch each other. Each corner atom touches 6 atoms. Hence each atom is surrounded by 6 equidistant nearest neighbors hence coordination number is 6.

Each corner atom contributes 1/8th to the unit cell, so the effective number of atoms to the unit cell is one. Hence the unit cell is primitive cell. This structure is a loosely packed one.



Atomic Packing Factor in Sc Structure:

Atomic Packing Factor in Sc Structure:

Let ‘r’ be the radius of atom. ‘a’ be the lattice parameter.(a=2r)

The effective no of atoms per unit cell = 1 i.e. $N_e=1$ Volume of unit cell=a^3

Volume of atom = $4/3\pi r^3$

Atomic packing factor = volume of atom / volume of unit cell = $\frac{4/3\pi r^3}{a3}$

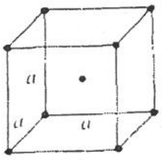
On substituting r =a/2 (or) a = 2r , we get Atomic Packing Fraction = $\pi/6 = 0.523 = 52$ %

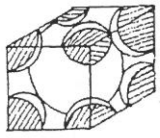
Atomic Packing Fraction of simple cubic structure is 0.523 = 52%

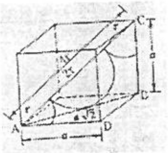
Structure and Packing Fraction of Body Centered Cubic (BCC):

There are 8 atoms at the corners of the unit cell and one atom at the center. The corner atoms do not touch each other but each corner atom touches the central atom. Since the corner atom at the center touches eight corners of the unit cell, hence the coordination number is 8.

The effective number of atoms in the unit cell = $(8 \times \frac{1}{8}) + 1 = 1+1 = 2$ atoms/cell







ATOMIC PACKING FACTOR IN BCC STRUCTURE:

Let ‘r’ be the radius of atom. ‘a’ be the lattice parameter.

From the right triangle ABC, $AC^2 = AB^2 + BC^2$

$$AC^2 = 2a^2 + a^2 = 3a^2$$

$$AC = \sqrt{3}\,a \quad \text{---- (1)}$$

And also from the figure body diagonal AC = 4r ----- (2)

From equations (1) and (2), we have $\sqrt{3}\,a = 4r \Rightarrow a=4r/\sqrt{3}$

The effective no of atoms per unit cell = 2 i.e. $N_e=2$

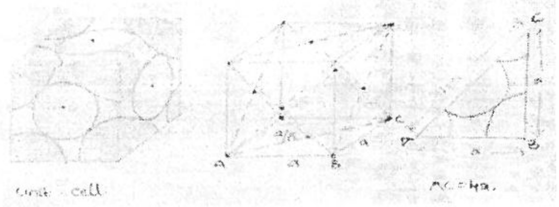
Volume of unit cell=a^3 Volume of atom= $4/3\pi r^3$

Atomic packing factor = volume of atoms/volume of unit cell $= \frac{2 \times (4/3\Pi r^3)}{a^3} = \frac{8/3\Pi r^3}{(4r/\sqrt{3})^3}$

Atomic Packing Fraction of BCC Structure is = $\frac{\sqrt{3}}{8}\pi = 0.68 = 68\%$

Structure and Packing Fraction of Face Centered Cubic (FCC):

It has eight atoms at the centres of the unit cell and six atoms at the centres of six faces of the cube.



Each atom at the corner is shared by eight unit cells and each atom at the centre of the face is shared by two unit cells. The no. of atoms per unit cell = 8× (1/8) + 6× (1/2) = 4 atoms/cell

The unit cell of FCC structure is non-primitive. For the atom at the centre of the faces there are 12 atoms at the same distance. Hence the Co-ordination number is 12.

ATOMIC PACKING FACTOR IN FCC STRUCTURE:

From the figure it is clear that AC = $\sqrt{2}$a and also AC = 4r.

Hence its face diagonal = 4r = ×a ⇒ a = 2 $\sqrt{2}$ r

$$a = 2\sqrt{2} \times r$$

Packing factor = volume of atoms / volume of unit cell $= \frac{4 \times (4/3\Pi r^3)}{a^3} = \frac{(16/3)\Pi r^3}{(2\sqrt{2.r})^3}$

$$= \frac{\pi}{3\sqrt{2}} = 0.74 = 74\%$$

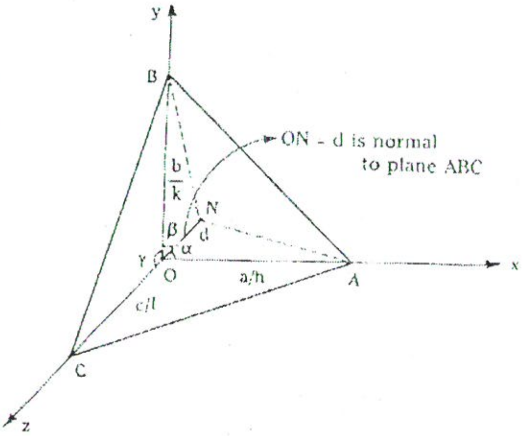
In FCC structure, 74% of its volume is occupied by the atoms and the remaining 26% is empty. FCC has the highest packing density. It is tightly packed than SC, BCC Structures.

Ex: Cu, Al and Ag have this type of structure.

Conclusion: SCC is most loosely packed of all three structures.

4. b) Distance of Separation Between Successive (h k l) Planes: **4M**

Let us consider a rectangular co-ordinate system with origin 'o' at any of the lattice points. Construct a plane ABC. Let (h k l) be the miller indices of the plane ABC. The direction of the plane is given by a normal drawn to the plane passing through the origin. Let ON be the normal drawn to the plane ABC such that 'ON' =d. Let the normal makes angles α, β, γ with X, Y and Z axes.



ABC is a plane, '*d*' is inter planar separation

OA, OB and OC be the intercepts of the plane ABC. X-intercept OA =a/h. Y-intercept OB=b/k.

Z- Intercept OC=c/l.

From the figure $\cos\alpha$ =ON/OA= d/(a/h) = dh/a.

$\cos\beta$ = ON/OB=d/(b/h) = dk/b.

$\cos\gamma$ = ON/OC=d/(c/h) = dl /c.

From the cosine rule· $\cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$ $d^2h^2/a^2 + d^2k^2/b^2 + d^2l^2/c^2 = 1$.

$$\Rightarrow d^2 = \frac{1}{\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}} \qquad \Rightarrow d = \frac{1}{\sqrt{\frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}}}$$

For a simple cube a=b=c, $d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$.

5. (a) Laue Method: 6M

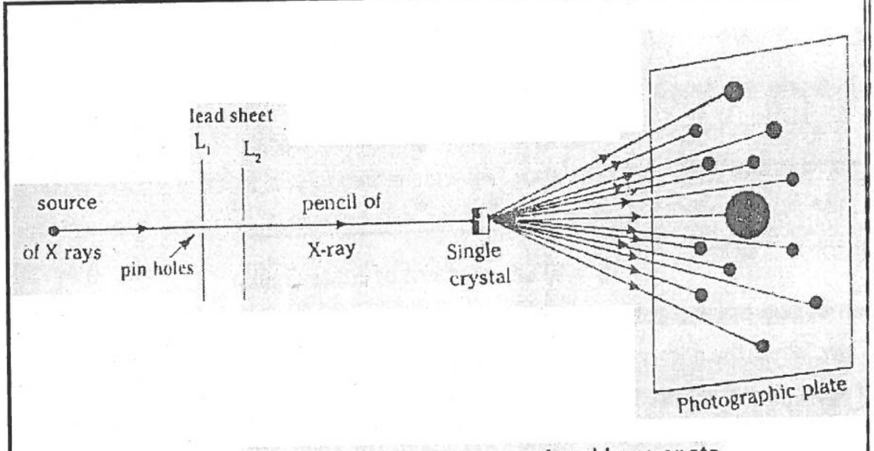
This Method is used for the determination of structure of single Crystal.

Experimental Arrangement:-

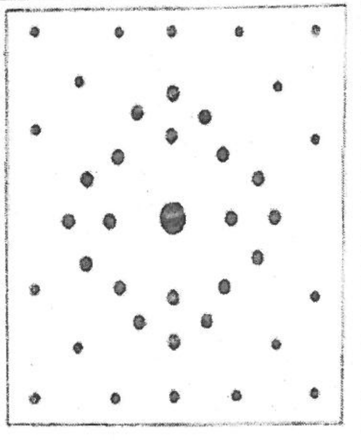
The experimental arrangement consists of the source of X-rays, pinhole collimator, crystal holder and photographic film or fluorescent screen. The source produces X-rays of short wavelength 0.2 to 2 A^0 are allowed to pass through a slit system S1 and S2 for a fine collimated beam. This collimated beam is allowed to incident on a crystal, which is placed in a crystal holder. A crystal is imagining possessing different set of planes with different orientations and different inter planar spacing. After passing through the crystal, the X-rays are diffracted and recorded on a photographic plate. The X-rays penetrate into the crystal and are scattered from different atomic diffraction centres. This is possible because there is whole range of wavelength in the continuous spectrum and there will be discrete values of wavelength ' λ' satisfying Braggs Law 2dsinθ =nλ.

The resulting diffraction pattern is recorded on a photographic plate. The diffraction pattern consists of central spot surrounded by concentric circular spots. The symmetrical pattern of spots is known as Laue patterns. Each spot in the Laue pattern corresponds to an interference maximum for a set of crystal planes satisfying the Bragg's condition, for a particular wavelength scattered from the incident beam.

The intensities of the Laue spot help in understanding the study of the position of the atom i.e. atomic arrangement. This method is helpful to find the lattice constant and the inter-planar spacing, and also to determine the crystal orientation, symmetry and also to study the crystalline imperfections. The Laue method is used to determine the structure of single crystal only.



Laue diffraction arrangement and Laue spots



Laue pattern of cubic crystal

5.(b) Bragg's Law: 4M

W.L.Bragg and W.H.Bragg gave a simple relation relating the θ, λ, d [wavelength of the incident radiation .the angular positions of the scattered beams and interplanar spacing d].

Statement: When a monochromatic beam of X-rays is incident on a crystal planes, each atom acts as a source of scattering radiation of the same wavelength. The rays interfere constructively or destructively will depend up on the path difference between the reflected rays .These two rays reinforce each other and produce an intense spot.

PROOF:

Let us consider a crystal of equidistant parallel planes with interplanar spacing d. Consider a monochromatic beam of X-ray of wavelength λ is incident of an angle θ to the atomic planes.

The 'dot' represents the position of atoms

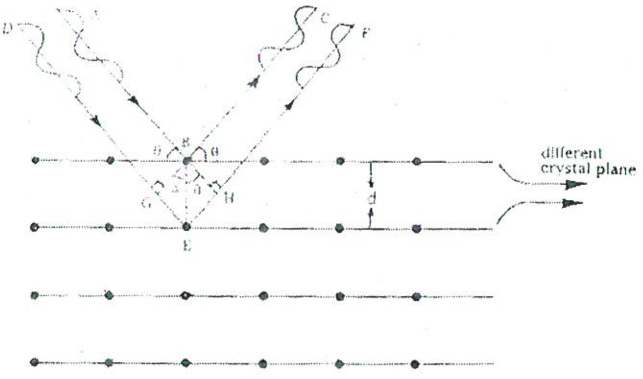


Fig. 3.8. Different planes and diffraction rays in a single crystal

Consider a ray AB incident on plane I at an atom B and reflected to C in the direction BC.

Another ray DE incident on plane II at an atom E, and reflected to F in the direction EF.

Draw two normals BG & BH from B on to the lines DE and EF respectively.

The path difference between the two rays ABC and DEF is (GE+EH).

From ΔBGE, sinθ=GE/BE = GE/d => GE =d sinθ.

From ΔBHE, sinθ=EH/BE = EH/d => EH =d sinθ.

Path difference = GE+EH = 2d sinθ.

Bragg's law states that the X-rays reflected from different parallel planes of a crystal interfere constructively when the path difference is integral multiple of the wavelength of X-rays.

i.e. 2d sinθ = nλ. This is Bragg's law equation. Where n is order of diffraction

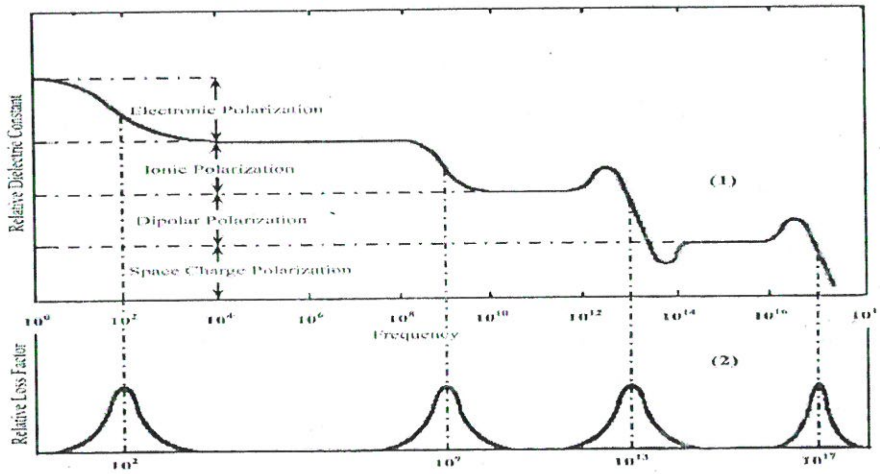
For first order maxima, n =1 => 2dsinθ=λ

For second order maxima, n =2 => 2dsinθ=2λ,etc….

Note: So Bragg's reflection occur only for wavelength $\lambda \leq 2d \Rightarrow \boxed{\lambda/2d \leq 1}$

6. (a) Frequency dependence polarization graph

4 M



Electronic polarization:

Electronic polarization is extremely rapid. Even when the frequency of the application voltage is very high in the optical range ($\sim 10^{15}$ Hz), electronic polarization occurs during every cycle of the applied voltage

Ionic polarization:

Ionic polarization is due to displacement of ions over a small distance due to the applied field. Since ions are heavier than electron cloud, the time taken for displacement is larger. The frequency with which ions are displaced is of the order as the lattice vibration frequency ($\sim 10^{13}$ Hz). This means that for optical frequency the ions do not respond, as the time required for lattice vibrations is nearly 100 times larger than the period of applied voltage at optical frequency. Hence, at optical frequencies, there is no ionic polarization. If the frequency of the applied voltage is less than 10^{13}Hz, the ions respond.

Orientation polarization:

The orientation polarization is even slower than ionic polarization the relaxation time for the orientation polarization in a liquid is less than that in a solid. Orientation polarization occurs when the frequency of the applied voltage is in the audio range. At 10^6 to 10^{10} Hz range contribution due to orientation polarization gets added.

Space charge polarization:

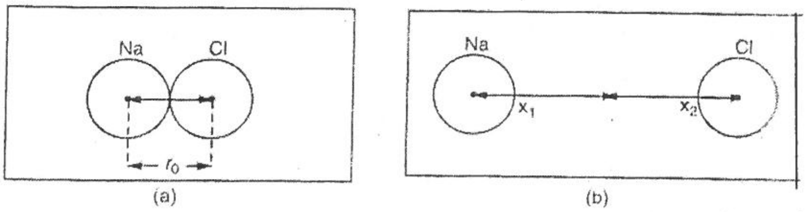
Space charge polarization is the slower process, as it involves the diffusion of ions over several inter-atomic distances. The relaxation time for this process is related to the frequency of successful jumps of ions under the influence of the applied field, a typical value being 10^2Hz. correspondingly, space charge polarization occurs at power frequencies (50-60Hz).

6. (b) Ionic Polarizability derivation **6M**

The ionic polarization is due to the displacement of cations and anions in opposite directions and occurs in an ionic solid.

The induced dipole moment due to displacement of ions within the molecule can be represented as $\mu = \alpha_i E$ --------- (1)

Let us consider NaCl when a field E is applied. Let M and m be the masses of Na^+ and Cl^- ions respectively.



(a) (b)

When E is applied +ve ions displaced in the direction of applied field through x_1 and –ve ions by x_2 units in opposite direction of the field.

The net distance between ions is given by $x = x_1+x_2$

So dipole moment $\mu = e\,(x_1+x_2)$ -------(2)

When ions are displaced from their mean position restoring forces are acting on them.

The restoring force acting on Na^+ is given by

$$F_1=K_1x_1 \Rightarrow x_1=\frac{F_1}{K_1} \quad \text{and } K_1=M\omega_O^2 \quad \Rightarrow \mathbf{x_1}=\frac{eE}{M\omega_O^2}$$ Where' ω_0 ' is angular velocity.

Now the restoring force acting on Cl^- is given by $F_2=K_2x_2 \Rightarrow x_2=\frac{F_2}{K_2}$ and $K_2=m\,\omega_O^2$

$$\Rightarrow \mathbf{x_2}=\frac{Ee}{m\omega_o^2}$$

The displacement x_1+x_2 is given by $=\frac{Ee}{m\omega_o^2}+\frac{eE}{M\omega_O^2}=\frac{eE}{\omega_O^2}(\frac{1}{M}+\frac{1}{m})$

Substituting this value in eqn. (2), we get

$$\mu=\frac{e^2E}{\omega_o^2}(\frac{1}{M}+\frac{1}{m}) \text{ ------------ (3)}$$

From (1) and (3) we have

$$\alpha_a E=\frac{Ee^2}{\omega_o^2}(\frac{1}{M}+\frac{1}{m}) \Rightarrow \boxed{\alpha_a=\frac{e^2}{\omega_o^2}(\frac{1}{m}+\frac{1}{M})}$$ Where α_i is called ionic polarizability.

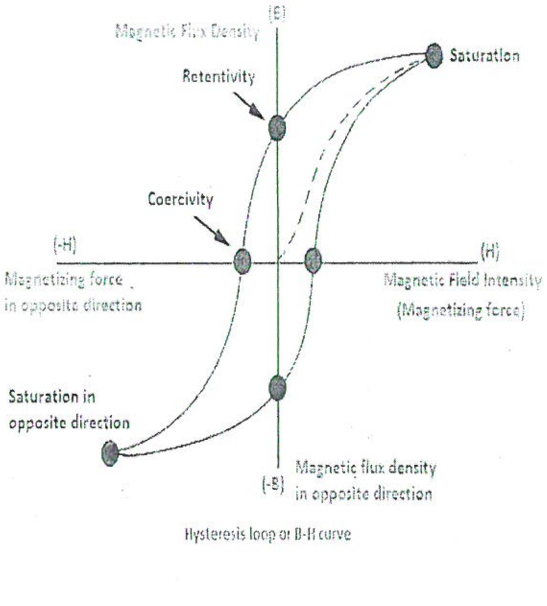
7. (a) HYSTERISIS CURVE: 5M

Hysteresis refers to the lag of magnetization behind the magnetizing filed.

The variation of flux density B with magnetic field intensity H is not linear. But it performs closed loop is known as **hysteresis loop**. Take a magnetic material completely in the unmagnified state.

If we increase the applied magnetic field the magnetization of the material first increases rapidly and then slowly until it attains a saturation value. Now the magnetic field is decreasing the rate of decrease of magnetization is less. Thus some amount of magnetism is present in the material even at H=0 This is known as **residual magnetism** (or) remanant magnetism (B_r).

Below the Ferro magnetic **Curie** temperature ferromagnetic materials exhibit the **hysteresis** in B verses H curve as shown in figure.

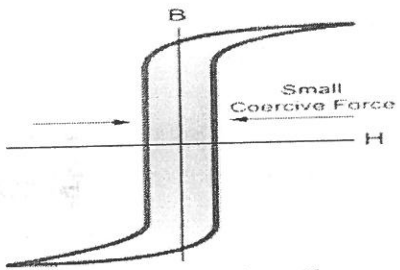
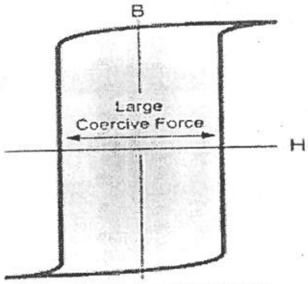


Hysteresis loop or B-H curve

For certain values of negative magnetizing force Magnetic induction B becomes zero. The amount of negative field which is used to destroy the residual magnetism is known as **coercivity** or **coercive field H_c**.

Further increasing the magnetic field in the same direction we attain negative saturation value. Finally the field once again reversed to get complete close loop. Thus B is lagging behind H. This is known as **hysteresis**.

7. (b) Any three differences of Soft & Hard Magnetic Materials. 5 M

SOFT MAGNETIC MATERIALS	**HARD MAGNETIC MATERIALS**
 "Soft" Ferromagnetic Material	 "Hard" Ferromagnetic Material
1. The figure shows nature of hysteresis loop of soft materials.	1.The figure shows nature of hysteresis Loop of hard materials.
2. These materials can be easily magnetized and demagnetized.	2.These materials cannot be easily magnetized and demagnetized.
3.They have small hysteresis loss due to small area of loop.	3.They have large hysteresis loss due to large area of loop.
4.In these materials the domain wall movement is easier. Even for a small change in applied field there is a large change in the magnetization.	4.In these materials the domain wall movement is difficult because of presence of impurity and defects.
5. The **coercivity** and **retentivity** are small.	5.The **coercivity** and **retentivity** are large.
6. They have high value of **susceptibility** and **permeability**.	6.They have small value of **susceptibility** and **permeability**.
7. The magnetostatic energy is very small since these are free from irregularities.	7. Because of presence of impurities and defects the mechanical strain is more. The magneto static energy is more.
8. Ex:-Iron-Silicon alloys, Fe-Ni, Ferrites and Fe-Co alloys.	8. Ex:- Al-Ni-Co alloys, Cu-Ni-Co alloys and Cu-Ni-Fe alloys.
9. They can be produced by heating and slow cooling.	9. They can be produced by heating and sudden cooling.
10. Low eddy current loss.	10. High eddy currents loss.

8. (a) Physical significance of wave function (Ψ): 1M

1. The wave function ψ is a complex quantity. It represents the variations of the matter wave.
2. ψ represents the probability of finding a particle in an atomic structure. we can say that wave function as probability amplitude since it is used to find the location of the particle.
3. $|\psi|^2$ is called probability density.
4. The probability of finding a particle in a volume dτ is $|\psi|^2 d\tau = \psi\,\psi^* d\tau$
5. $\iiint |\psi|^2$ **$d\Gamma = 1$** when the particle's presence is certain in the space. The wave function ψ must have a finite or zero value at any point.

Derivation for Time Independent Schrodinger wave equation: 5M

Time independent Schrodinger wave equation is used to know the position of a particle or the different energy states occupied by the particle in a system is independent of time or it is called stationary system.

The total wave function $\Psi(x,t)$ is divided into space part and time part

The space part wave function is denoted as $\Psi_0 = A\exp(\frac{ipx}{\hbar})$ therefore the total wavefunction

$$\Psi(x,t) = \Psi_0 \exp(-\frac{iEt}{\hbar}) \quad \text{................(1)}$$

Now differentiating with respect to x

$$\frac{\partial \Psi}{\partial x} = \frac{\partial \Psi_0}{\partial x}\exp(-\frac{iEt}{\hbar})$$

$$\frac{\partial^2 \Psi}{\partial x^2} = \frac{\partial^2 \Psi_0}{\partial x^2}\exp(-\frac{iEt}{\hbar}) \quad \text{..............(2)}$$

Now differentiating with respect to t

$$\frac{\partial \Psi}{\partial t} = \Psi_0 \exp(-\frac{iEt}{\hbar})\ [-\frac{iE}{\hbar}]$$

$$i\hbar\frac{\partial \Psi}{\partial t} = E\,\Psi_0 \exp(-\frac{iEt}{\hbar}) \quad \text{................(3)}$$

Substituting equations (2) & (3) in Time dependent Schrodinger wave equation, we get

Time dependent one dimensional Schrodinger wave equation is

$$i\hbar\frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m}\frac{\partial^2 \Psi}{\partial x^2} + V\Psi$$

$$E\,\Psi_0 \exp(-\frac{iEt}{\hbar}) = -\frac{\hbar^2}{2m}\frac{\partial^2 \Psi_0}{\partial x^2}\exp(-\frac{iEt}{\hbar}) + V\,\Psi_0\exp(-\frac{iEt}{\hbar})$$

Since $\exp(-\frac{iEt}{\hbar})$ is not zero, it can be cancelled throughout the equation and multiplied with $-\frac{2m}{\hbar^2}$. Then

$$\frac{\partial^2\Psi_0}{\partial x^2} - \frac{2m}{\hbar^2} V\Psi_0 = - \frac{2m}{\hbar^2} E\,\Psi_0 \quad \text{Then}$$

$$\frac{\partial^2\Psi_0}{\partial x^2} + \frac{2m}{\hbar^2}(E-V)\,\Psi_0 = 0 \qquad \text{.................} (4)$$

This is Time Independent one dimensional Schrodinger wave equation.

Time Independent Three dimensional Schrodinger wave equation is

$$\nabla^2\Psi_0 + \frac{2m}{\hbar^2}(E-V)\,\Psi_0 = 0$$

8. (b) Numerical

4 M

Formula –	1 M
Substitution of parameters-	1 M
Calculation-	1 M
Answer -	1 M

Solution: The width of the box $L=10^{-10}$m.

$$\boxed{E_n = \frac{n^2h^2}{8mL^2}}$$

For the ground state n=1

$$E_n = \frac{1h^2}{8ml^2} = E_n = \frac{(6.625x10^{-34})^2}{8x9.1x10^{-31}x(10^{-10})^2} = 6.0289 \text{ x } 10^{-18} \text{ J} = 37.62 \text{ eV}$$

For the first excited energy level n=2

$$E_n = \frac{4h^2}{8ml^2} = E_n = \frac{4x(6.625x10^{-34})^2}{8x9.1x10^{-31}x(10^{-10})^2} = 24.1157 \text{ x } 10^{-18} \text{ J} = 150.52 \text{ eV}$$

9.(a) Electrical conductivity expression based on Quantum free electron theory 6 M

We assume that electrons move freely in a solid similar to gas molecules. They may be considered to be subjected to a constant potential V. For convenience if we assume the potential to be zero, the Schrodinger equation becomes

$$-\frac{\hbar^2}{2m}\nabla^2\psi = E\psi$$

where E the total energy is totally kinetic in this case.

We assume a plane wave solution of the type.

$$\psi = \psi_o \exp(ik \cdot r)$$

where the wave-vector $k = 2\pi/\lambda$ and $r^2 = x^2 + y^2 + z^2$

$$\text{Hence} \quad \frac{\partial\psi^2}{\partial x^2} = -k^2x\psi$$

$$\frac{\partial^2\psi}{\partial y^2} = -k^2y\psi$$

$$\frac{\partial^2\psi}{\partial z^2} = -k^2z\psi$$

so that

$$\begin{aligned}\nabla^2\psi &= \frac{\partial^2\psi}{\partial x^2} + \frac{\partial^2\psi}{\partial y^2} + \frac{\partial^2\psi}{\partial z^2}\\ &= -(k_x^2 + k_y^2 + k_z^2)\psi\\ &= -k^2\psi\end{aligned}$$

$$\text{Therefore} \; -\frac{\hbar^2}{2m}(-k^2\psi) = E\psi$$

$$\begin{aligned}\text{or} \quad E &= \frac{\hbar^2k^2}{2m} = \left(\frac{h}{2\pi}\right)^2\left(\frac{2\pi}{\lambda}\right)^2 \cdot \frac{1}{2m}\\ &= \frac{h^2}{2m\lambda^2} = \frac{h^2p^2}{2mh^2} \quad (\text{since} \quad \lambda = h/p)\end{aligned}$$

$$E = \frac{p^2}{2m}$$

Equation (11) represents the energy of a free particle (i.e., electron). From the Fig. 2 it is seen that the energy is continuous. If L is the length of the solid, applying the boundary conditions,

$$k = \frac{2\pi n}{L} \text{ we get}$$

$$E(n) = \frac{\hbar^2 k^2}{2m} = \frac{n^2 h^2}{8mL^2} \qquad (12)$$

If L is large, say 1 cm, the adjacent permitted energy levels differ by about 10^{-19} eV. Since the separation is too small, the energy levels can be considered to form a quasicontinuous band.

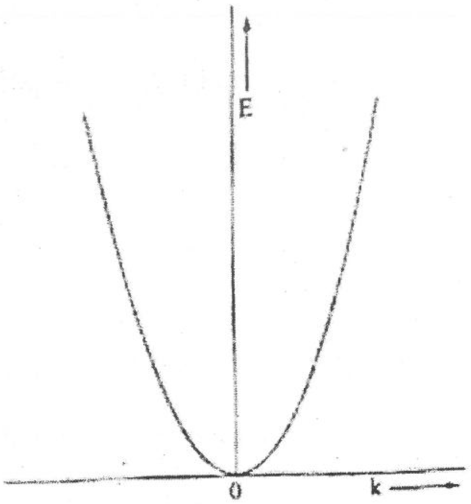


Fig. 2 Electron energy (E) as a function of wave number (k) of free electrons.

When an external electric field E is applied, the force exerted on the electron is $-eE$. Since force is also rate of change of momentum,

$$-eE = \frac{dp}{dt}.$$

Since momentum $p = \frac{h}{\lambda} = \frac{h}{2\pi} \times \frac{2\pi}{\lambda} = \hbar k$

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

$$\text{or} \quad dk = -\frac{eE}{\hbar}dt.,$$

This means that origin of the k space moves through a distance dk in time dt o application of external field. Because of collisions with imperfections, displaceme of k space becomes steady ($= \Delta k$) and dt is then the average collision time τ.

$$\text{Hence} \quad \Delta k = -\frac{eE\tau}{\hbar}.$$

Since $p = mv = \hbar k$, incremental velocity Δv is given by

$$\Delta v = \frac{\hbar}{m}\Delta k = -\left(\frac{\hbar}{m}\right)\left(\frac{eE\tau}{\hbar}\right)$$

$$= -\frac{eE\tau}{m}.$$

If the number of electrons per unit volume is n, then the current density J is given by

$$
\begin{aligned}
J &= n(-e)\Delta v \\
&= \frac{ne^2 E\tau}{m} \\
&= \sigma E \quad \text{(Ohm's law)}
\end{aligned}
$$

where the electrical conductivity

$$\sigma = \frac{ne^2\tau}{m}$$

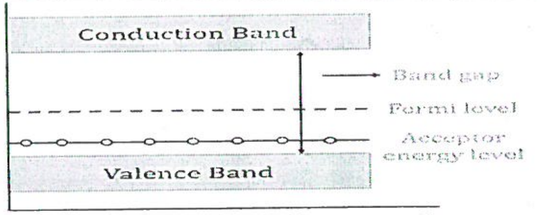
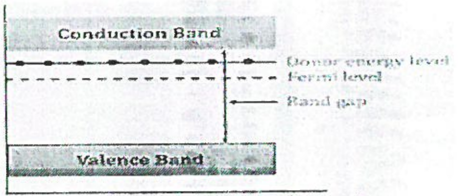
9. (b) Fermi Energy : 4M

The highest occupied energy level by the electrons at 0K is called Fermi Level.

At 0K, below the Fermi level all the energy states are completely filled by the electrons and above the Fermi level all the energy states are empty.

The maximum energy of filled state by the electrons at 0 K is called Fermi Energy. i.e., the energy of the state at which the probability occupation of electrons is half at any temperature other than 0K is called the Fermi Energy.

10. (a) Any three differences of P-type & N-type 4 M

P-Type Semiconductor	N-Type Semiconductor
Semiconductor doped with trivalent impurities (e.g., B, Al).	Semiconductor doped with pentavalent impurities (e.g., P, As).
Holes (positive charge carriers) Major Charge Carriers.	Electrons (negative charge carriers) Major Charge Carriers.
Trivalent (3 valence electrons).	Pentavalent (5 valence electrons).
Conduction occurs due to the movement of holes.	Conduction occurs due to the movement of free electrons.
Higher concentration of holes than electrons.	Higher concentration of electrons than holes.
Holes move toward the negative terminal in external Electric Field	Electrons move toward the positive terminal in external Electric Field.
Fermi level Lies closer to the valence band.	Fermi level Lies closer to the conduction band.
 Energy level diagram of P type semiconductor	 Energy level diagram of N type semiconductor

10.(b) Concentration of Electrons in conduction band in Intrinsic Semiconductor: 6M

Let us assume the number of states in the energy range E and E+dE is Z(E) dE, where Z(E) is the density of states. Since each of these states has an occupation probability F(E), the number of electrons in the energy range E and E+dE is given by

$$dn = Z(E)F(E)dE \text{.........(1)}$$

If E_c is the energy corresponding to the bottom of the conduction band, the number of electrons in the conduction band can be calculated by integrating the above equation from E_c to the energy corresponding to the top of the conduction band ∞. Then,

$$n = \int_{E_c}^{\infty} Z(E)F(E)dE \text{............(2)}$$

We know that the density of states i.e., the number of energy states per unit volume within the energy interval E and E +dE is given by,

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

Since the electron is moving in a periodic potential, its mass has to be replaced by its effective mass m_e^*. Hence,

$$Z(E)dE = \frac{4\pi}{h^3}(2m_e^*)^{\frac{3}{2}}E^{\frac{1}{2}}dE$$

For semiconductors, E starts at the bottom of the conduction band E_c. Hence,

$$Z(E)dE = \frac{4\pi}{h^3}(2m_e^*)^{\frac{3}{2}}(E-E_c)^{\frac{1}{2}}dE \text{ ....(3)}$$

The probability occupation of an electron in an energy state E under thermal equilibrium is

$$F(E) = \frac{1}{1+exp\left(\frac{E-E_F}{k_BT}\right)}$$

Where k_B is Boltzmann constant and T is temperature in Kelvin. E_F is the energy of the Fermi level.

$$F(E) = \left[1+exp\left(\frac{E-E_F}{k_BT}\right)\right]^{-1}$$

For all possible temperatures, $E-E_F >> k_BT$

Hence, $F(E) \cong exp\left(-\frac{E-E_F}{k_BT}\right) \cong exp\left(\frac{E_F-E}{k_BT}\right)$................(4)

Substituting equations (3) & (4) in equation(2) , we get

$$n = \int_{E_c}^{\infty} \frac{4\pi}{h^3} (2m_e^*)^{\frac{3}{2}} (E - E_c)^{\frac{1}{2}} exp\left(\frac{E_F - E}{k_B T}\right) dE$$

$$n = \frac{4\pi}{h^3} (2m_e^*)^{\frac{3}{2}} \int_{E_c}^{\infty} (E - E_c)^{\frac{1}{2}} exp\left(\frac{E_F - E}{k_B T}\right) dE$$

To solve this integral, let us put, $E - E_c = x$. If $E = E_c$, then $x = 0$

Therefore $E = E_c + x$ and $dE = dx$

$$n = \frac{4\pi}{h^3} (2m_e^*)^{\frac{3}{2}} exp\left(\frac{E_F}{k_B T}\right) \int_{0}^{\infty} (x)^{\frac{1}{2}} exp\frac{-(E_c + x)}{k_B T} dx$$

It can be shown that using gamma function

$$\int_{0}^{\infty} (x)^{\frac{1}{2}} exp\frac{-(x)}{k_B T} dx = (k_B T)^{\frac{3}{2}} \frac{\pi^{\frac{1}{2}}}{2}$$

Hence

$$n = \frac{4\pi}{h^3} (2m_e^*)^{\frac{3}{2}} exp\left(\frac{E_F - E_c}{k_B T}\right) (k_B T)^{\frac{3}{2}} \frac{\pi^{\frac{1}{2}}}{2}$$

i.e The number of electrons per unit volume of the material is given by

$$n = 2\left(\frac{2\pi\, m_e^* k_B T}{h^2}\right)^{\frac{3}{2}} exp\left(\frac{E_F - E_c}{k_B T}\right) \text{............(5)}$$

This is the expression for concentration of electrons in the conduction band of an intrinsic semiconductor.

11.(a). Carrier concentration in P-type extrinsic semiconductors **6M**

We know that density of holes in valence band is

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

$$N_a F(E_a) = \frac{N_a}{1 + exp\left(\frac{E_a - E_F}{K_B T}\right)}$$

When $E_a - E_F \gg K_B T$

$$N_a F(E_a) = N_a exp\left(\frac{E_a - E_F}{K_B T}\right)$$

The number of electrons present in the acceptor level is equal to the density of holes. So,

$$2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}} exp\left(\frac{E_v - E_F}{k_B T}\right) = N_a exp\left(\frac{E_a - E_F}{K_B T}\right)$$

$$exp\left(\frac{E_v + E_a - 2E_F}{k_B T}\right) = \frac{N_a}{2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}}}$$

$$\left(\frac{E_v + E_a - 2E_F}{k_B T}\right) = log \frac{N_a}{2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}}}$$

$$E_F = \frac{E_v + E_a}{2} - \frac{k_B T}{2} log \frac{N_a}{2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}}}$$

So substituting E_F in density of holes

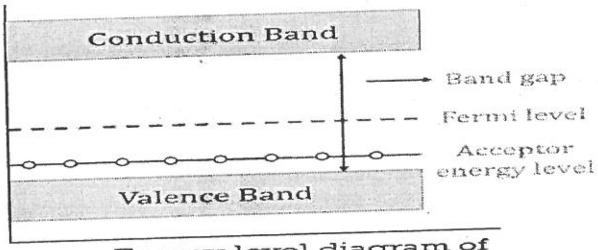
Then equation becomes $p = 2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}} exp\left(\frac{E_v - \frac{E_v + E_a}{2} - \frac{k_B T}{2} log \frac{N_a}{2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}}}}{k_B T}\right)$

$$= 2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}} exp\left(\frac{E_v - E_a}{2k_B T} + \frac{1}{2} log \frac{N_a}{2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}}}\right)$$

$$= 2\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{2}} exp\left(\frac{E_v - E_a}{2k_B T} + log \frac{N_a^{\frac{1}{2}}}{2^{\frac{1}{2}}\left(\frac{2\pi m_h^* k_B T}{h^2}\right)^{\frac{3}{4}}}\right)$$

$$p = (2N_d)^{\frac{1}{2}}\left(\frac{2\pi\, m_e^* k_B T}{h^2}\right)^{\frac{3}{4}} exp\left(\frac{E_v - E_a}{2k_B T}\right)$$

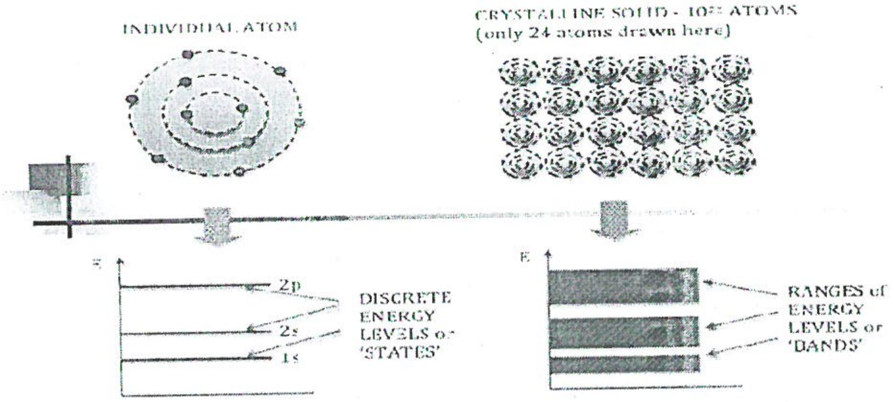
This is an equation for carrier concentration in p-type semi conductor.



Energy level diagram of P type semiconductor

11. (b) Origin and formation of energy bands **4M**

In an isolated atom, the electrons are tightly bound and have discrete, sharp energy levels . When two identical atoms are brought closer the outermost orbits of these atoms overlap and interact. When the wave functions of the electrons of the different atoms begin to overlap considerably, the energy levels corresponding to those wave functions split into two as in below Fig. If more atoms are brought together more energy levels are formed and for a solid of N atoms, each of the energy levels of an atom splits into N levels of energy. The levels are so close together that they form an almost continuous band. The width of this band depends on the degree of overlap of electrons of adjacent atoms and is largest for the outermost atomic electrons.



In a solid many atoms are brought together so that the split energy levels form a set of bands of very closely spaced levels with forbidden energy gaps between them as shown in Fig. There are two energy bands called valence and conduction bands. The band corresponding to the outer most gaps between these two allowed bands is called forbidden energy gap or band gap since electrons can't have energy values within the forbidden energy gap.

According to the width of the gap between the bands and band occupation by electrons, all solids can be classified broadly into three groups, namely conductors, semiconductors and insulators.

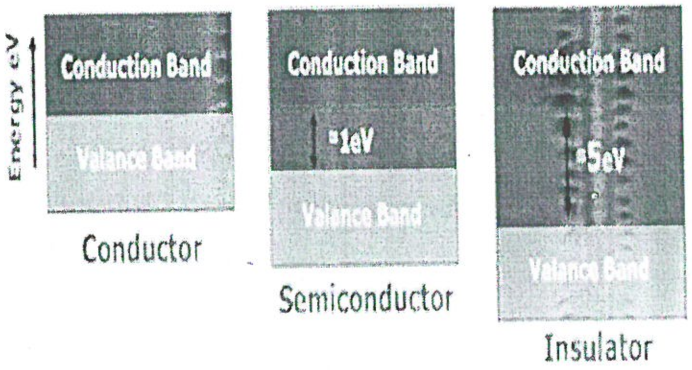


Fig: Classification of Solids on the basis of electricity Conduction