APPLIED PHYSICS 1

(CBCGS DEC 2016)

Q1](a) What are crystal imperfections? Mention any two significance of it. (3)

Ans:- *In an ideal crystal atoms or molecules are arranged in a regular and periodic manner. Any deviation in a crystal from a crystal from a perfect periodic structure is called IMPERFECTION. Real crystals are always imperfect in some respect as ideal crystal do not exist in nature and cannot even be produced artificially. Imperfections have some advantages as the resistivity, conductivity, colour, luminescence , mechanical and plastics properties of matter can be controlled by regulating imperfection. Point defects are localized defects which means that in the same crystal different types of points are observed at its different parts.*

The crystal defects are classified into the following types:

- *POINT DEFECTS which are zero dimensional defects.*
- *LINE DEFECTS which are one dimensional.*
- *SURFACE DEFECTS which are two dimensional defects and*
- *VOLUME DEFECTS which are two dimensional defects.*

Q1](b) Write schrodinger's time dependent and time independent wave equations of matter waves in one dimensional and state physical significance of these Equations (3)

Ans:- *1. ONE DIMENSIONAL TIME DEPENDENT SCHRODINGER EQUATION.*

$$\frac{-\hbar}{2m}\times\frac{\partial^2\Psi(x,t)}{\partial x^2} + V\Psi(x,t) = j\hbar\frac{\partial\Psi(x,t)}{\partial t}$$

The first and second term on the left hand side represents the kinetic and potential energies respectively of the particles and the right hand side represents the total potential.

2. ONE DIMENSIONAL TIME INDEPENDENT SCHRODINGER EQUATION.

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

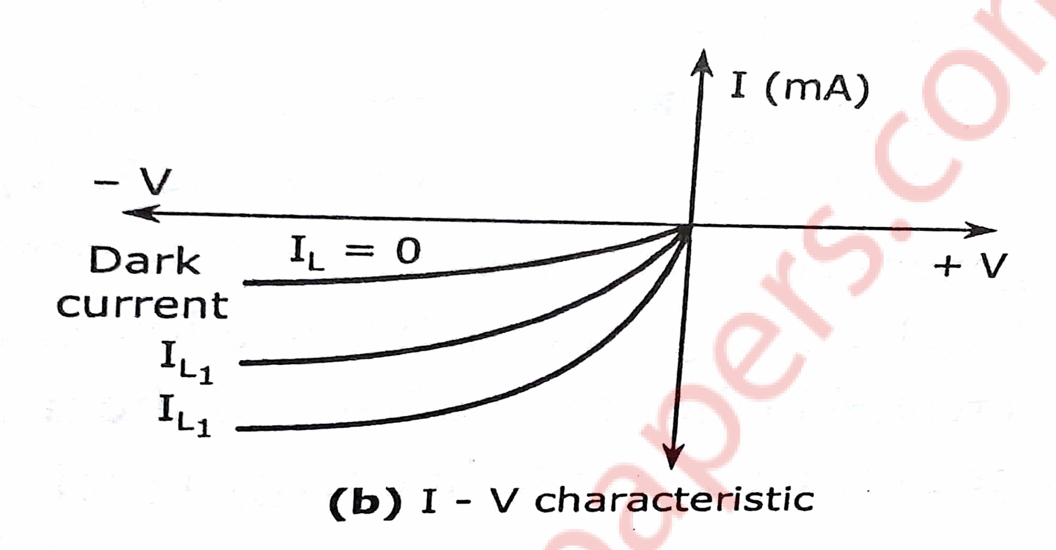
3. THREE DIMENSIONAL TIME INDEPENDENT SCHRODINGER EQUATION

$$H = -\frac{\hbar^2}{2m}\nabla^2 + V$$

Schrodinger equation is the fundamental equation of quantum mechanics. This is extremely useful for investing various quantum mechanical problems. The wave function, the probability *density, the energy values of a quantum mechanical particle, etc. in various situation can be calculated with the help of this equation.*

Q1] (c) Draw the I-V characteristics of a photo -diode. What is meant by dark current? (3)

Ans:-



(b) I - V characteristic

DARK CURRENT:

***dark current** is the relatively small electric current that flows through photosensitive devices such as a photomultiplier tube, photo diode, or charge coupled device even when no photons are entering the device; it consists of the charges generated in the detector when no outside radiation is entering the detector. It is referred to as reverse bias leakage current in non-optical devices and is present in all diodes. Physically, dark current is due to the random generation of electrons and holes within the depletion region of the device.*

Q1](d) Define super conductivity and critical temperature. Plot the variation of resistance versus temperature in case of superconducting state of the material. (3)

Ans:- *Superconductivity is a state of matter exhibited by some normal conductors when their resistivity suddenly drops to zero at a very low temperature. The superconductivity property of a material can be easily be effected by temperature , magnetic field and current.*

Superconductivity is a property of some conductors the resistivity of which suddenly drops to zero at a certain low temperature , T_c*. These materials behave as superconductors below the critical temperature ,* T_c *and as normal conductors .*

The CRITICAL TEMPERATURE is the temperature at which the normal state of a conductor changes to superconducting state. critical temperature is different for different *superconductors.*

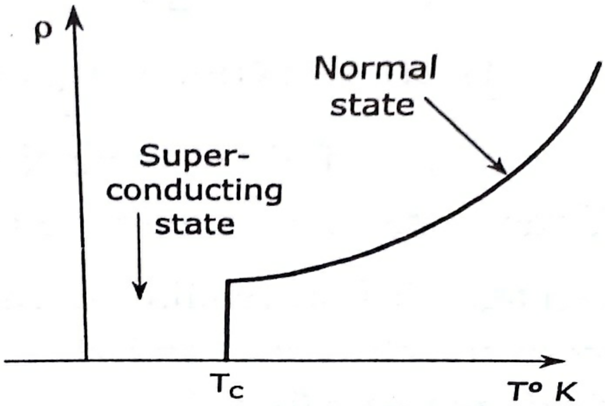


Figure 4.2 : Resistivity of a Superconductor

Q1](e)What is reverberation time? Discuss sabine formula. (3)

Ans:- *The time taken by the sound to fall from its average intensity to inaudibility is called the reverberation time. It is also defined as time during which the sound intensity falls from its steady state value to its one-millionth value after the source is shut off*

$$\therefore \frac{I}{I_0} = 10^{-6}$$

SABINES FORMULA.

Sabines derived an expression for the reverberation time of a furnished hall as follows.

The decay intensity is given by,

$$I = I_0 e^{-KT}$$

$$\therefore \frac{I}{I_0} = 10^{-6}$$

Hence, $T = \frac{1}{K}\log_e \frac{I_0}{I} = \frac{2.303}{K}\log_{10}\frac{I_0}{I} = \frac{2.303}{k}\times 6$

Hence reverberation time is given by $T = 0.161 \times \frac{V}{A}$ *……………………….(1)*

Hence equation (1) is called as sabines formula.

Q1](f) State 'magnetostriction effect'. Mention any two application of ultrasonic waves. (3)

Ans:- *When a ferromagnetic rod is placed along a magnetic field it undergoes a small change in it length. If the steady magnetic field is replaced by an alternating magnetic field it undergoes alternate extension and contraction. If the frequency of the alternating magnetic field is high the* *rod starts vibrating exhibiting longitudinal vibrations. When the frequency of the applied field is high the rod produces ultrasonic waves in the surrounding medium.*

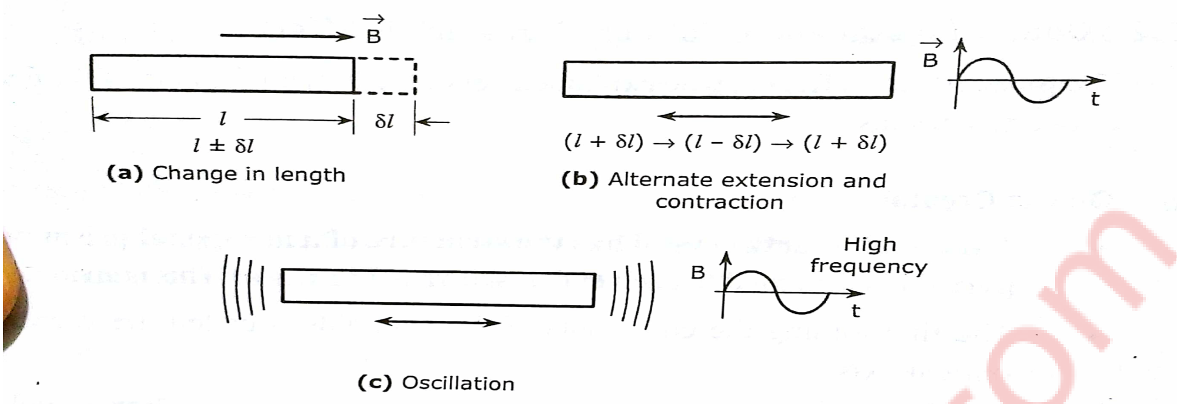


Figure 6.1 : Magnetostriction effect

APPLICATION:

- *Acoustic transducer : SONAR, Hydrophone, ultrasonic cleamimg, ultrasonic friction welding.*
- *Actuator: pump, Active valve, Rotary motor.*
- *Sensor: vibration sensor, position sensor, torque sensor.*

Q1](g) Calculate conductivity of a germanium sample if a donar impurity atoms are added to the extent to one part in 10^6 germanium atoms at room temperature.

Assume that only one electron of each atom takes part in conduction process.

Given:- Avogadro's number = 6.023 × 10^{23} atom/ gm- mol.

Atomic weight of Ge = 72.6

Mobility of electrons = 3800 $\frac{\text{cm}^2}{\text{volts}}$sec

Density of Ge = 5.32 gm/ cm^3 . ***(3)***

Ans:- *Given data :- N = 6.023 × 10^{23} atoms/ gm-mole , atomic weight of Ge, A = 72.6,*

$\mu_e = 0.38\frac{\text{m}^2}{\text{V}}$ - sec, $\rho = 5320\ \text{kg/m}^3$

Formula :- $\sigma = n_e e \mu_e$

Solution :- *no .of atoms / unit volume =* $\frac{N\rho}{A} = \frac{6.023 \times 10^{26} \times 5320}{72.6}$

$= 441.35 \times 10^{26}$

No .of electrons added/ unit vol $= n_e = \dfrac{441.35\times10^{26}}{10^6}$

$= 441.35 \times 10^{20}$

Conductivity , $\sigma = n_e e \mu_e$

$= 441.35 \times10^{20}\times1.6\times10^{-19}\times0.38$

$= 2683$

Conductivity $= 2683$ mho/ m.

Q2](a) Describe with the necessary theory the davisson and german establishing wave nature of electrons. Calculate the de-broglie wavelength of an alpha particle accelerating through a potential difference of 200 volts given:- mass of alpha particle = 6.68$\times10^{-27}$ kg. (8)

Ans:- *According to de Broglie's hypothesis, a beam of material particle must possess wave like characteristics and should undergo phenomena like reflection , refraction, interference, diffraction and polarization as the ordinary light waves do. The first experimental verification of wave nature of atomic particles was provided by davisson and germer.*

DAVISSON-GERMER EXPERIMENT.

In this experiment , from a hot filament F electrons are accelerated by a small voltage V to strike a target made of a single nickel crystal.

- *The electrons are scattered off the crystal in all directions.*
- *Help of an scattered electrons in all directions can be recorded with the help of an electron detector which can be rotated on a circular graduated scale.*
- *For any accelerating voltage ,V the scattering curve shows a peak or maximum in a particular direction. It is found that for an accelerating voltage of 54 volts a very large number of electrons are scattered at a particular angle ,* $\emptyset = 50°$.
- *It is assumed that the electron undergoes diffraction and the peak represents the first order spectrum at an angle of* $50°$.

The diffraction effects is explained as follows.

- *The atomic planes of the nickel crystal act like the ruling of a diffraction grating.*
- *The interatomic distances of a nickel crystal is known to be a = 2.15 A°.*
- *The interatomic spacing of a nickel crystal is*

d = 0.09 A°.

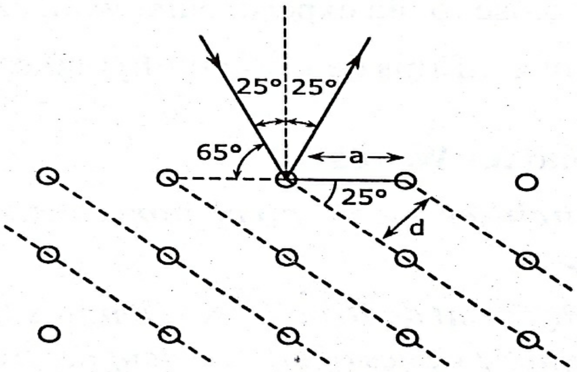


Figure 2.2 : Electron diffraction by Nickel crystal

- *Since, it is assumed that the electrons undergo diffraction they must follow braggs law,*

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

- *It is seen that the glancing angle* $\theta = 65°$. *Assuming the order of diffraction , n= 1 the electron wavelength is experimentally calculated as*

$$\lambda_E = 1.65\ A°.$$

- *On the other hand since the electron energy is*

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

The wavelength associated with an electron wave can be written as

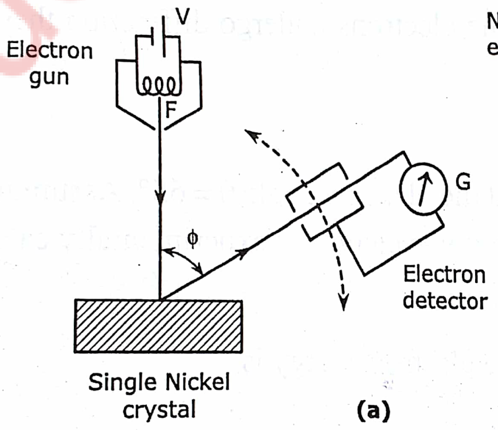
$$\lambda_T = \frac{h}{\sqrt{2mE}} = \frac{h}{\sqrt{2meV}} = \frac{12.25}{\sqrt{V}}$$

- *here the accelerating potential V = 54 volts for which the theoretical electron wavelength is found to be*

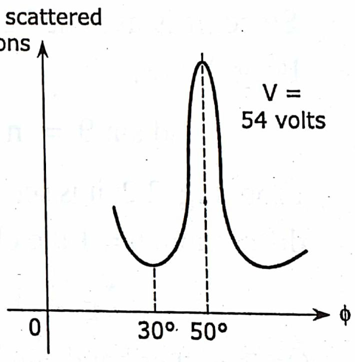
$$\lambda_T = 1.67\ A°.$$

Which is very close to the experimental value , λ_E.

- *This agreement confirms de Broglie hypothesis of matter waves.*



(a)



(b)

NUMERICAL:

Given data : - $m_p = 6.68 \times 10^{-27}$ *kg,* $q_\alpha = 4e = 6.4 \times 10^{-19} C$

V = 200 volts.

Formula :- $\frac{1}{2}mv^2 = q_\alpha V$, $\lambda = \frac{h}{mv}$

Solutions :- - $\frac{1}{2}mv^2 = q_\alpha V$, $v = \sqrt{\frac{2q_\alpha V}{m}}$

$$\lambda = \frac{h}{\sqrt{2q_\alpha mV}}$$

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 6.4 \times 10^{-19} \times 6.68 \times 10^{-27} \times 200}}$$

$$= 0.507$$

Answer : de Broglie wavelength of an alpha particle

λ_α *= 0.507 A°.*

Q2](b) Define the term drift current and mobility of a charge carriers. Calculate the current product in a germanium sample of area of cross section 1 cm^2 ***and thickness of 0.01 m, when a potential difference of 2V is applied cross it. Given :- the concentration of free electron in germanium is*** $2 \times 10^{19}/m^3$ ***and mobilities of electrons and holes are 0.36*** m^2**/volts** ***sec and 0.17*** m^2**/volts** ***sec respectively.***

(7)

Ans:- *DRIFT CURRENT :-*

Drift current is the electric current caused by particles getting pulled by an electric field. Direction of the drift current is always in the direction of the electric field.

The amount of drift current depends on the concentration of charge carriers and their mobility in the material or medium.

MOBILITY OF CHARGE CARRIERS :-

This is a property of conductor, defined as the ratio of drift velocity to applied electric field in a conductor. Drift velocity of charge carriers in a conductor depend upon two factors, one is the intensity of applied electric field across the conductor and other is one property of the conductor called Mobility of Charge Carrier.

The SI unit of mobility is $\frac{m^2}{V}sec$

NUMERICAL:

Given data :- A = 1$\mathrm{cm}^2 = 10^{-4}\mathrm{m}^2$, *t = 0.01m, V = 2 volts.*

$$n_i = 2\times10^{19}/\mathrm{m}^3, \qquad \mu_e = 0.36\frac{\mathrm{m}^2}{\mathrm{V}}\text{-sec}, \quad \mu_h = 0.17\frac{\mathrm{m}^2}{\mathrm{V}}\text{-sec}$$

Formula :- $\sigma = n_i(\mu_e+\mu_h)e, \quad R = r\frac{t}{A}$, *V = IR.*

Solution :-

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

$$= 2\times 10^{19}(0.36+0.17)\times1.6\times10^{-19}$$

$$= 1.696\ \mathrm{mho/m}$$

$$R = r\frac{t}{A} = \frac{1}{\sigma}\frac{t}{A}$$

$$= \frac{1}{1.696}\times\frac{0.01}{10^{-4}} = 58.96\,\Omega$$

$$I = \frac{V}{R} = \frac{2}{58.96} = 0.0339\ \mathrm{Amp}$$

Current :- 0.0339 Amp.

Q3](a) Draw and explain the unit cell of sodium chloride (NaCl) crystal determine effective number of NaCl molecule per unit cell and co-ordination number. (8)

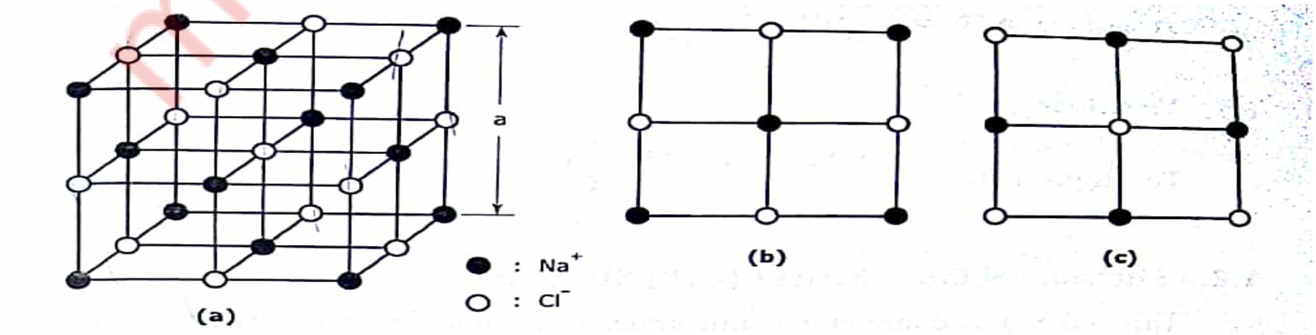
Ans:- NaCl STRUCTURE:-

This is an ionic structure in which the Na^+ *ions and* Cl^- *ions are alternately arranged. It is a combination of two FCC sublattice one made up of* Na^+ *ions and the other of* Cl^- *ions as if one sublattice is translated through the other along the cube edges.*

NaCl unit cell with Na^+ *ions occupying the regular FCC lattice points with* Cl^- *ions positioned at alternate points. A face of this unit cell is shown.*

Another NaCl unit cell can be considered with the positions of Na^+ *and* Cl^- *ions interchanged. The face of such a unit cell is shown.*

NaCl UNIT CELL PARAMETER:



(a) Total number of molecule / unit cells

Calculation for Na^+ *= Here* Na^+ *forms a FCC structure. Hence total number of* Na^+ *ions = 4*

Calculation for Cl^- *= There are 12*Cl^- *ions at the edges. Every edge lattice points is shared by four neighbouring unit cell. Hence every edge lattice point carries ¼ of an atom. There is one whole* Cl^- *ion at the centre of the structure. Hence ,*

Total number of Cl^- *ions =* $(12 \times \frac{1}{4}) + 1 = 4.$

Since there are 4 Na^+ *ions and four* Cl^- *ions in a NaCl unit cell , there are four NaCl molecule present in a unit cell.*

Hence number of molecule / unit cell = 4.

(b) Atomic Radius (r)

Since NaCl is an ionic structure and cations are smaller than anions it is assumed that radius of cation = r_C *and the radius of an anion =* r_A.

(c) Atomic packing factor(APF)

$$\mathrm{APF} = \frac{\left(4 \times \frac{4}{3}\pi r_C^3\right) \times \left(4 \times \frac{4}{3}\pi r_A^3\right)}{a^3}$$

it is found that $a = 2r_C + 2r_A$

Hence, $$\mathrm{APF} = \left(\frac{2\pi}{3}\right)\frac{r_C^3 + r_A^3}{(rC+rA)^3}$$

(d) Void space.

This is given by $$\left[1- \left(\frac{2\pi}{3}\right)\frac{r_C^3 + r_A^3}{(rC+rA)^3}\right]$$

Q3](b) State application of Hall effect. In a Hall effect experiment a potential difference of 4.5 μV ***is developed across a foil of zinc of thickness 0.02mm when a current of 1.5 A is carrying in a direction perpendicular to applied magnetic field of 2 tesla. Calculate :-***

(a)Hall coefficient for zinc.

(b)Concentration of electron. ***(7)***

Ans:- *If a current carrying conductor or semiconductor is placed in a transverse magnetic field, a potential difference is developed across the specimen in a direction perpendicular to both the current that the magnetic field. The phenomenon is called as HALL EFFECT.*

The net electric field E acting on the charge carriers is a constant of the applied electric field E_x *and hall electric field* E_H. *The angle made by E with the x axis is called the Hall angle which is given by:-*

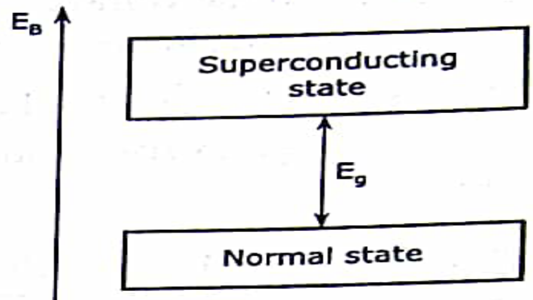
$$\boxed{\theta_H = \tan^{-1}\left(\frac{E_H}{E_X}\right)}$$

Q4](a) Discuss formation of copper pairs and energy gap in superconductor on the basis of BCS theory.

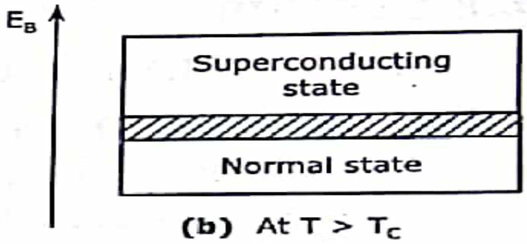
(5)

Ans:- *The quantum theory of superconductivity developed by bardeen, cooper and schrieffer is known as BCS theory.*

- *During conduction the electron motion is interrupted by these phonon waves and resistivity aries in normal conductors.*
- *In superconductors during the interaction of electrons with phonons some electron absorbs phonons and their energy increases by an amount* $h\vartheta$*. When they release this energy as phonons other electron absorbs them. In this way electron in superconductors interact with each other through the emission and absorption of phonons.*
- *If a phonon emitted by one electron is absorbed by another electron, the electron form a pair called Cooper pair. This phonon mediated electron interaction is attractive.*
- *There exist an energy gap between the superconducting state and the normal state. this is different from the energy gap in band theory of solids. This energy gap represents the binding energy of a cooper pair. This is of the order of* 10^{-3} *eV at low temperature .*
- *In the cooper pairs of electrons the spin and the momenta are correlated. Cooper pairs have a spin zero.*
- *The stability of copper pairs results in superconductivity.*



(a) At $T < T_C$
$E_g \sim 10^{-3}$ eV



(b) At $T > T_C$
$E_g = 0$

Q4](b) State any five factors affecting the acoustics of the building and give the remedies for each. (5)

Ans:- *The defects ,that commonly affect the acoustics of a hall and how to eliminate them to design a good auditorium are described as follows:-*

1. *Defect = NOISE*

   Any unwanted sound which can be created inside the hall or can be carried by air from outside into the hall is called noise.

   Design = Proper site selection

   A site with quite surrounding is proper for a hall or auditorium. The background noise level of the hall should be below 40-50 dB.

2. *Defect = Echo*

   Echo is a sound wave reflected from a parallel hard smooth surface. Excessive echo affects the acoustics of the hall.

   Design = A splayed floor plan and the covering of interior surface with suitable absorbent material minimize the defect and distribute the sound energy uniformly throughout the hall.

3. *Defect = Echelon Effect*

   Successive echo of a sound from a set of regularly spaced parallel and smooth surfaces cause Echelon effect which makes the original sound unintelligible.

   Design = the steps inside the hall should be covered with absorber like carpets.

4. *Defect = Insufficient loudness*

Excessive absorption and low reflection of the sound leads to this defect.

Design = in addition to loud speaker large sounding boards are used behind the source of sound. The absorbent materials are adjusted for this purpose, as well.

Q4](c) An ultrasonic pulse of 0.09M Hz sends down towards the sea-bed which returns after 0.55 seconds. The velocity of ultrasonic waves in sea water is 1800 m/sec . calculate the depth of sea and wavelength of ultrasonic pulse.
(5)

Ans:- *Given data :-* $f = 0.09 \times 10^6$ *Hz, t=0.55 sec , v=1800m/sec.*

Formula :- 2d = vt , v = fλ

Solution :-

$$d = \frac{vt}{2} = \frac{1800 \times 0.55}{2} = 495\ m$$

$$\lambda = \frac{v}{f} = \frac{1800}{0.09 \times 10^6} = 0.2\ A^\circ$$

Answer :- depth of sea = 495 m

Wavelength = 0.2A°

Q5](a) How does the position of fermi energy level changes with increasing doping concentration in p-type semi-conductor ? sketch diagram. (5)

Ans:- *This type of break down occurs when a high reverse voltage is applied to a lightly doped junction diode as shown. In this case , the minority electron of the p side acquire high kinetic energy with which they knock out the valence electrons of the host atoms producing electron-hole pairs. These electron hole pairs gain kinetic energy from the electric field and in turn produce more and more electron pairs. This is called avalanche multiplication which occurs in a very short time to give large reverse current.*

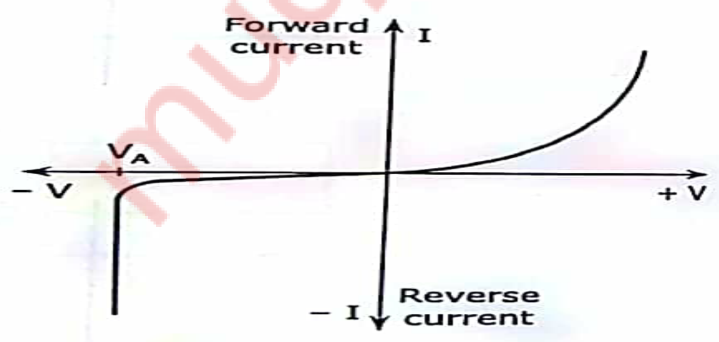


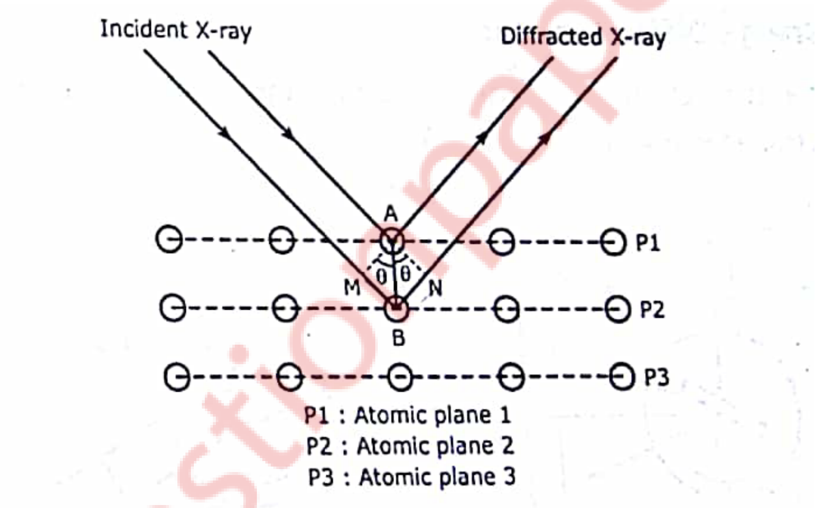
Figure 3.23 : Avalanche breakdown

Q5](b) Explain analysis of crystal structure using Bragg's X ray spectrometer (5)

Ans:- *W.L Bragg's explained the phenomenon of X-ray diffraction from a single crystal shown as follows*

When a beam of X-rays is incident on a crystal it is scattered by individual atoms of the rich atomic planes. Thus, each atom become a source of scattered radiation. The atomic planes responsible for the X-ray diffraction are called BRAGG'S PLANES. Therefore the sets of Braggs planes constitute the crystal grating. Bragg's scattering or Bragg's diffraction is also referred as Braggs reflection. Bragg derived a law called Bragg's law to explain the X-ray diffraction effect.

Here a beam of X-ray is incident on a set of parallel planes of a crystal. The rays makes a glancing angle θ *and are practically reflected from different successive planes. The phase relationship of the scattered rays can be determined from their path differences. Here two parallel X-rays are reflected from two consecutive planes PI and P2. The path differences between then as shown*



$$\delta = MB + BN = 2MB = 2AB\sin\theta$$

Here AB = d, the interplanar spacing of the crystal. Hence,

$$\delta = 2d\sin\theta$$

The two diffracted rays reinforce each other when they interfere constructively when their path difference δ *is equal to* $n\lambda$

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

This is called Bragg's law.

Q5](c)Find the minimum energy of neutron confined to a nucleus of size of the order of 10^{-14} m.

Given mass of neutron = 1.675×10^{-27} **kg** ***(5)***

Ans:- *Given data :- L =* 10^{-14}m

Formula :- $E_n = n^2(\frac{h^2}{8mL^2})$ ……………………(n = 1,2,3…..)

Solution :- $E_n = n^2(\frac{h^2}{8mL^2}) = \frac{(6.63 \times 10^{-34})\times(6.63 \times 10^{-34})}{8\times1.67 \times10^{-27}\times(10^{-14})^2}$ …..(n=1)

$E_1 = 3.29 \times 10^{-13} J$

Lower energy = $3.29 \times 10^{-13} J$

Q6](a) Calculate the critical radius ratio of an ionic crystal in ligancy-6 . what is the maximum size of cation in ligancy 6 configuration when size of anion is 2.02A° ?(5)

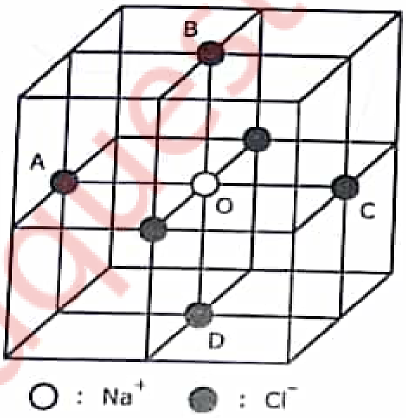
Ans:- OCTAHEDRAL CONFIGURATION:

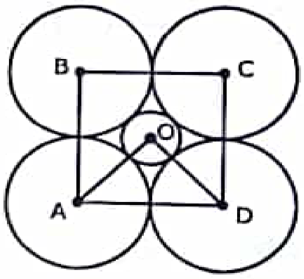
The octahedral configuration of neighbouring anions is found in NaCl structure. Here four anions A, B ,C and D are arranged at the corners of a square with the cation O at the centre of the square. Two more anions are situated in front and at the back of the cation. The centres of all six anions form an octahedron.

Here in Δ *BOC , < BOC = 90°, BC =* $2r_A$ *, OB =* $r_C + r_A$ *and <BCO =45°,*

Hence, $\frac{BO}{BC} = \cos45°$

Or, $\frac{r_C+r_A}{2r_A} = \frac{1}{\sqrt{2}}$





The critical radius ratio here is,

$$\boxed{\frac{r_C}{r_A} = 0.414}$$

NUMERICAL:

Given data :- $r_{A(max)} = 2.02A°$ *, ligancy = 6.*

Formula :- *for ligancy 6 ,*$(\frac{r_C}{r_A})$ *= 0.732.*

Calculations :- $r_C = r_A \times 0.732 = 2.02 \times 0.732 = 1.478\ A°$

Answer :- $r_c = 1.478A°$

Q6](b) What do you mean by group and phase velocity? Show that the de-Broglie group velocity associated with the wave packet is equal to the velocity of the particle. (5)

Ans:- *GROUP VELOCITY:-*

When a number of waves of slightly different wavelengths and velocities travel together in a medium the observed velocity of this group of waves is called the Group velocity. Such a group of waves is called a wave packet.

PHASE VELOCITY:-

The velocity with which a wave travels through a medium is known as phase velocity or wave velocity.

RELATION BETWEEN PHASE AND GROUP VELOCITY.

Consider a particle of rest mass m_o *moving with a velocity v, which is very large and comparable to c with v<c , its mass is given by the relativistic formula.*

$$m = \frac{m_o}{\sqrt{1-(\frac{v^2}{c^2})}}$$

$$\omega = 2\pi\vartheta\text{........(} \omega \text{ = angular frequency)}$$

$$= 2\pi\left(\frac{E}{h}\right) = 2\pi(\frac{mc^2}{h})$$

And $$k = \frac{2\pi}{\lambda} = \frac{2p\pi}{h} = \frac{2\pi}{h}(mv)$$

Wave velocity is the phase velocity given as

$$V_p = \frac{\omega}{k} = \frac{c^2}{v}$$

$$V_p = \frac{d\omega}{dk}$$

$$V_g = \frac{d\omega/dv}{dk/dv}$$

$$V_g = V$$

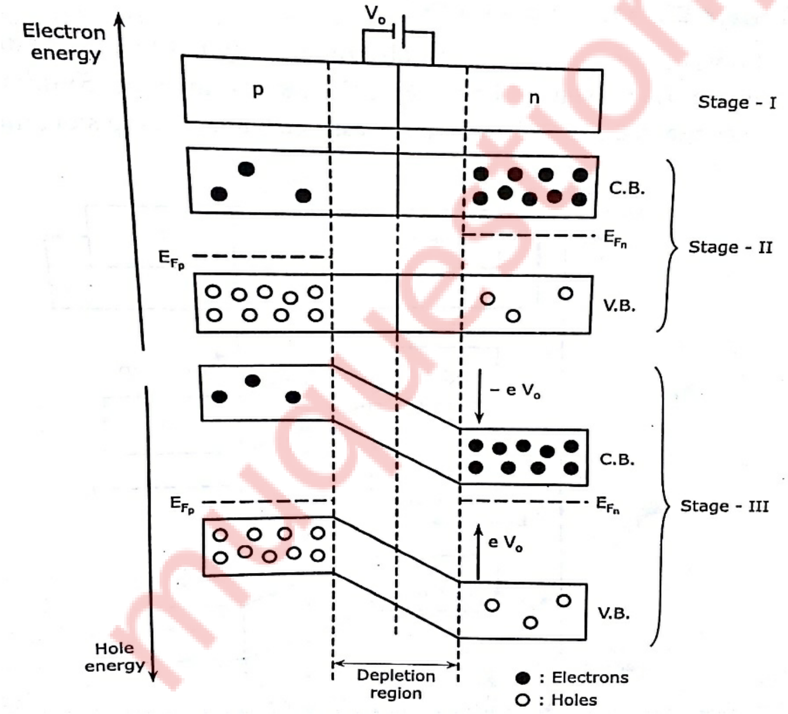
This shows that a matter particles in motion is equivalent to a packet moving with group velocity V_g *whereas the component waves moves with phase velocity* V_p.

Hence the relation between phase velocity and group velocity is:-

$$\boxed{\therefore V_p V_g = c^2}$$

Q6](c)Explain the formation of potential barrier across the unbiased p-n junction region (5)

Ans:- *The p-n junction is formed at the initial stage , the fermi level on the p and n sides are at different energy states. This is because of the fact that p side has excess holes and n side has excess electrons as free carriers.*



- *The diffusion through the junction start to equalize the number of charge carrier on both sides. As the conduction band of the n side has high density of carrier, electrons of the conduction band diffuse through the junction from the n side to the p side. Similarly holes of the valence band diffuse through the junction from p side to n side.*

- *As more electrons occupy band of p side the fermi level* E_{FP}*starts moving upwards along with the entire p-type energy band structure. Similarly more holes entering the valence band of n-side make the fermi level* E_{Fn} *moves downwards. The energy band structure also move downwards with* E_{Fn}*. Finally a stage comes when the charge density on both sides of the same band is uniform. In this equilibrium condition the fermi levels* E_{Fn} *and* E_{Fp} *align with each other.*
- *The conduction band and the valence band of both sides are positioned in such a manner that a conduction hill of height* $-eV_0$ *and valence hill of height* eV_0 *are formed. These are the potential energies of the electrons and holes respectively due to the potential barrier* V_0.

APPLIED PHYSICS 1

(CBCGS MAY 2017)

Q1](a) Draw the unit cell of HCP structure and work out the no. of atoms per unit cell. (3)

Ans:- *Each corner atom is shared by 6 neighbouring unit cells. Hence each corner carriers (1/6)th of an atom as shown:-*

Each face centre carriers ½ atom. In the middle layer there are three atoms. Hence total number of atoms/unit cells are

$$n = 2\left(6\times\frac{1}{6}\right) + 2\left(\frac{1}{2}\right) + 3 = 6$$

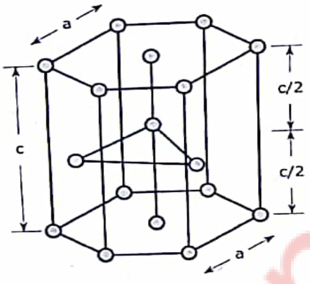


Figure 1.9 (a) : HCP structure

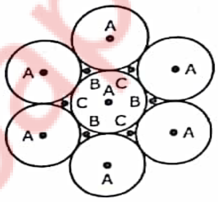


Figure 1.9 (b) : Atomic arrangement of HCP structure

Q1](b)The mobility of holes is 0.025m^2/V-sec. what would be the resistivity of n-type Si if the Hall coefficient of the sample is 2.25× $10^{-5}\mathrm{m}^3$/C. (3)

Ans:- *Given Data :-* $\mu_h = 0.025\mathrm{m}^2$/V-sec $\quad R_H = 2.25\times 10^{-5}\mathrm{m}^3/C$

Formula :- $\rho = \frac{1}{\sigma}$, $\mu_h = \sigma R_H$

Calculations :- $\sigma = \frac{\mu_H}{R_H} = \frac{0.025}{2.25\times10^{-5}}$ = *1111.11 mho/m*

$$\rho = 9\times10^{-4}\Omega\text{ - m}$$

Answer :- *Resistivity =* $9\times10^{-4}\ \Omega\text{ - m}$

Q1](c) What is the principle of solar cell? Write its advantages and disadvantages. (3)

Ans:- *PRINCIPLE :-*

In photoelectric effect when radiation is incident on a metal surface electron are ejected. In photovoltaic effect, certain materials being exposed to radiation generates electron hole pairs available for conduction. As a result a voltage is developed across the material. The radiation energy E= $h\vartheta$ *is required to be greater then the band gap energy* E_g *of the material. This is a phenomenon in which light energy is converted into electrical energy.*

ADVANTAGES :-

- *Environmentally friendly.*
- *No noise, no moving parts.*
- *No emission.*
- *Minimum maintenance required.*
- *Long lifetime, up to 30 years.*
- *PV operator even in cloudy weather condition.*

Disadvantages:-

- *PV cannot operate without light .*
- *High initial costs that overshadow the low maintenance costs and lack of fuel costs.*
- *Large area needed for large scale applications.*
- *PV generates direct current special DC appliances or an inverter are needed.*

Q1](d) An electron is confined in a box of dimension 1A°. calculate minimum uncertainty in its velocity. (3)

Ans:- *Given Data :-* $L = 10^{-10} m$

Formula :- $\Delta X_{ma}.\Delta p_{mi} = \hbar$

Calculations :- since the electron is probable anywhere within the box of length $10^{-10}m$*, the maximum uncertainty in locating it is,*

$$\Delta X_{ma} = 10^{-10} m$$

$$\Delta X_{ma}.m.\Delta v_{mi} = \hbar$$

$$\Delta v_{mi} = \frac{\hbar}{m\Delta X_{ma}}$$

$$= \frac{6.63\times10^{-34}}{2\times3.14\times9.1\times10^{-31}\times10^{-8}}$$

$$\Delta v_{mi} = 1.16\times10^{5}\ m/sec$$

Answer :- minimum uncertainty in velocity = 1.16×10^{5} *m/s*

Q1](e) Explain the factors on which reverberation time depends . (3)

Ans:- *The most important factor in all regulations is reverberation time, which is defined as the time it takes for the sound pressure level to drop 60 dB below its original level.*

In most cases, a low reverberation time improves the acoustical comfort. In some situations, however, such as concerts or conference halls, a higher reverberation time can improve listening comfort.

Reverberation time depends on the size and shape of the space along with the amount, quality and positioning of absorbing surfaces within the space. The more sound absorption in the room, the lower the reverberation time.

Q1](f) Explain cavitation effect. (3)

Ans:- *Liquids contains microscopic bubbles of size* 10^{-9} *m to* 10^{-8} *m. ultrasonic waves propagates longitudinally through liquids. The molecules of the medium moves back and forth in the direction of propagation of the wave. This movement induces alternate regions of compression and rare fraction. A decrease in pressure at the area of rarefaction causes local boiling of the liquid. This causes an intense evaporation in the bubbles and the bubbles grow in size. The growth of the bubbles leads to their collapse within a very short span of one millisecond. The collapse of numerous bubbles results into a large number of shockwaves due to which the local temperature increases by about* 10^{4} *°C. The shock waves develop high crushing power of the liquid due to which the cavitation effect has applications like.*

1. *Ultrasonic cleaning.*
2. *Emulsification.*
3. *Alloy formation.*

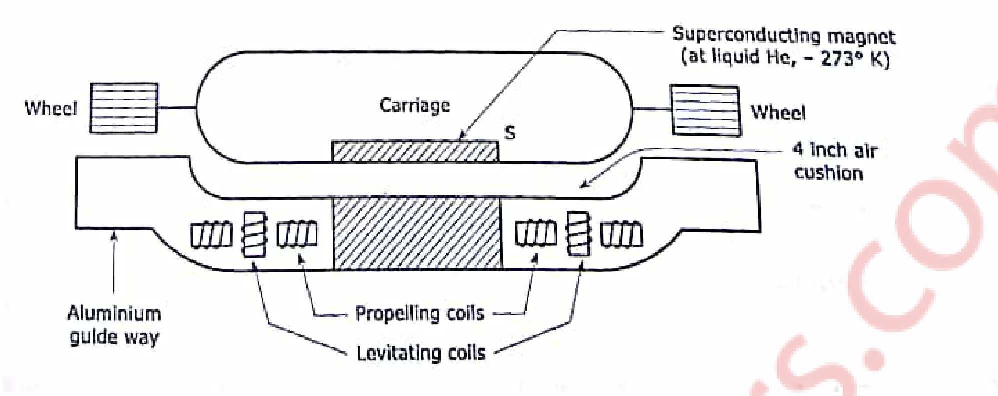
This method is also called as agglomeration.

Q1](g) What is Maglev? How it can have very high speed? (3)

Ans:- *MAGLEV is an acronym of magnetic levitation. The most spectacular applications of this would be maglev trains. The coaches of the train do not slide over steel rails but float on a four inch air cushion above the track using Meissner effect of super conducting magnets.*

The current flowing through its horizontal coils produce a vertical magnetic field. By Meissner effect the superconducting magnet S expels the vertical magnetic flux. This levitates the train and keeps it afloat the guide way, the horizontal coils are thus called levitating coils. On the other hand current passing through the vertical coil produce a horizontal magnetic field which pushes the train forward. Thus the vertical coils are called propelling coils.

The train is fitted with retractable wheels similar to the wheels of an aircraft. Once the train is levitated in air the wheels are retracted into the body and the train glides forward on the air cushion.

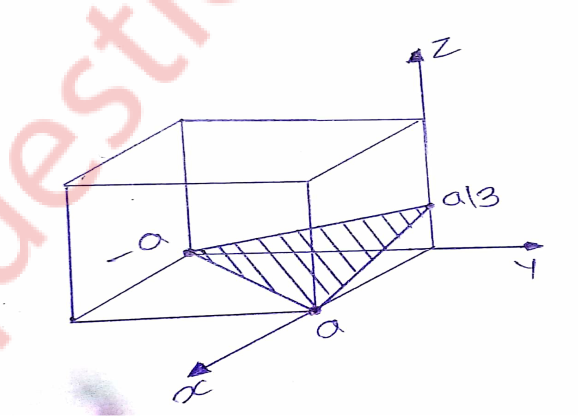


Q2](a) Draw the following : (1,-1,3) ,(2,0,0) , [0,0,-1]

An electron is accelerated through 1200 volts and is reflected from a crystal. The second order reflection occurs when glancing angle is 60°. Calculate the inter planar spacing of the crystal. (8)

Ans:- *1. Miller indices : (1 1 3)*

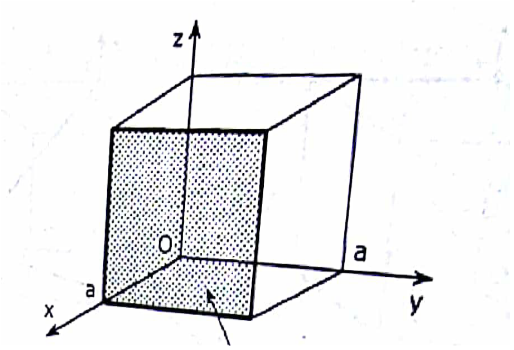
Intercepts : a , -a, a/3



2. Miller indices : (200) …………(can also be written as (100))

Reciprocals : 1, ∞ ,∞

Intercepts : a, ∞ ,∞



Q2](b) Explain the concept of fermi level. Prove that the Fermi level exactly at the centre of the Forbidden energy gap in intrinsic semiconductor. (7)

Ans:- *FERMI LEVEL*

Fermi level is not an allowed energy level it is an imaginary reference level used to specify other energy levels. Fermi level is defined as the highest filled energy level in any solid at absolute zero temperature.

Hence, at absolute zero temperature all energy levels below E_F *are empty for which the probability of occupancy can be written from Fermi-Dirac distribution function.*

At any temperature T>0K in an intrinsic semiconductor a number of electrons are found in the conduction band and the rest of the valence electrons are left behind in the valence band.

$$N = n_c + n_V$$

$$f(E_C) = \frac{1}{1+e^{(E_C-E_F)/kT}} \qquad \text{..........................}(1)$$

$$f(E_v) = \frac{1}{1+e^{-(E_C-E_F)/kT}} \qquad \text{..........................}(2)$$

$$n_V = Nf(E_v) = \frac{N}{1+e^{-(E_C-E_F)/kT}}$$

$$N = \frac{N}{1+e^{-(E_C-E_F)/kT}} + \frac{N}{1+e^{(E_C-E_F)/kT}}$$

$$1 = \frac{1}{1+e^{-(E_C-E_F)/kT}} + \frac{1}{1+e^{(E_C-E_F)/kT}}$$

$$1 = \frac{2+e^{(E_C-E_F)/kT}+e^{-(E_C-E_F)/kT}}{\left[1+e^{\frac{E_C-E_F}{kT}}\right]\left[1+e^{\frac{-E_C+E_F}{kT}}\right]}$$

Solving above equation using cross multiplication method.

$$e^{(E_C-2E_F+E_V)/kT} = 1$$

$$\frac{E_C - 2E_F + E_V}{kT} = 0$$

$$E_F = \frac{E_C + E_V}{2}$$

Hence it is proved that fermi energy level in intrinsic semiconductor is at the Centre of forbidden energy gap.

Q3](a) Find the following parameter for DC(Diamond Cubic) structure:- (8)

1. ***No. of atoms per unit cell.***
2. ***Co-ordination number.***
3. ***Nearest atomic distance.***
4. ***Atomic radius.***
5. ***APF.***

Ans:- *This can be thought of as a combination of two FCC sublattice as if one FCC sublattice is translated along a body diagonal of the other sublattice through a distance* $\sqrt{3}a/4$ *from one of its corners. Therefore in addition to regular FCC atoms additional atoms, one on each of the four body diagonals are found in this structure. Two FCC sublattice can form the DC structure.*

1. *NUMBER OF ATOMS/ UNIT CELL(n):-*

Total number of atoms/ unit cell = $(\frac{1}{8} \times 8 \text{ corners}) + \left(\frac{1}{2} \times 6 \text{ face corners}\right) + (4\times 1 \text{ on each body diagonal})$

$$\therefore n = 8$$

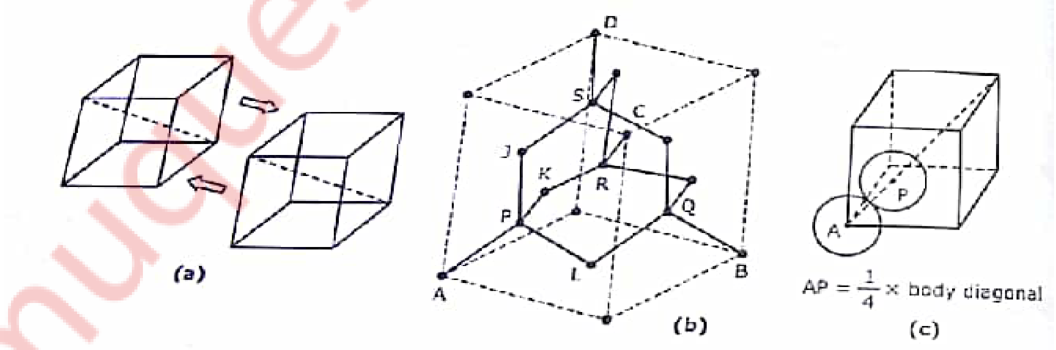


Figure 1.6 : Diamond Cubic Structure

2. *CO-ORDINATION NUMBER(N)*

Every atom with co-ordination (a/4, a/4, a/4) has four nearest neighbour, one at the nearest corner and three at the face centres of the three adjacent faces passing through the nearest corner. For example, the atom A, J, K and L are the nearest neighbours of the additional atom P. the five atoms A, J, K and P from a tetrahedron

$$\therefore N = 4$$

3. *ATOMIC RADIUS (r):-*

The distance between two nearest neighbours is

$$AP = \frac{\sqrt{3}a}{4} = 2r \qquad \therefore r = \frac{\sqrt{3}a}{8}$$

4. *ATOMIC PACKING FACTOR(APF):-*

$$APF = \frac{8\times\frac{4\pi}{3}(\frac{\sqrt{3}a}{8})^3}{a^3} = 0.34$$

Packing efficiency = 34%

Hence , it is a loosely packed structure. But as all the atoms are attached with covalent bonds this is a strong structure.

5. *VOID SPACE:-*

The void space in a DC unit cell is 66% of the entire cell structure.

Q3](b) Define drift current, diffusion current and P-N junction. The electrical conductivity of a pure silicon at room temperature is 4×10^{-4} mho/m . if the mobility of electron is 0.14m^2/V-S and that of hole is $0.04m^2$/V-S. calculate the intrinsic carrier density. (7)

Ans:- DRIFT CURRENT :-

Drift current is the electric current, or movement of charge carriers, which is due to the applied electric field, often stated as the electromotive force over a given distance.

DIFFUSION CURRENT:-

Diffusion current is a current in a semiconductor caused by the diffusion of charge carriers. This is the current which is due to the transport of charges occurring because of nonuniform concentration of charged particles in a semiconductor.

P-N JUNCTION:-

A diode is a PN junction with p-type on one side and n-type on the other. When a positive voltage is applied to the p-type side , it shrinks and overcomes the depletion zone, causing the current flow from the p-type to the n-type side.

NUMERICAL:-

Given Data :- $\sigma = 4\times10^{-4}$ *mho/m* , $\mu_e = 0.14m^2$/V-sec , $\mu_h = 0.04m^2$/V-S

Formula :- $\sigma_i = n_i(\mu_e + \mu_h).e$

Calculations :- $n_i = \dfrac{\sigma_i}{(\mu_e + \mu_h).e}$

$$= \frac{4\times10^{-4}}{1.6\times10^{-19}(0.14+0.040)}$$

$n_i = 1.388\times10^{16}/m^3$

Answer :- carrier concentration = $1.388\times10^{16}/m^3$

Q4](a) Distinguish between Type I and Type II superconductor. (5)

Ans:-

TYPE I SUPERCONDUCTOR	TYPE II SUPERCONDUCTOR
1. They exhibit complete Meissner effect .	1.They exhibit partial Meissner effect.
1. These are perfect diamagnetics.	2.These are not perfect diamagnetics.
2. These are known as soft superconductors.	3.These are known as hard superconductors.
3. They have only one critical magnetic field.	4.They have two critical magnetic fields.
4. These materials undergoes a sharp transition from the superconducting state of the normal state at the critical magnetic field.	5.These materials undergoes a gradual transition from the superconducting state to the normal state between the two critical magnetic fields.
5. The highest value of critical magnetic field is 0.1 wb/m^2.	6.The upper critical field can be of the order of 50 wb/ m^2.
6. Applications are very limited.	7.They are used to generate very high magnetic field.
7. Examples:- lead, tin, mercury , etc.	8.Examples:- alloys like Nb-Sn, Nb-Ti, Nb- Zr, etc.

Q4](b) A classroom has dimension $10\times8\times6 m^3$. the reverberation time is 3 sec. calculate the total absorption of surface and average absorption. (5)

Ans:- Given Data :- $V = 10\times8\times6 = 480 m^3$

$S = 2[(10\times8) + (8\times6) + (10\times6)] = 376\ m^3$

$T = 3$ sec.

Formula :- $T = 0.161\frac{V}{A} = 0.161\frac{V}{\alpha_{av}.S}$

Calculations:- $A = \frac{0.161 \times V}{T} = \frac{0.161 \times 480}{3} = 25.76$ *sabine*-m^2

$$\alpha_{av} = \frac{A}{S} = \frac{25.76}{376} = 0.068 \textit{ sabine.}$$

Answer :- *Total absorption , A = 25.76 sabine*-m^2

Average absorption coefficient, $\alpha_{av} = 0.068$ *sabine.*

Q4](c) Explain the principle, construction and working of a Magnetostriction Oscillator. (5)

Ans:- *This is based on the principle of magnetostriction effect.*

- *A ferromagnetic rod MN is clamped in the middle. Two coils* L_1 and L_2 *are wound round its two halves.*
- *The coil* L_1 *is connected in the plate – cathode circuit and the coil* L_2 *is connected in the grid cathode circuit of a triode valve oscillator.*
- *The capacitor C has a variable capacitance .*
- *As the circuit is switched on the plate current* I_p *starts flowing through coil* L_1 *producing a magnetic field B along the axis of the rod as shown:-*
- *Now the rod is placed in a magnetic field along its length as a result of which its overall length will change by a small amount.*
- *As the length changes the flux linked with* L_1 *and* L_2 *also changes giving rise to an induced emf , e= -dφ/dt across* L_2.
- *The induced emf is fed to the grid-cathode circuit and the oscillator valve gives an amplified alternating voltages as output to the plate-cathode circuit causing an alternating plate current.*
- *Due to the alternating current flowing through coil* L_1 *the magnetic field becomes an alternating magnetic field giving rise to the vibration of the rod.*
- *The frequency of mechanical vibration of the rod is given by*

$$f_{rod} = \frac{p}{2L}\sqrt{\frac{Y}{\rho}}$$

Where p = mode of vibration

L = length of the rod.

Y = Young's modulus of the material of the rod and,

density of the material of the rod.

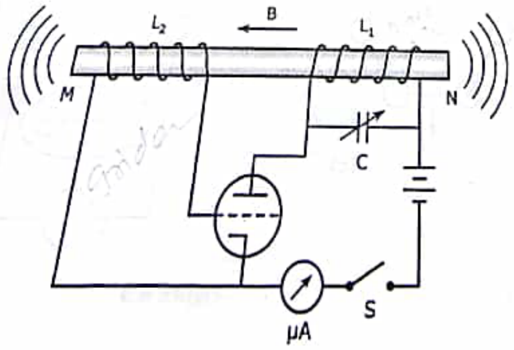


Figure 6.7 : Magnetostriction oscillator

For first harmonic p =1 and the frequency of vibration becomes

$$f_{rod} = \frac{p}{2L}\sqrt{\frac{Y}{\rho}}$$

The frequency of the triode valve oscillator is given by

$$f_{osc} = \frac{1}{2\pi\sqrt{L_1 C}}$$

By varying the capacitance C of the variable capacitor the oscillator frequency , f_{osc} *can be adjusted to the mechanical frequency of the rod* f_{rod}. *In the case*

$$f_{rod} = f_{osc}$$

And resonance takes place.

- *At resonance the rod vibrates vigorously emitting ultrasonic waves from both its ends.*
- *By adjusting the length of the rod and the capacitance of the variable capacitor ultrasonic waves of frequency up to 300KHz can be produced .*

Q5](a) Write Fermi Dirac distribution function. With the help of diagram. Explain the variation of Fermi level with temperature in n-type semiconductor. (5)

Ans:- *Each energy band in a crystal accommodates a large number of electron energy levels. According to Pauli's exclusion principle any energy level can be occupied by two electrons only, one spin up and down . however, all the available energy states are not filled in an energy band. The separation between the consecutive energy level is very small around* 10^{-27}eV *due to which the energy states are not filled in an energy band.*

FERMI DIRAC DISTRIBUTION FUNCTION.

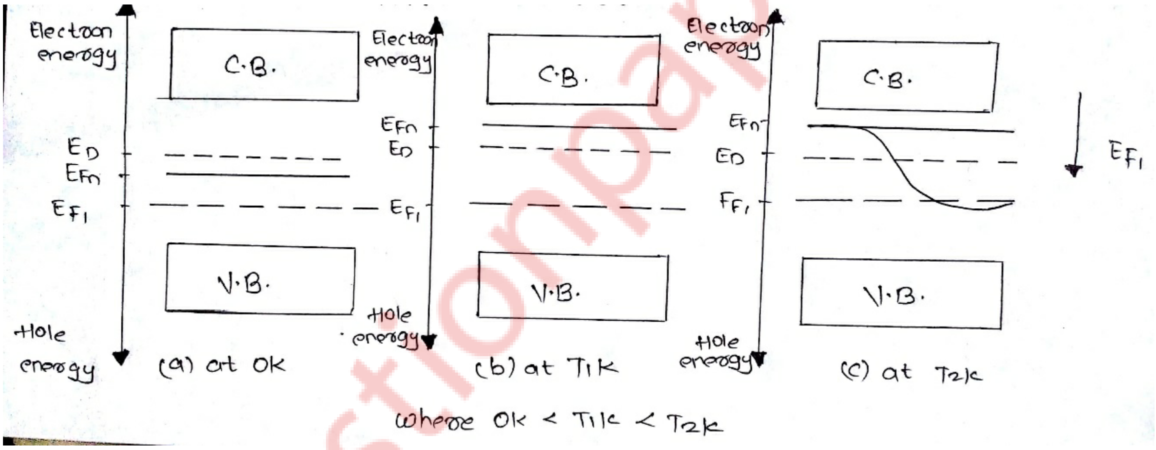
The carrier occupancy of the energy states is represented by a continuous distribution function known as the Fermi-Dirac distribution function, given by

$$f(E) = \frac{1}{1+e^{(E-E_F)/kT}}$$

This indicates the probability that a particular quantum state at the energy level E is occupied by an electron. Here k is Boltzmann's constant and T is absolute temperature of the semiconductor. The energy E_F *is called Fermi energy that corresponds to a reference level called Fermi level.*

IN n-TYPE SEMICONDUCTOR.

- *At 0K the fermi level* E_{Fn} *lies between the conduction band and the donor level.*
- *As temperature increases more and more electrons shift to the conduction band leaving behind equal number of holes in the valence band. These electron hole pairs are intrinsic carriers.*
- *With the increase in temperature the intrinsic carriers dominate the donors.*
- *To maintain the balance of the carrier density on both sides the fermi level* E_{Fn} *gradually shifts downwards.*
- *Finally at high temperature when the donor density is almost negligible* E_{Fn} *is very close to* E_{Fi}.



Q5](b)Derive Schrodinger time dependent wave equation for matter waves. (5)

Ans:- :- *For one dimensional case, the classical wave is described by the wave equation*

$$\frac{dy^2}{dx^2} = \frac{1}{v^2} \times \frac{d^2y}{dt^2}$$

where y is the displacement and v is the velocity of the wave travelling in a direction. The displacement of the particle at any instant 't', at any point 'x' in space

$$y(x, t) = Ae^{j(kx-\omega t)}$$

$$\text{where } \omega = 2\pi\vartheta \text{ and } k = 2\pi/\lambda$$

in analogy with this the wave function which describes the behaviour of the matter particle at any instant 't', at any point 'x' in space can be written as

$$\Psi(x,t) = Ae^{j(kx-\omega t)}$$

Where , $\omega = 2\pi\vartheta = 2\pi\frac{E}{h} = \frac{E}{\hbar}$

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

The total energy of the particle is given by

$$E = \text{kinetic energy} + \text{potential energy}$$

$$= \frac{1}{2}mv^2 + V = \frac{(mv)^2}{2m} + V$$

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

Operating this on the wave function Ψ(x, t) it is found that

$$E\Psi(x,t) = \frac{p^2}{2m}\Psi(x,t) + V\Psi(x,t)$$

Differentiating equation with respect to ‘x’ and ‘t’ it is obtained that

$$\frac{\partial^2\Psi(x,t)}{\partial x^2} = -p^2Ae^{j(kx-\omega t)} = -k^2\Psi(x,t)$$

Hence $\frac{p^2}{\partial t}\Psi(x,t) = -jA\omega e^{j(kx-\omega t)} = -j\omega\Psi(x,t)$

Hence the final equation is as follows:-

$$j\hbar\frac{\partial\Psi(x,t)}{\partial t} = -\frac{\hbar}{2m}\times\frac{\partial^2\Psi(x,t)}{\partial x^2} + V\Psi(x,t)$$

Or $-\frac{\hbar}{2m}\times\frac{\partial^2\Psi(x,t)}{\partial x^2} + V\Psi(x,t) = j\hbar\frac{\partial\Psi(x,t)}{\partial t}$

The first and the second term on the left hand side represents the kinetic and potential energies respectively of the particle and the right hand side represents the total energy.

This is called as the one dimensional time dependent Schrodinger equation.

Q5](c)Find the depth of sea water from a ship on the sea surface it the time interval of two seconds is required to receive the signal back. Given that: temperature of sea water is 20°C, salinity of sea water is 10gm/lit. (5)

Ans:- *Given Data :- t = 2sec , Temperature = 20°C,*

S = 10 gm/lit = 10 kg/m^3

Formula :- $d = \frac{\vartheta t}{2}$

$$\vartheta = 1510 + 1.14S + 4.21t - 0.037t^2$$

Calculations :- $\vartheta = 1510 + (1.14\times10) + (4.21\times20) - 0.037(20)^2$

$\vartheta =$ *1590.8m/s*

$D = \dfrac{1590.8\times2}{2}$ *= 1590.8 m*

Answer :- *Depth of sea water = 1590.8m*

Q6](a) Define the critical temperature. Slow that in the superconducting state the material is perfectly diamagnetic. (5)

Ans:- *The critical temperature is the transition temperature at which the normal state of a conductor changes to superconducting state.*

A superconducting material kept in a magnetic field expels the magnetic flux out its body when cooled below the critical temperature and exhibits perfect diamagnetism. This is called MEISSNER EFFECT.

- *It is found that as the temperature of the specimen is lowered to* T_c*, the magnetic flux is suddenly and completely expelled from it. The flux expulsion continues for* $T < T_c$*. The effect is reversible.*
- *When the temperature is raised from below* T_c*. The flux density penetrates the specimen again at* $T = T_c$ *and the material turns to the normal state.*
- *For the normal state the magnetic induction inside the specimen is given by:*

  $B = \mu_o(H+M) = \mu_0(1+\chi)H$………………………………………*(1)*

Here H is the applied magnetic field , m is the magnetization produced within the specimen , is χ *the susceptibility of the material and* μ_o *is the permeability of free space.*

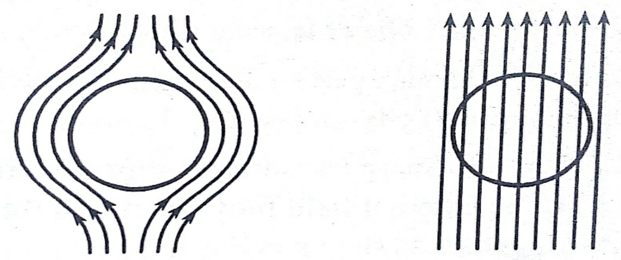
- *At* $T < T_c$ *as seen above*

  $B = 0$

  Hence equation (1) reduced to,

  $M = -H$

  And thus $\chi = \dfrac{M}{H} = -1$
- *The specimen is therefore a perfect diamagnetic. The diamagnetism produces strong repulsion to the external magnets.*
- *This effect is used to identify a superconductor , in levitation effect and suspension effect.*



(a) Superconducting state at $T < T_C$ or $H < H_C$ (b) Normal state at $T > T_C$ or $H > H_C$

Q6](b) In a solid the energy level is lying 0.012 eV below Fermi level. What is the probability of this level not being occupied by an electron 27°C? (5)

Ans:- Data :- $E_F - E = 0.012\text{eV}$, $T = 27^\circ C = 300K$

$$K = 1.38 \times 10^{-23} \text{J/K} = \frac{1.38\times10^{-23}}{1.6\times10^{-19}} = 86.25\times 10^{-6}\text{eV/K}$$

Formula :- $f(E_C) = \dfrac{1}{1+e^{(E_C-E_F)/kT}}$

Calculations :- Total probability = 1

Probability of occupying an energy state + Probability of not occupying the energy state = 1.

$f(E)$ + Probability of not occupying the energy state = 1

Probability of not occupying the energy state = 1- $f(E)$

Here $f(E) = \dfrac{1}{1+e^{(E-E_F)/kT}} = \dfrac{1}{1+e^{(0.012/86.25\times10^{-6}\times300)}} = 0.386$

Hence, 1- f(E) = 1-0.386 = 0.614

Answer :- Probability of not occupying = 0.614

Q6](c) What is the wavelength of a beam of neutron having:

1. **An energy of 0.025 eV?**
2. **An electron and photon each have wavelength of 2A°. what are their momentum and energy ? $m_n = 1.676\times10^{-27}$ kg, $h = 6.625\times10^{-34}$ J-sec. (5)**

Ans:- 1. Given Data :- energy of neutron = 0.025eV.

To find :- wavelength of a beam.

Calculation :- $\lambda = \dfrac{h}{\sqrt{2meV}}$

$$= \frac{6.626\times10^{-34}}{\sqrt{2\times1.676\times10^{-27}\times0.025\times10^{-19}\times1.6}}$$

= 1.8095 A°.

Hence wavelength is equal to = 1.8095 A°.

2.Given Data :- $\lambda = 2A°$, $m_n = 1.676\times10^{-27}$ *kg,* $h = 6.625\times10^{-34}$ *J-sec.*

To find :- *momentum and energy.*

Calculations :- $\lambda = \frac{h}{p}$, ………………….(for momentum)

$$2\times10^{-10} = \frac{6.625\times10^{-34}}{p}$$

$P = 3.3125\times10^{-24}$ *kg-m/sec.*

$$\lambda = \frac{h}{\sqrt{2mE}}$$

$$2\times10^{-10} = \frac{6.625\times10^{-34}}{\sqrt{2\times1.676\times10^{-27}\times E}}$$

$E = 5.721\times10^{-11}$ *joules.*

Hence momentum = 3.3125 $\times10^{-24}$ *kg-m/sec. and energy is = 5.721* $\times10^{-11}$ *joules.*

APPLIED PHYSICS 1

(CBCGS DEC-2017)

Q1](a) 'Crystal acts as three dimensional grating for X-rays', explain. (3)

Ans:- *Crystal act as three dimensional grating with X-rays*

1. *Since the wavelength of X-rays is in the order of 1 A° , ordinary grating which has 6000 lines per cm cannot produce an appreciable diffraction pattern of X-rays.*
2. *Therefore, in the case of X-rays, instead of ordinary grating crystals gratings are used. In crystal grating atoms are arranged at lattice points in a regular fashion.*
3. *These arranged atoms correspond to grating lines and the distance between two atoms is the grating element, in the order of le cm.*
4. *The crystal grating differs from optical grating in such a way that in crystal grating, the atomic centres are not in one plane but are distributed in 3-dimensional space. But in optical grating, they are limited to one plane.*
5. *Hence, crystal act as three dimensional grating with X-rays*

Q1](b) Calculate the frequency and wavelength of photon whose energy is 75eV. (3)

Ans:- *Given Data* :- $E = 75eV = 75\times1.6\times10^{-19} = 1.20\times10^{-17}$

Formula :- $E = \frac{1}{2}mv^2$, $\lambda = \frac{h}{mv} = \frac{h}{p}$

Calculations :- $E = \frac{1}{2}mv^2 = \frac{(mv)^2}{2m} = \frac{h^2}{2m\lambda^2}$

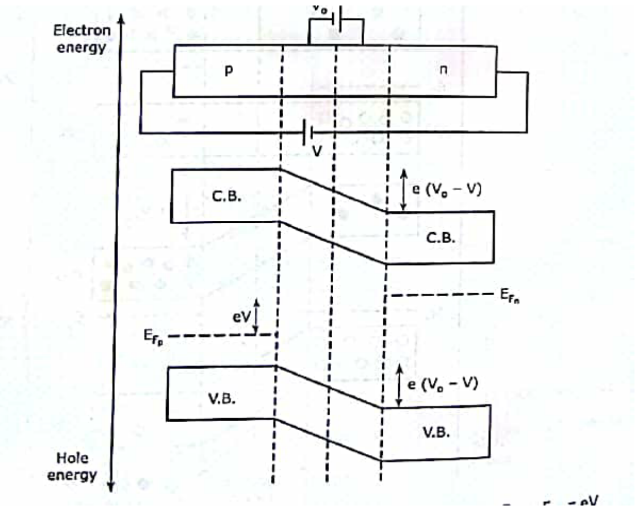
$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.20\times10^{-17}}} = 1.41\ A°$$

wavelength = 1.41 A°

$$\text{frequency} = \frac{1}{\lambda} = 7.048\times10^{9}$$

Q1](c) Draw the energy band diagram of p-n junction diode in forward and reverse bias condition. (3)

Ans:- *Forward biasing increases the electron density in the conduction band of the n-side. As a result the fermi level moves upwards. Similarly due to the increase in the hole density in the valence band of the p side , the fermi level moves downwards. The fermi levels and are displaced relatively by an amount eV equal to the potential energy due to the applied voltage, V which cause the displacement.*

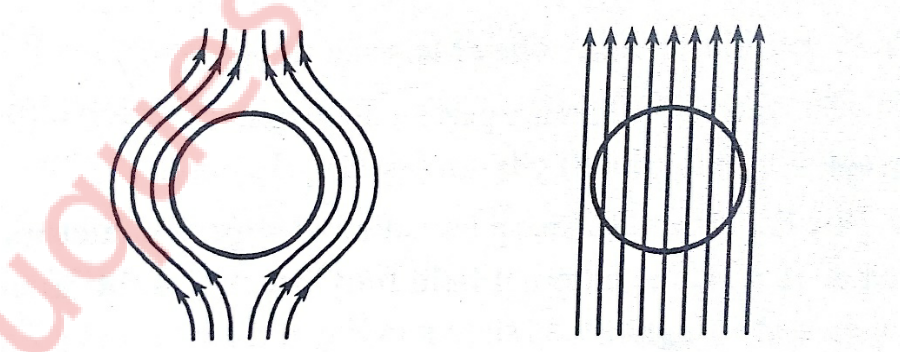


The height of the conduction hill reduces by the same amount eV and becomes e$(V_o - V)$*. Similarly the height of the valence hill becomes -e*$(V_o - V)$*. This makes the charge flow through the junction easier.*

Q1](d) "Superconductor is a perfect diamagnetic", Explain . (3)

Ans:- *A superconducting material kept in a magnetic field expels the magnetic flux out its body when cooled below the critical temperature and exhibits perfect diamagnetism. This is called MEISSNER EFFECT.*

- *It is found that as the temperature of the specimen is lowered to* T_c*, the magnetic flux is suddenly and completely expelled from it. The flux expulsion continues for* $T < T_c$*. The effect is reversible.*
- *When the temperature is raised from below* T_c*. The flux density penetrates the specimen again at* $T = T_c$ *and the material turns to the normal state.*



(a) Superconducting state at $T < T_C$ or $H < H_C$ **(b)** Normal state at $T > T_C$ or $H > H_C$

- *For the normal state the magnetic induction inside the specimen is given by:*

  $B = \mu_o(H+M) = \mu_0(1+\chi)H$……………………………………………*(1)*

Here H is the applied magnetic field , m is the magnetization produced within the specimen , is χ *the susceptibility of the material and* μ_o *is the permeability of free space.*

- *At* $T < T_c$ *as seen above*

B = 0

Hence equation (1) reduced to,

M = -H

And thus $\chi = \frac{M}{H} = -1$

- *The specimen is therefore a perfect diamagnetic. The diamagnetism produces strong repulsion to the external magnets.*
- *This effect is used to identify a superconductor , in levitation effect and suspension effect.*

Q1](e) What is reverberation time? How is it important? Write the factors affecting Reverberation time. (3)

Ans:- *In reverberation sound produced in an enclosure continues to be heard for some time. A sound produced in a room undergoes multiple reflections from the walls, the floor and the ceiling before becoming inaudible. The prolongation of sound in an enclosed place even when the sound source has stopped is called reverberation.*

The time taken by the sound to fall from its average intensity to inaudibility is called the reverberation time. It is also defined as time during which the sound intensity falls from its steady state value to its one-millionth value after the source is shut off

$$\therefore \frac{I}{I_0} = 10^{-6}$$

And from equation it, is found as ,

$$L = -60 \text{ dB}$$

Thus during reverberation time the intensity level drops by 60 dB.

Q1(f) A quartz crystal of thickness 1.5mm is vibrating with resonance. Calculate it's fundamental frequency if the Young's modulus of quartz crystal is 7.9×10^{10} **N/**m^2 **and density is 2650 kg/**m^3**. (3)**

Ans:- *Given Data* :- $t_1 = 1mm = 10^{-3}mm$ $Y = 7.9 \times 10^{10} N/m^2$

$\rho = 2650 \ kg/m^3$

Formula :- $f = \frac{1}{2t}\sqrt{\frac{Y}{\rho}}$

Calculations :- $f = \frac{1}{2 \times 10^{-3}} \sqrt{\frac{7.9 \times 10^{10}}{2650}} = 2.73 \text{ MHz}$

Answers :- Frequency = 2.73 MHz

Q1](g) Mobility's of electron and hole in a sample of Ge at room temperature are 0.36m^2/V-sec and 0.17m^2/V-sec respectively. If electron and hole densities are equal and it is 2.5 $\times 10^{13}/\text{cm}^3$, calculate its conductivity. (3)

Ans:- *Data :-* μ_e *= 0.36* m^2*/V-sec* μ_h *= 0.17*m^2*/V-sec T =300°K*

$$n_i = 2.5\times10^{13}/\text{cm}^3 = 2.5\times10^{19}\text{m}^3$$

Formula :- $\sigma = n\left(\mu_e - \mu_h\right).\, e$

Calculations :- $\sigma = 2.5\times10^{19}(0.36 + 0.17)\times1.6\times10^{-19}$

$$= 2.12 \text{ mho/metre}$$

Answer :- $\sigma =$ *conductivity =* 2.12 mho/metre

Q2](a) With Heisenberg's uncertainty principle prove that electron cannot survive in nucleus. An electron has a speed of 300m/sec. with uncertainty of 0.01% . find the accuracy in its position. (8)

Ans:- *Initially assume that an electron is a part of a nucleus. The size of a nucleus is about 1 fermi =* 10^{-15}*m if an electron is confined within a nucleus the uncertainty in its position must not be greater than the dimension of the nucleus i.e.,* 10^{-15}*m. hence,*

$$\Delta x_m = 10^{-15} m$$

From the limiting condition of Heisenberg's uncertainty principle given in the equation it can be written as

$$\Delta x_m . \Delta p_{mi} = \hbar$$

$$\Delta p_{mi} = \frac{\hbar}{\Delta x_{mi}} = \frac{6.63\times10^{-34}}{2\times3.14\times10^{-15}} = 1.055\times10^{-19} \text{ kg-m/sec}$$

$$\text{Now},\ \Delta p_{mi} = m\Delta v_{mi}$$

$$\text{Hence},\quad \Delta v_{mi} = \frac{\Delta p_{mi}}{m} = \frac{1.055\times10^{-19}}{9.1\times10^{-31}} = 1.159\times10^{11} m/s > c$$

$$\text{As},\ \Delta v_{mi} < v,\ v > 1.159\times10^{11} m/s > c$$

Therefore the electron inside the nucleus behaves as a relativistic particle.

The relativistic energy of the electron is $E = \sqrt{m_o^2c^4} + \sqrt{p^2c^2}$

Since the actual momentum of the electron p>> $\Delta p_{mi}.p^2.c^2 \gg m_o^2.c^2$*, the rest mass energy of the electron the value of which is 0.511 MeV. Hence, E= pc*

Assuming p = Δp_{mi} *the least energy that an electron should posses within a nucleus is given by*

$$E_{mi} = \Delta p_{mi}.c$$

$$= 1.055\times10^{-19}\times3\times10^{8}$$

$$= 3.165\times10^{-11} J$$

$$E_{mi} = \frac{3.165\times10^{-11}}{1.6\times10^{-19}} = 197\ MeV.$$

In reality the only source of generation of electron with in a nucleus is the process of β-decay. The maximum kinetic energy possessed by the electrons during β-decay is about 100KeV. This shows that an electron can not exist within a nucleus.

NUMERICAL:-

Given Data :- $V = 300 m/sec, \quad \frac{\Delta v}{v} = 0.01\ \%$

Formula :- $\Delta x.\Delta p \ge \hbar$

Calculations :- $\Delta x.m.\Delta p \ge \hbar$

$$\Delta v = 300\times\frac{0.01}{100} = 0.03$$

$$\Delta x \ge \frac{\hbar}{m\Delta v} \ge \frac{6.63\times10^{-34}}{2\times3.14\times9.1\times0.03\times10^{-31}}$$

$$\ge 3.8\times10^{-3}$$

Therefore uncertainty in position $= 3.8\times10^{-3} m$

Q2](b) Show that fermi energy level in intrinsic semiconductor is at the Centre of forbidden energy gap.

What is the probability of an electron being thermally excited to the conduction band in Si at 30°C. The band gap energy is 1.12 eV. (7)

Ans:- *At any temperature T>0K in an intrinsic semiconductor a number of electrons are found in the conduction band and the rest of the valence electrons are left behind in the valence band.*

$$N = n_c + n_V$$

$$f(E_C) = \frac{1}{1+e^{(E_C-E_F)/kT}} \quad \text{.........................(1)}$$

$$f(E_v) = \frac{1}{1+e^{-(E_C-E_F)/kT}} \quad \text{.........................(2)}$$

$$n_V = Nf(E_v) = \frac{N}{1+e^{-(E_C-E_F)/kT}}$$

$$N = \frac{N}{1+e^{-(E_C-E_F)/kT}} + \frac{N}{1+e^{(E_C-E_F)/kT}}$$

$$1 = \frac{1}{1+e^{-(E_C-E_F)/kT}} + \frac{1}{1+e^{(E_C-E_F)/kT}}$$

$$1 = \frac{2+e^{(E_C-E_F)/kT}+e^{-(E_C-E_F)/kT}}{\left[1+e^{\frac{E_C-E_F}{kT}}\right]\left[1+e^{\frac{-E_C+E_F}{kT}}\right]}$$

Solving above equation using cross multiplication method.

$$e^{(E_C-2E_F+E_V)/kT} = 1$$

$$\frac{E_C-2E_F+E_V}{kT} = 0$$

$$E_F = \frac{E_C+E_V}{2}$$

Hence it is proved that fermi energy level in intrinsic semiconductor is at the Centre of forbidden energy gap.

NUMERICAL:-

Given Data :- $T = 30°C = 303K$ $E_g = 1.12 eV$

$$K = 1.38\times10^{-23} J/K = \frac{1.38\times10^{-23}}{1.6\times10^{-19}} = 86.25\times10^{-6} eV/K$$

Formula :- $f(E_C) = \dfrac{1}{1+e^{(E_C-E_F)/kT}}$

Calculations :- *Si is an intrinsic semiconductor. Hence,*

$$E_C - E_F = \frac{E_g}{2} = 0.56 \text{ eV}$$

$$f(E_C) = \frac{1}{1+\exp\left(\frac{0.56}{86.25\times10^{-6}\times303}\right)} = 4.9\times10^{-10}$$

probability = 4.9×10^{-10}.

Q3](a) With neat diagram of unit cell , explain the structure of HCP crystal and calculate the no. of ions per unit cell, co ordination no., lattice constant and packing factor of the structure. **(8)**

Ans:- *This is the most common metallic structure exhibited by about twenty five metals, this structure has atomic arrangement in three layers as shown :-*

STRUCTURE:-

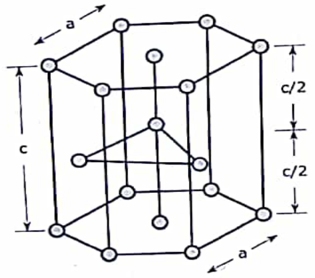


Figure 1.9 (a) : HCP structure

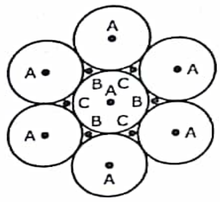


Figure 1.9 (b) : Atomic arrangement of HCP structure

- *In the bottom layer the central atom is surrounded by six other identical atoms. The positions of these seven atoms are marked by A.*
- *In the middle layer at height c/2 three atoms are positioned either at point B or at point C.*
- *In the top layer at height C atomic distribution is similar to that of the bottom layer i.e., at point A.*

NUMBER OF ATOMS/UNIT CELLS:-

Each corner atom is shared by 6 neighbouring unit cells. Hence each corner carriers (1/6)th of an atom as shown:-

Each face centre carriers ½ atom. In the middle layer there are three atoms. Hence total number of atoms/unit cells are

$$n = 2\left(6\times\frac{1}{6}\right) + 2\left(\frac{1}{2}\right) + 3 = 6$$

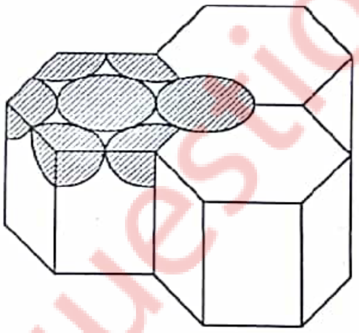


Figure 1.10 (a)

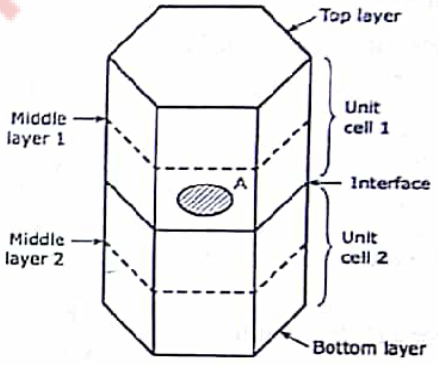


Figure 1.10 (b)

COORDINATION NUMBER:-

Consider the face centred atom A of the interface of two adjacent unit cells. It touches six corner atoms of the interface three atoms of the middle layer of the upper unit cell and three atoms of the middle layer of the lower unit cell .

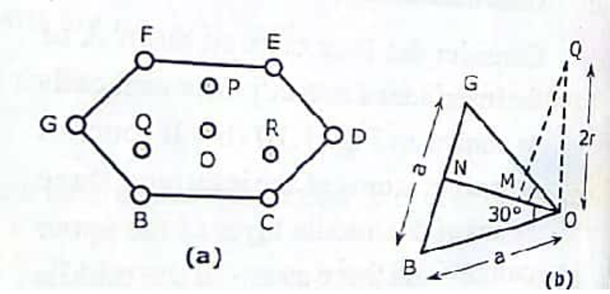
Hence , coordination number = 3(of middle layer 1) + 6(of the interface)+ 3(of middle layer 2).

Therefore co-ordination number of HCP structure = 12.

ATOMIC PACKING FRACTION:-

1. *Calculation of c/a :-*

Consider the bottom layer of the unit cell shown. The atom are marked as B, C, D, E, F, G and O. the middle layer at height. c/2 consists of atoms marked as P, Q, and R. where a triangle is formed by joining O, B and G. this is an equilateral triangle of side a.



Consider the middle layer atom Q which touches the face centred atom O. hence ,

$$OQ = 2r.$$

Draw a perpendicular QM from Q on ON. OM is the height of Q from the bottom layer. Hence = c/2

Since M is the orthocentre of Δ OBG.

$$OM = \frac{2}{3}ON = \frac{2}{3}a\cos 30° = \frac{2}{3}a\frac{\sqrt{3}}{2} = \frac{a}{\sqrt{3}}$$

In Δ OQM $$OQ^2 = QM^2 + OM^2$$

$$(2r)^2 = \left(\frac{c}{2}\right)^2 + \left(\frac{a}{\sqrt{3}}\right)^2$$

As $r = \frac{a}{2}$. *This can be written as*

Therefore , $a^2 = \left(\frac{c}{2}\right)^2 + \left(\frac{a}{\sqrt{3}}\right)^2$

$$\boxed{\text{Hence } \frac{c}{a} = \sqrt{\frac{8}{3}}}$$

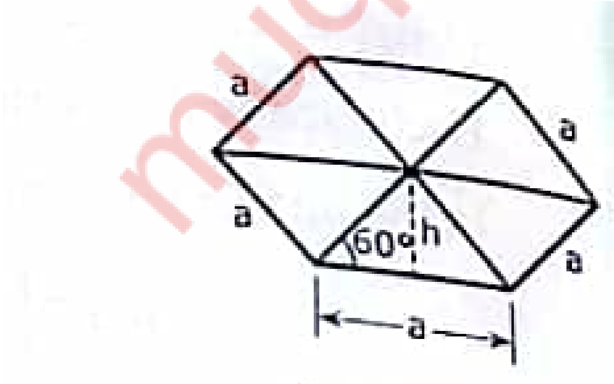


Figure 1.10 (d)

$$\text{APF} = \frac{n \times \frac{4}{3} \times \pi \times r^3}{\text{volume of the unit cell}}$$

As seen in figure, area of the hexagonal face = 6 × area of equilateral triangle

$$= 6 \times \frac{1}{2} ah \quad = 3a \times a \sin 60°$$

$$= \frac{3\sqrt{3}}{2} a^2$$

Volume of the unit cell = Area × Height $= \frac{3\sqrt{3}}{2} a^2 c$

For a HCP unit cell $\frac{c}{a} = \sqrt{\frac{8}{3}}$

Hence volume of the unit cell $= \frac{3\sqrt{3}}{2} a^3 \frac{c}{a} = 3\sqrt{2}a^3$

Therefore APF $= \frac{6 \times (\frac{4}{3}) \pi (\frac{a}{2})^3}{3\sqrt{2}a^3} = \frac{\sqrt{2}}{6} \pi = 0.74$

3](b) State the Hall effect. Derive the expression for Hall coefficient with neat diagram. (7)

Ans:- *if a current carrying conductor or semiconductor is placed in a transverse magnetic field, a potential difference is developed across the specimen in a direction perpendicular to both the current and magnetic field. The phenomenon is called HALL EFFECT.*

As shown consider a rectangular plate of a p-type semiconductor of width 'w' and thickness 'd' placed along x-axis. When a potential difference is applied along its length 'a' current 'I' starts flowing through it in x direction.

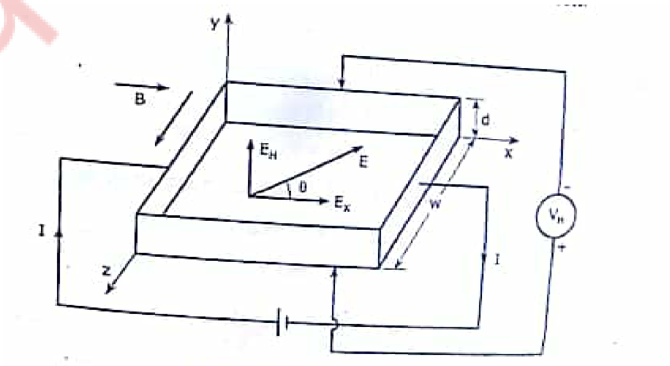


Figure 3.25 : Hall effect set up

As the holes are the majority carriers in this case the current is given by

$$I = n_hAev_d \qquad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where n_h *= density of holes*

A = w × d = cross sectional area of the specimen

v_d *= drift velocity of the holes.*

The current density is

$$J = \frac{I}{A} = n_hev_d \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

The magnetic field is applied transversely to the crystal surface in z direction. Hence the holes experience a magnetic force

$$F_m = ev_dB \qquad \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

In a downward direction. As a result of this the holes are accumulated on the bottom surface of the specimen.

Due to this a corresponding equivalent negative charge is left on the top surface.

The separation of charge set up a transverse electric field across the specimen given by,

$$E_H = \frac{V_H}{d} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where V_H is called the HALL VOLTAGE and E_H *the HALL FIELD.*

In equilibrium condition the force due to the magnetic field B and the force due to the electric field E_H *acting on the charges are balanced. So the equation (3)*

$$eE_H = ev_dB$$

$$E_H = v_dB \qquad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Using equation (4) in the equation (5)

$$V_H = v_dB\,d \qquad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

From equation (1) and (2), the drift velocity of holes is found as

$$v_d = \frac{I}{en_hA} = \frac{J}{en_h} \qquad \ldots\ldots\ldots\ldots\ldots(7)$$

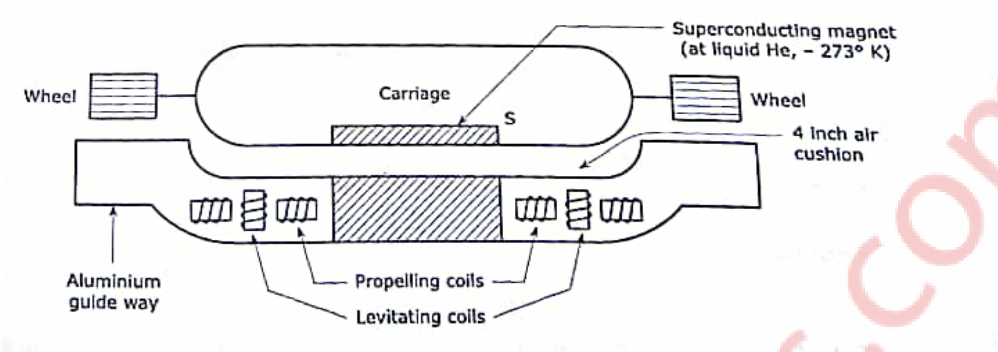
Hence hall voltage can be written $\boxed{V_H = \frac{IBd}{en.\,A} = \frac{J_xBd}{en.}}$ *as*

An important parameter is the hall coefficient defined as the hall field per unit current density per unit magnetic induction.

$$\boxed{R_H = \frac{E_H}{J_xB}}$$

Q4](a) What is the working principle of maglev? Explain how it can acquire high speed? (5)

Ans:- *MAGLEV is an acronym of magnetic levitation. The most spectacular applications of this would be maglev trains. The coaches of the train do not slide over steel rails but float on a four inch air cushion above the track using Meissner effect of super conducting magnets.*



- *The train has a superconducting magnet built into the base of the carriages.*
- *An aluminium guide way is laid on the ground and carriers electric current.*
- *The walls of the guide way have a series of horizontal and vertical coils mounted inside the guide way. These coils are made up of normal conductors*
- *The current flowing through its horizontal coils produce a vertical magnetic field. By Meissner effect the superconducting magnet S expels the vertical magnetic flux. This levitates the train and keeps it afloat the guide way, the horizontal coils are thus called levitating coils.*
- *On the other hand current passing through the vertical coil produce a horizontal magnetic field which pushes the train forward. Thus the vertical coils are called propelling coils.*
- *The train is fitted with retractable wheels similar to the wheels of an aircraft. Once the train is levitated in air the wheels are retracted into the body and the train glides forward on the air cushion.*
- *When the train is to be halted the current through the levitating and propelling coils are switched off. The train descends slowly on to the guide way and runs some distance on it till it stops.*
- *The utility of such levitation is that in the friction the energy loss is minimized allowing the speed of the train rise up to 581 kmph.*

Q4](b) A hall of dimension $25 \times 18 \times 12\ \mathrm{m}^3$ ***has an average absorption coefficient 0.2. find the reverberation time. If a curtain cloth of area 150*** m^2 ***is suspended at the Centre of hall with coefficient of absorption 0.75, what will be the reverberation time***

(5)

Ans:- *Given Data :- volume of hall =* $25 \times 18 \times 12$ *= 5400*

$\alpha = 0.75$ $\alpha_{av} = 0.2$ $S_{curtain} = 100 \text{ m}^2$

Formula :- $T_1 = 0.161 \times \dfrac{V}{\alpha_{av} \times S}$

$$T_2 = 0.161 \times \frac{V}{\alpha_{av} \times S + \alpha_{curtain} \times S'}$$

Calculate :- $S = 2[(20 \times 15)+(15 \times 10)+(10 \times 20)] = 1300 \text{m}^2$

$V = 20 \times 15 \times 10 = 3000 \text{ m}^2$

$T_1 = 0.161 \times \dfrac{3000}{0.1 \times 1300}$ = *3.7 sec.*

∴ *Absorption takes place by both the surfaces of the curtain*

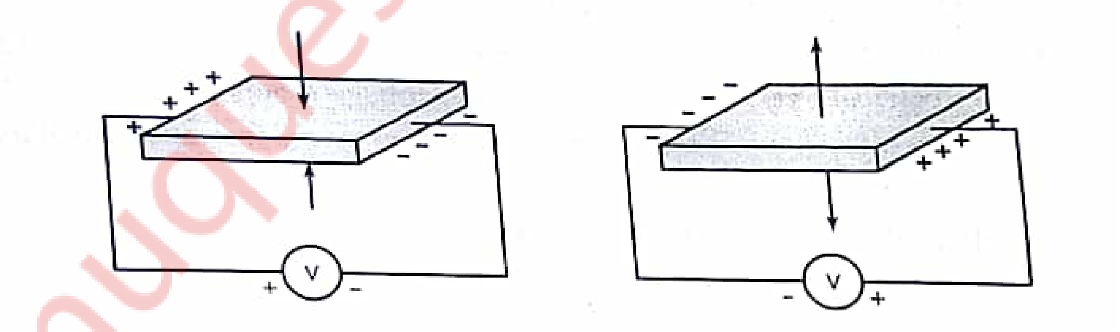
$S' = 2 \times 100 \text{ m}^2 = 200 \text{ m}^2$

$$T_2 = 0.161 \times \frac{3000}{(0.1 \times 1300)+(0.66 \times 200)} = 1.84 \text{ sec}$$

Answer :- Change in reverberation time = 1.85 sec.

Q4](c) State the piezoelectric effect. With neat circuit diagram explain the principle and working of piezoelectric oscillator. (5)

Ans:- *The piezoelectric crystals e.g., quarts , tourmaline etc have a very special characteristics. Thin slices of these crystals develop a potential difference across the two opposite faces when subjected to a mechanical stress in a perpendicular direction. This is known as DIRECT PIEZOELECTRIC EFFECT. If the direction of the mechanical stress is reversed the potential difference changes its polarity as:-*



PIEZOELECTRIC EFFECT:

Construction:-

- *Piezoelectric oscillator consists of two circuits interacting with each other by means of mutual inductance between inductors L, L1L1, and L2L2.*
- *A DC supply is connected to a tank circuit consisting of a variable capacitor (C) and an inductor L2L2.*
- *The tank circuit is connected to collector terminal of an NPN transistor.*

- *The base terminal of the transistor is connected to another coil L2L2, which is connected to ground on the other end along with emitter terminal of transistor and negative terminal of the DC supply.*

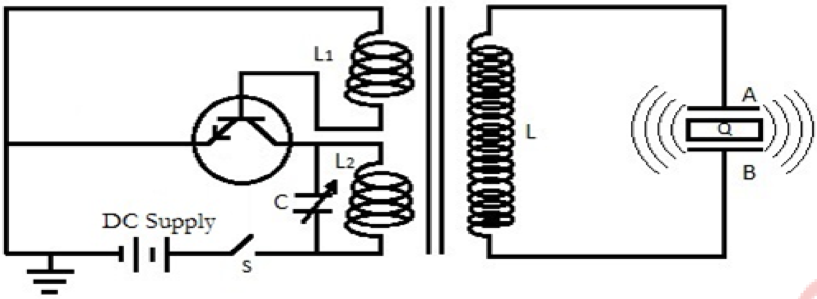


Fig. 7.1: Piezoelectric Oscillator

Working:-

- *A variable capacitor (C) and an inductor (L2)(L2) form a tank circuit.*
- *The frequency of the oscillations can be changed by changing the value of capacitance.*
- *When the circuit is closed, the current flows through the circuit and charges the capacitor.*
- *Then the capacitor starts discharging through the inductor, thus the electric energy is stored in the form of electric and magnetic field of capacitor and inductor respectively.*
- *Thus electric oscillations are produced in the tank circuit.*
- *The frequency of this oscillating electricity is given by*

  f=12πL2C√f=12πL2C
- *With the help of the other electronic components including a transistor, electrical oscillations are produced continuously.*
- *This is fed to the secondary circuit connected to Quartz crystal (Q).*
- *The oscillating electric field is converted to mechanical vibration of crystal owing to the piezoelectric effect.*
- *This vibration produces sound wave of the frequency equal to the frequency of vibration, which is the frequency of electric oscillations.*
- *In this way ultrasonic sound waves can be produced.*
- *Natural frequency of crystal is given by*

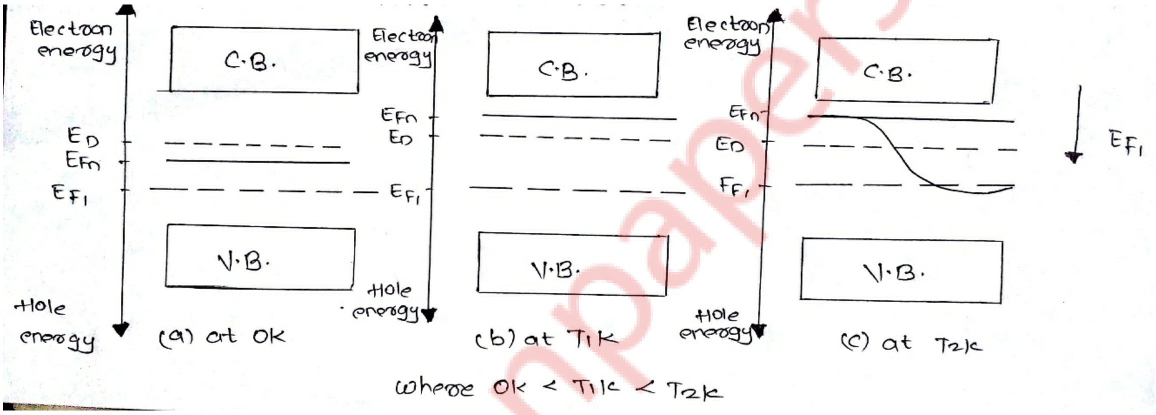
$$f = \frac{k}{2t}\sqrt{\frac{Y}{\rho}}$$

  - *t = Thickness of crystal slab*
  - *Y = Young's Modulus*
  - *ρ = Density*
  - *k = 1, 2, 3, ... (Integer Multiple)*
- *When the frequency of electric oscillations is equal to that of natural frequency of the crystal, resonance is achieved and the sound waves of maximum amplitude are produced.*

Q5](a) With energy band diagram ,explain the variation of fermi energy level with temperature in extrinsic semiconductor. ***(5)***

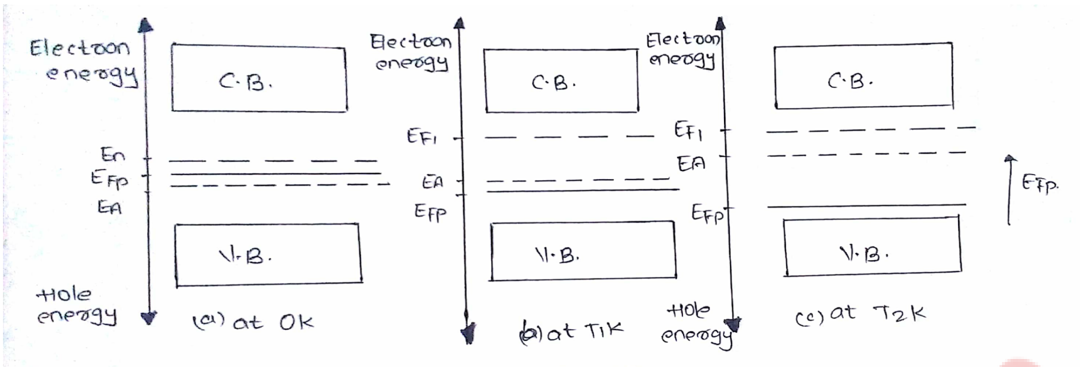
Ans:- *IN n-TYPE SEMICONDUCTOR.*

- *At 0K the fermi level* E_{Fn} *lies between the conduction band and the donor level.*
- *As temperature increases more and more electrons shift to the conduction band leaving behind equal number of holes in the valence band. These electron hole pairs are intrinsic carriers.*
- *With the increase in temperature the intrinsic carriers dominate the donors.*
- *To maintain the balance of the carrier density on both sides the fermi level* E_{Fn} *gradually shifts downwards.*
- *Finally at high temperature when the donor density is almost negligible* E_{Fn} *is very close to* E_{Fi}.



IN p-TYPE SEMICONDUCTOR.

- *At 0K the fermi level* E_{Fp} *in a p-type semiconductor lies between the acceptor level and the valence band.*
- *With the increase in temperature more and more holes are created in the valence band as equal number of electrons move to the conduction band.*
- *As temperature increases the intrinsic holes dominate the acceptor holes.*
- *Hence the number of intrinsic carriers in the conduction band and in the valence band become nearly equal at high temperature.*
- *The fermi level* E_{Fp} *gradually shifts upwards to maintain the balance of carrier density above and below it.*
- *At high temperature when the acceptor density become insignificant as compared to the intrinsic density,* E_{Fp} *is positioned very close to the intrinsic fermi level* E_{Fi} *but little below it.*



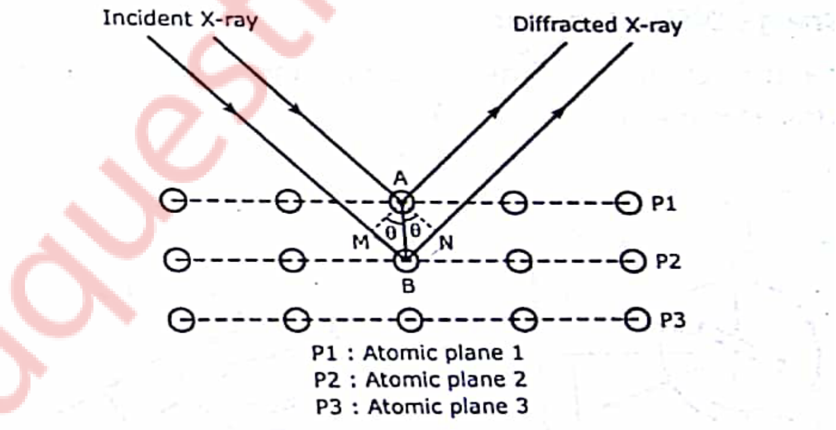
Where 0K < T1K < T2K

Q5](b) Explain with example how to determine crystal structure by Bragg's X-ray spectrometer. (5)

Ans:- *W.L Bragg's explained the phenomenon of X-ray diffraction from a single crystal shown as follows*

When a beam of X-rays is incident on a crystal it is scattered by individual atoms of the rich atomic planes. Thus, each atom become a source of scattered radiation. The atomic planes responsible for the X-ray diffraction are called BRAGG'S PLANES. Therefore the sets of Braggs planes constitute the crystal grating. Bragg's scattering or Bragg's diffraction is also referred as Braggs reflection. Bragg derived a law called Bragg's law to explain the X-ray diffraction effect.

Here a beam of X-ray is incident on a set of parallel planes of a crystal. The rays makes a glancing angle θ and are practically reflected from different successive planes. The phase relationship of the scattered rays can be determined from their path differences. Here two parallel X-rays are reflected from two consecutive planes PI and P2. The path differences between then as shown



$$\delta = MB + BN = 2MB = 2AB\sin\theta$$

Here AB = d, the interplanar spacing of the crystal. Hence,

$$\delta = 2d\sin\theta$$

The two diffracted rays reinforce each other when they interfere constructively when their path difference δ *is equal to* $n\lambda$

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

This is called Bragg's law.

Q5](c) Obtain one dimensional time dependent Schrodinger equation . (5)

Ans:- *For one dimensional case, the classical wave is described by the wave equation*

$$\frac{dy^2}{dx^2} = \frac{1}{v^2} \times \frac{d^2y}{dt^2}$$

where y is the displacement and v is the velocity of the wave travelling in a direction. The displacement of the particle at any instant 't', at any point 'x' in space

$$y(x, t) = Ae^{j(kx-\omega t)}$$

$$\text{where } \omega = 2\pi\vartheta \text{ and } k = 2\pi/\lambda$$

in analogy with this the wave function which describes the behaviour of the matter particle at any instant 't', at any point 'x' in space can be written as

$$\Psi(x,t) = Ae^{j(kx-\omega t)}$$

$$\text{Where,} \quad \omega = 2\pi\vartheta = 2\pi\frac{E}{h} = \frac{E}{\hbar}$$

$$\text{And} \quad k = \frac{2\pi}{\lambda} = \frac{2\pi}{h}\times p = \frac{p}{\hbar}$$

The total energy of the particle is given by

$$E = \text{kinetic energy} + \text{potential energy}$$

$$= \frac{1}{2}mv^2 + V = \frac{(mv)^2}{2m} + V$$

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

Operating this on the wave function Ψ(x, t) it is found that

$$E\Psi(x,t) = \frac{p^2}{2m}\Psi(x, t) + V\Psi(x, t)$$

Differentiating equation with respect to 'x' and 't' it is obtained that

$$\frac{\partial^2\Psi(x, t)}{\partial x^2} = -p^2Ae^{j(kx-\omega t)} = -k^2\Psi(x, t)$$

$$\text{Hence} \quad \frac{p^2}{\partial t}\Psi(x, t) = -jA\omega e^{j(kx-\omega t)} = -j\omega\Psi(x, t)$$

Hence the final equation is as follows:-

$$j\hbar\frac{\partial\Psi(x, t)}{\partial t} = -\frac{\hbar}{2m}\times\frac{\partial^2\Psi(x, t)}{\partial x^2} + V\Psi(x, t)$$

Or $$-\frac{\hbar}{2m}\times\frac{\partial^2\Psi(x,t)}{\partial x^2} + V\Psi(x,t) = j\hbar\frac{\partial\Psi(x,t)}{\partial t}$$

The first and the second term on the left hand side represents the kinetic and potential energies respectively of the particle and the right hand side represents the total energy.

This is called as the one dimensional time dependent Schrodinger equation.

Q6](a) Define ligancy and critical radius ratio. Calculate critical radius radio for ligancy 6. (5)

Ans:- *LIGANCY:-*

In an ionic solid the cation and anion are positioned at alternate lattice points. Generally cations are smaller than anions in size. In a given crystal the number of anions surrounding a cation is called the ligancy i.e., the coordination number of an ionic crystal.

RADIUS RATIO:-

If the surrounding anions touch each other as well as touch the central cations the condition is called critical. In this case the cation-anion radius ratio is called the critical radius ratio r_C/r_A. *Here* r_C and r_A *are the cation and anion radii respectively.*

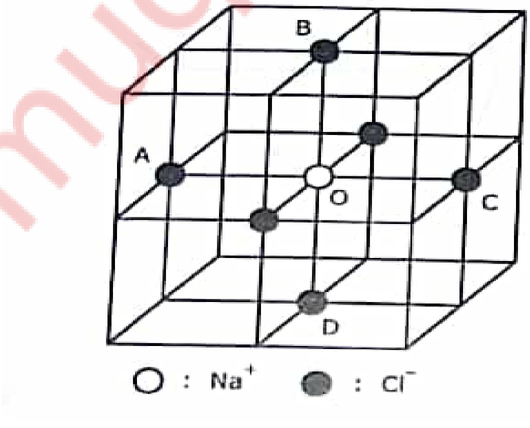
OCTAHEDRAL CONFIGURATION:

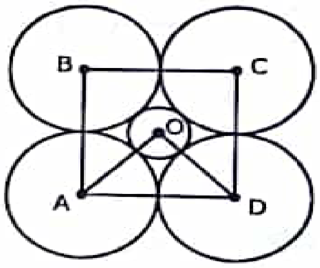
The octahedral configuration of neighbouring anions is found in NaCl structure. Here four anions A, B ,C and D are arranged at the corners of a square with the cation O at the centre of the square. Two more anions are situated in front and at the back of the cation. The centres of all six anions form an octahedron.

Here in Δ *BOC , < BOC = 90°, BC =* $2r_A$, *OB =* $r_C + r_A$ *and <BCO =45°,*

Hence, $$\frac{BO}{BC} = \cos 45°$$

Or, $$\frac{r_C+r_A}{2r_A} = \frac{1}{\sqrt{2}}$$





The critical radius ratio here is,

$$\boxed{\frac{r_C}{r_A} = 0.414}$$

Q6](b) What is the significance of wave function? Derive the expression for energy Eigen

Values for free particle in one dimensional potential well. (5)

Ans:- *Wave represents the propagation of a disturbance in a medium. A wave function which describes the behaviour of a matter wave as a function of position and time. It has no direct physical significance as it is not an observable quantity. However , the values of the wave function is related to the probability of finding the matter particle at a given point in space at a given time.*

In classical physics it is known that

The intensity of radiation is directly proportional to the square of Amplitude of the electromagnetic wave.

In an analogy in quantum mechanics it can be written that.

The density of matter particle is directly proportional to the square of Amplitude of the matter wave.

An one dimensional potential well is a potential energy function mathematically given by.

$V(x) = 0$ at $0 \leq x < L$

$= \infty$ at $x \leq 0$ and $x \geq L$

The potential energy is zero inside the well and infinite at the boundaries. A particle trapped inside the infinitely high potential well can propagate along x-axis and gets reflected from the boundary walls at x = 0 and x = L, but can never leave the well. Such a state is called bound state.

With zero potential energy the particle behaves as a free particle inside the well. Therefore the schodinger equation reads.

$$\frac{\hbar^2}{2m}.\frac{d^2\Psi(x)}{dx^2} = E\Psi(x)$$

$$\frac{d^2\Psi}{dx^2} + \frac{2mE}{\hbar^2} = 0$$

$$\frac{d^2\Psi}{dx^2} + k^2E(x) = 0$$

The behaviour of the particle describe by the solution of equation (+x) and the term Be^{-jkx} *represents the motion in the backward (-x) direction. Here A and B are constants.*

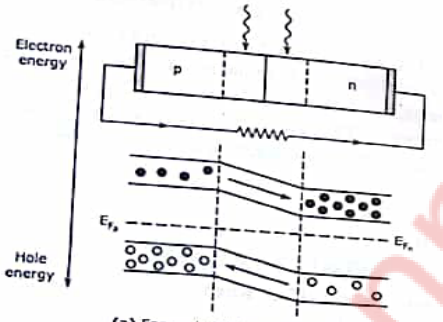
$$\boxed{\Psi(x) = Ae^{jkx} + Be^{-jkx}}$$

Q6](c) What is photovoltaic effect? Explain the principle and working of Solar cell. (5)

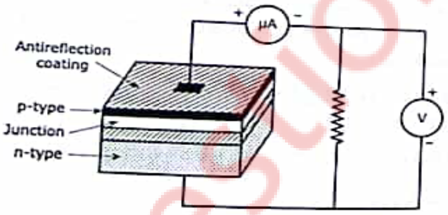
Ans:- *PHOTOVOLTAIC EFFECT:-*

In photoelectric effect when radiation is incident on a metal surface electron are ejected. In photovoltaic effect, certain materials being exposed to radiation generates electron hole pairs available for conduction. As a result a voltage is developed across the material. The radiation energy E= $h\vartheta$ *is required to be greater then the band gap energy* E_g *of the material. This is a phenomenon in which light energy is converted into electrical energy.*

SOLAR CELL.



(a) Energy band structure of a solar cell



(b) Solar cell circuit

Figure 3.30

- *Solar cell is a semiconductor device that converts solar energy into electrical energy. This is a p-n junction diode with very doping level. Solar cells have a flat shape with a very thin top layer. So that the incident solar energy can reach the junction area.*
- *As the solar radiation is incident on the device due to the radiation energy* $E = h\vartheta \geq E_g$ *electron hole pairs are generated in p and n region.*
- *In the energy band structure of the solar cell in fig it is seen that the conduction band is lower in the region than that in the p region. Hence , the generated electrons of the conduction band of p region travel to the conduction band of n region which is at a lower electron energy level. Similarly the holes created in the valence band of the n region move to the valence band of the p region at a lower hole energy level.*
- *This diffusion of electrons and holes through the junction constitutes the current .*
- *The top surface of the solar cell is coated with an antireflection film to maximize the*

utilization of the incident solar energy by the junction .

- *A solar cell does not need a power supply. It generates power.*
- *Materials used for solar cell are different types pf semiconductor, single crystal , polycrystal, thin silicon wafers etc*

APPLIED PHYSICS 1

(CBCGS MAY 2018)

Q1](a) Why X-rays are used to study the crystal structure? (3)

Ans:- *It is well known that X-rays can penetrate solids since these are very high energetic radiations of very short wavelength (1A°). In a crystalline solid the atoms are very closely distributed in crystal planes. The crystal planes, thus form a three dimensional slit system with a spacing (1A°). Due to this fact X-rays get strongly diffracted from various crystal planes. By analysing the diffraction pattern of a crystal its internal atomic arrangement can be determined. Hence W.H Bragg explained the phenomenon of X-ray diffraction from a single crystal. Hence this was the reason for using X-rays for the study of crystal structure.*

Q1](b)Calculate the frequency and wavelength of photon whose energy is 75eV . (3)

Ans:- Given Data :- $E = 75eV = 75\times1.6\times10^{-19} = 1.20\times10^{-17}$

Formula :- $E = \frac{1}{2}mv^2$, $\lambda = \frac{h}{mv} = \frac{h}{p}$

Calculations :- $E = \frac{1}{2}mv^2 = \frac{(mv)^2}{2m} = \frac{h^2}{2m\lambda^2}$

$$\lambda = \frac{h}{\sqrt{2mE}} = \frac{6.63\times10^{-34}}{\sqrt{2\times9.1\times10^{-31}\times1.20\times10^{-17}}} = 1.41\ A°$$

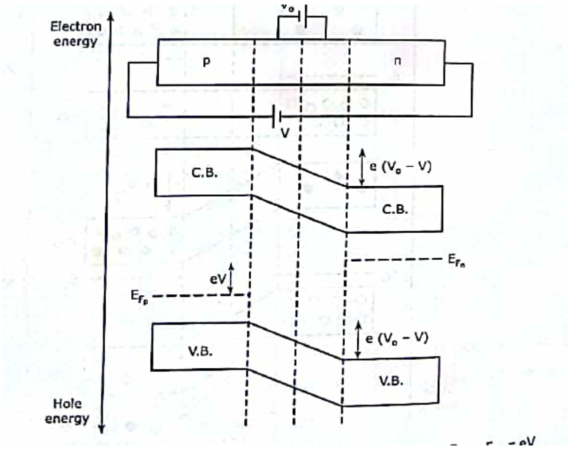
wavelength = *1.41 A°*

frequency $= \frac{1}{\lambda} = 7.048\times10^{9}$.

Q1](c) Draw the energy band diagram of p-n junction diode in forward and reverse bias condition. (3)

Ans:- *Forward biasing increases the electron density in the conduction band of the n-side. As a result the fermi level moves upwards. Similarly due to the increase in the hole density in the valence band of the p side , the fermi level moves downwards. The fermi levels and are displaced relatively by an amount eV equal to the potential energy due to the applied voltage, V which cause the displacement.*

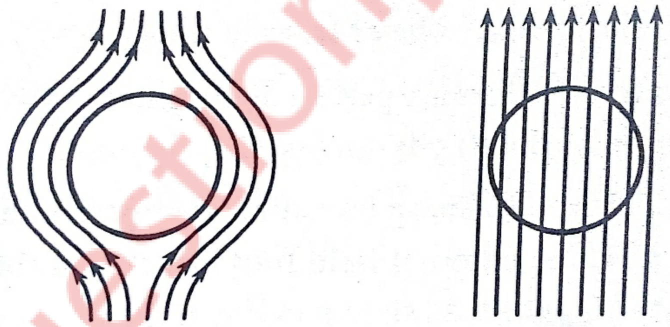
The height of the conduction hill reduces by the same amount eV and becomes $e(V_o - V)$. *Similarly the height of the valence hill becomes* $-e(V_o - V)$. *This makes the charge flow through the junction easier.*



Q1](d) "Superconductor is a perfect diamagnetic", Explain. (3)

Ans:- A superconducting material kept in a magnetic field expels the magnetic flux out its body when cooled below the critical temperature and exhibits perfect diamagnetism. This is called MEISSNER EFFECT.

- It is found that as the temperature of the specimen is lowered to T_c, the magnetic flux is suddenly and completely expelled from it. The flux expulsion continues for $T < T_c$. The effect is reversible.
- When the temperature is raised from below T_c. The flux density penetrates the specimen again at $T = T_c$ and the material turns to the normal state.



(a) Superconducting state at $T < T_C$ or $H < H_C$

(b) Normal state at $T > T_C$ or $H > H_C$

- For the normal state the magnetic induction inside the specimen is given by:

  $B = \mu_o(H+M) = \mu_0(1+\chi)H$…………………………………………(1)

Here H is the applied magnetic field , m is the magnetization produced within the specimen , is χ the susceptibility of the material and μ_o is the permeability of free space.

- At $T < T_c$ as seen above

  B = 0

  Hence equation (1) reduced to,

  M = -H

And thus $\chi = \frac{M}{H} = -1$

- *The specimen is therefore a perfect diamagnetic. The diamagnetism produces strong repulsion to the external magnets.*
- *This effect is used to identify a superconductor , in levitation effect and suspension effect.*

Q1](e) What is reverberation time? How it is important ? write the factors affecting reverberation time. *(3)*

Ans:- *In reverberation sound produced in an enclosure continues to be heard for some time. A sound produced in a room undergoes multiple reflections from the walls, the floor and the ceiling before becoming inaudible. The prolongation of sound in an enclosed place even when the sound source has stopped is called reverberation.*

The time taken by the sound to fall from its average intensity to inaudibility is called the reverberation time. It is also defined as time during which the sound intensity falls from its steady state value to its one-millionth value after the source is shut off

$$\therefore \frac{I}{I_0} = 10^{-6}$$

And from equation it, is found as ,

$$L = -60 \text{ dB}$$

Thus during reverberation time the intensity level drops by 60 dB.

Q1](f) A quartz crystal of thickness 1.5mm vibrating with resonance. Calculate it's fundamental frequency if the Young's modulus of quartz crystal is 7.9×10^{10} N/m^2 and density is 2650 kg/m^3 . *(3)*

Ans:- *Given Data* :- $t_1 = 1mm = 10^{-3} mm$ $Y = 7.9 \times 10^{10} N/m^2$

$\rho = 2650\ kg/m^3$

Formula :- $f = \frac{1}{2t}\sqrt{\frac{Y}{\rho}}$

Calculations :- $f = \frac{1}{2 \times 10^{-3}}\sqrt{\frac{7.9 \times 10^{10}}{2650}}$ *= 2.73 MHz*

Answers :- *Frequency = 2.73 MHz*

Q1](g) Mobility of electron and hole in a sample of Ge at room temperature are 0.36 m^2/V-sec and 0.17m^2/V-sec respectively. If electron and holes densities are equal and it is 2.5 ×10^{13}/cm^3, calculate its conductivity. (3)

Ans:- *Data* :- μ_e = 0.36 m^2/V-sec μ_h = 0.17m^2/V-sec T =300°K

$n_i = 2.5\times10^{13}/cm^3 = 2.5\times10^{19}m^3$

Formula :- $\sigma = n(\mu_e - \mu_h).\,e$

Calculations :- $\sigma = 2.5\times10^{19}(0.36 + 0.17)\times1.6\times10^{-19}$

$= 2.12$ mho/metre

Answer :- σ = *conductivity* = 2.12 mho/metre.

Q2](a) Arrive at Heisenberg's uncertainty principle with single slit electron diffraction.

An electron has a speed of 300n/sec with uncertainty of 0.01 %. Find the accuracy in its position. (8)

Ans:- *SINGLE SLIT ELECTRON DIFFRACTION : THE WAVE CHARACTRISTICS OF AN ELECTRON*

- *Consider an electron moving in 'x' direction with a velocity 'V_x' and an initial momentum of* $p_x = mv_x$ *incident on a narrow slit of width 'd'.*
- *The electron is diffracted through an angle* θ *and strikes the screen the screen at point* Q_1 *or point* Q_2 *on either side of the central point O.*
- *On the way to the screen the electron gains a y component of momentum '*p_y*'. As a result it reaches the point* Q_1 *with a resultant momentum of p.*
- *It is seen that* $p_y = p\sin\theta$, *which varies with the angle of diffraction* θ.

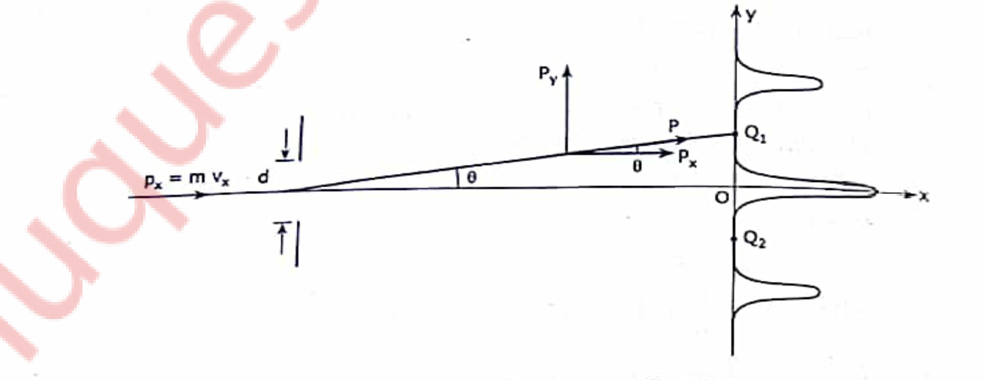


Figure 2.5 : Single slit electron diffraction

- *As there is no force acting in x-direction on the electron ,* p_x *remains constant. Therefore the inaccuracy in the measurement of momentum arises from* p_y.

  The maximum uncertainty in the measurement of momentum can be the momentum itself. Therefore, $\Delta p_y = p_y = p\sin\theta$. ……………………………….(1)

- *For* θ *small it can be assumed that* Q_1 *is the first minimum of the electron diffraction* *pattern. In that case the condition for first minimum is:-*

d sinθ = λ . …………………………………(2)

- *From (1) and (2) it can be written as* $\Delta p_y = p\frac{\lambda}{d}$ *………………………………(3)*
- *On the other hand the electron needs to pass through any point of the slit , to be diffracted. Therefore the inaccuracy in determining the position of the electron in very small given by*

$$\Delta y_m = d \qquad \text{……………………………(4)}$$

- *From (3) and (4) it is found that*

$$\Delta y_m \Delta p_{yma} = d.p\frac{\lambda}{d} = p\lambda$$

$$\Delta y_m . \Delta p_{yma} = h$$

This verifies the uncertainty principle.

NUMERICAL:-

Given Data :- V = 300m/sec , $\frac{\Delta v}{v} = 0.01\ \%$

Formula :- $\Delta x . \Delta p \ \geq \ \hbar$

Calculations :- $\Delta x . m . \Delta p \ \geq \ \hbar$

$$\Delta v = 300 \times \frac{0.01}{100} = 0.03$$

$$\Delta x \ \geq \ \frac{\hbar}{m\Delta v} \ \geq \ \frac{6.63 \times 10^{-34}}{2 \times 3.14 \times 9.1 \times 0.03 \times 10^{-31}}$$

$$\geq \ 3.8 \times 10^{-3}$$

Therefore uncertainty in position = 3.8×10^{-3} *m*

Q2](b) Write the Fermi Dirac distribution function and terms in it. What is the probability of an electron being thermally excited to the conduction band in Si at 30 °C. The band gap energy is 1.12 eV. (7)

Ans:- *Each energy band in a crystal accommodates a large number of electron energy levels. According to Pauli's exclusion principle any energy level can be occupied by two electrons only, one spin up and down . however, all the available energy states are not filled in an energy band. The separation between the consecutive energy level is very small around* 10^{-27} eV *due to which the energy states are not filled in an energy band.*

FERMI DIRAC DISTRIBUTION FUNCTION.

The carrier occupancy of the energy states is represented by a continuous distribution function known as the Fermi-Dirac distribution function, given by

$$f(E) = \frac{1}{1+e^{(E-E_F)/kT}}$$

This indicates the probability that a particular quantum state at the energy level E is occupied by an electron. Here k is Boltzmann's constant and T is absolute temperature of the semiconductor. The energy E_F *is called Fermi energy that corresponds to a reference level called Fermi level.*

FERMI LEVEL

Fermi level is not an allowed energy level it is an imaginary reference level used to specify other energy levels. Fermi level is defined as the highest filled energy level in any solid at absolute zero temperature.

Hence, at absolute zero temperature all energy levels below E_F *are empty for which the probability of occupancy can be written from Fermi-Dirac distribution function.*

NUMERICAL:-

Given Data :- $T = 30^\circ C = 303\ K$, $E_g = 1.12 eV$,

$$K = 1.38 \times 10^{-23} J/K = \frac{1.38 \times 10^{-23}}{1.6 \times 10^{-19}} = 86.25 \times 10^{-6} eV/K$$

Formula :- $f(E_C) = \frac{1}{1+e^{(E_C-E_F)/kT}}$

Calculation :- *Si is an intrinsic semiconductor. Hence ,*

$$E_C - E_F = \frac{E_g}{2} = 0.56\ eV.$$

$$f(E_C) = \frac{1}{1+\exp\left[\frac{0.56}{86.25\times10^{-6}\times303}\right]} = 4.9\times10^{-10}.$$

Answer :- *Probability* $= 4.9\times10^{-10}$.

Q3](a) With neat diagram of unit cell, explain the structure of NaCl crystal and calculate the no .of ions per unit cell, co ordination no. and lattice constant. Calculate the packing factor of NaCl crystal assuming the radius of Na^+ **is 0.98 A° and radius of** Cl^- **is 1.81 A°. (8)**

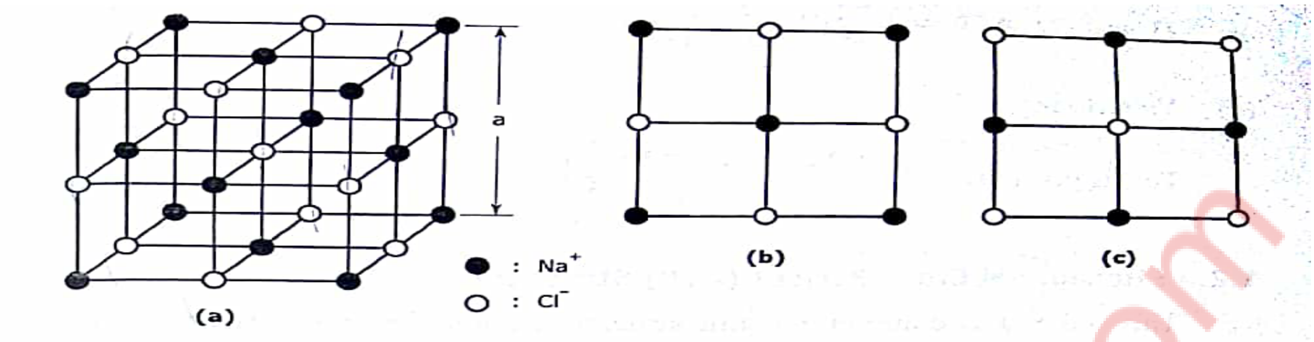
Ans:- :- *NaCl STRUCTURE:-*

This is an ionic structure in which the Na^+ *ions and* Cl^- *ions are alternately arranged. It is a combination of two FCC sublattice one made up of* Na^+ *ions and the other of* Cl^- *ions as if one sublattice is translated through the other along the cube edges.*

NaCl unit cell with Na^+ *ions occupying the regular FCC lattice points with* Cl^- *ions positioned at alternate points. A face of this unit cell is shown.*

Another NaCl unit cell can be considered with the positions of Na^+ *and* Cl^- *ions interchanged. The face of such a unit cell is shown.*

NaCl UNIT CELL PARAMETER:



(a) Total number of molecule / unit cells

Calculation for Na^+ *= Here* Na^+ *forms a FCC structure. Hence total number of* Na^+ *ions = 4*

Calculation for Cl^- *= There are 12*Cl^- *ions at the edges. Every edge lattice points is shared by four neighbouring unit cell. Hence every edge lattice point carries ¼ of an atom. There is one whole* Cl^- *ion at the centre of the structure. Hence ,*

Total number of Cl^- *ions =* $(12 \times \frac{1}{4}) + 1 = 4.$

Since there are 4 Na^+ *ions and four* Cl^- *ions in a NaCl unit cell , there are four NaCl molecule present in a unit cell.*

Hence number of molecule / unit cell = 4.

(b) Atomic Radius (r)

Since NaCl is an ionic structure and cations are smaller than anions it is assumed that radius of cation = r_C *and the radius of an anion =* r_A.

(c) Atomic packing factor(APF)

$$APF = \frac{\left(4 \times \frac{4}{3}\pi r_C^3\right) \times \left(4 \times \frac{4}{3}\pi r_A^3\right)}{a^3}$$

it is found that $a = 2r_C + 2r_A$

Hence, $$APF = \left(\frac{2\pi}{3}\right)\frac{r_C^3 + r_A^3}{(rC+rA)^3}$$

(d) Void space.

This is given by $$\left[1 - \left(\frac{2\pi}{3}\right)\frac{r_C^3 + r_A^3}{(rC+rA)^3}\right]$$

NUMERICAL:-

Given Data :- $r_C = 0.98A°$, $r_A = 1.81A°$

Formula :- *APF =* $\frac{2\pi}{3} \cdot \frac{r_C^3 + r_A^3}{(r_C + r_A)^3}.$

Calculations :- *APF* = $\frac{2\pi}{3}.\frac{0.98^3+1.81^3}{(0.98+1.81)^3}$ = *0.66.*

Answer :- *APF = 0.66*

Q3](b) State the Hall effect. Derive the expression for Hall voltage and Hall coefficient with neat diagram. ***(7)***

Ans:- *if a current carrying conductor or semiconductor is placed in a transverse magnetic field, a potential difference is developed across the specimen in a direction perpendicular to both the current and magnetic field. The phenomenon is called HALL EFFECT.*

As shown consider a rectangular plate of a p-type semiconductor of width 'w' and thickness 'd' placed along x-axis. When a potential difference is applied along its length 'a' current 'I' starts flowing through it in x direction.

As the holes are the majority carriers in this case the current is given by

$$I = n_h A e v_d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where n_h *= density of holes*

A = w × d = cross sectional area of the specimen

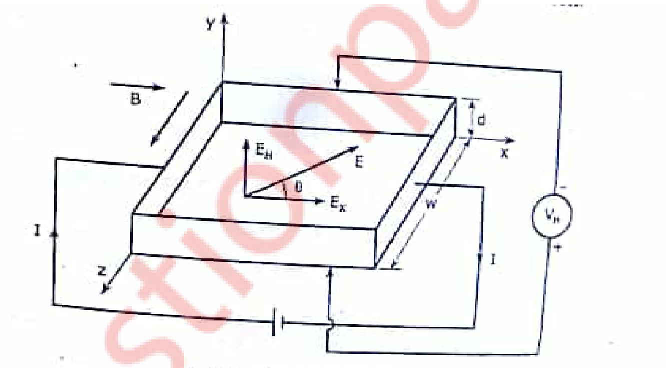


Figure 3.25 : Hall effect set up

v_d = *drift velocity of the holes.*

The current density is

$$J = \frac{I}{A} = n_h e v_d \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The magnetic field is applied transversely to the crystal surface in z direction. Hence the holes experience a magnetic force

$$F_m = e v_d B \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

In a downward direction. As a result of this the holes are accumulated on the bottom surface of the specimen.

Due to this a corresponding equivalent negative charge is left on the top surface.

The separation of charge set up a transverse electric field across the specimen given by,

$$E_H = \frac{V_H}{d} \quad \text{..............................}(4)$$

Where V_H is called the HALL VOLTAGE and E_H *the HALL FIELD.*

In equilibrium condition the force due to the magnetic field B and the force due to the electric field E_H *acting on the charges are balanced. So the equation (3)*

$$eE_H = ev_dB$$

$$E_H = v_dB \quad \text{..................................}(5)$$

Using equation (4) in the equation (5)

$$V_H = v_dB\,d \quad \text{.............................}(6)$$

From equation (1) and (2), the drift velocity of holes is found as

$$v_d = \frac{I}{en_hA} = \frac{J}{en_h} \quad \text{........................}(7)$$

Hence hall voltage can be written *as*

$$\boxed{V_H = \frac{IBd}{en.\,A} = \frac{J_xBd}{en.}}$$

An important parameter is the hall coefficient defined as the hall field per unit current density per unit magnetic induction.

$$\boxed{R_H = \frac{E_H}{J_xB}}$$

Q4](a) What is working principle of SQUID ? Explain how it is used to detect the magnetic field? (5)

Ans:-

- *SQUID is an acronym of superconducting Quantum Interference Device .*
- *A SQUID is a superconducting device that can measure an extremely small magnetic field, voltage or current. It is a very sensitive magnetometer in which a superconducting loop is used with one or more Josephson junctions.*
- *A schematic diagram of SQUID is shown, the SQUID is kept in a magnetic field. A DC super current I enters the device through port C, gets divided into two ports* I_1 *and* I_2*. The current* I_1 *and* I_2 *undergoes a phase shift while crossing the Josephson junctions P and Q and become* I_1' and I_2' *respectively. The super currents* I_1' and I_2' *interface at port D.*

  In superconductors the current is caused by the Cooper pairs. So the interfering waves are the de Broglie waves of the Cooper pairs. The phase shifts of the waves occur due to the applied magnetic field. In the absence of the magnetic field the phase shift and the phase difference are zero.

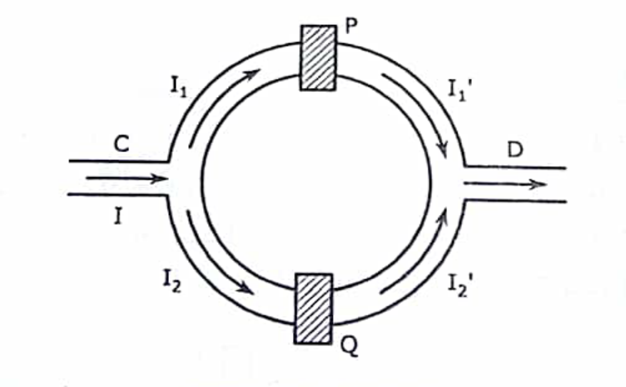


Figure 4.8 : SQUID

- *The resultant current at port D oscillates between maxima and minima. The maxima occurs when the magnetic flux increases by one quantum given by*

$$\varphi_o = \frac{h}{2e} = 2.06 \times 10^{-15} \text{wb}$$

- *In practice instead of the current the voltage V across the SQUID is measured. The voltage also oscillates with the changing magnetic field.*
- *Thus the SQUID is a flux-to-voltage transducer which converts a small change in magnetic flux into voltage.*
- *Because of their extreme sensitivity to magnetic field SQUIDS have application in many field like geology, medicine, engineering, etc.*
- *Some of them are listed below:-*

  1. *In measuring rock magnetism and continental drift SQUIDs are used.*
  2. *The human brain generates magnetic fields of about 10^{-14} wb/m^2 . to detect them SQUID are used in brain imaging.*
  3. *The SQUIDs are used in non destructive testing like testing of the aluminium sheets to be used for aircrafts.*

Q4](b) A hall of dimension $25 \times 18 \times 12 m^3$ has an average absorption coefficient 0.2. find the reverberation time. If a curtain cloth of area 150m^2 is suspended at the centre of Hall with coefficient of absorption 0.75, What will be the reverberation time? (5)

Ans:- *Given Data :- volume of hall* $= 25 \times 18 \times 12$ = *5400*

$\alpha = 0.75$ $\alpha_{av} = 0.2$ $S_{curtain} = 100 \text{ m}^2$

Formula :- $T_1 = 0.161 \times \dfrac{V}{\alpha_{av} \times S}$

$$T_2 = 0.161 \times \frac{V}{\alpha_{av} \times S + \alpha_{curtain} \times S'}$$

Calculate :- $S = 2[(20 \times 15)+(15 \times 10)+(10 \times 20)] = 1300\text{m}^2$

$V = 20\times15\times10 = 3000 \text{ m}^2$

$$T_1 = 0.161 \times \frac{3000}{0.1\times1300} = 3.7 \text{ sec.}$$

∴ *Absorption takes place by both the surfaces of the curtain*

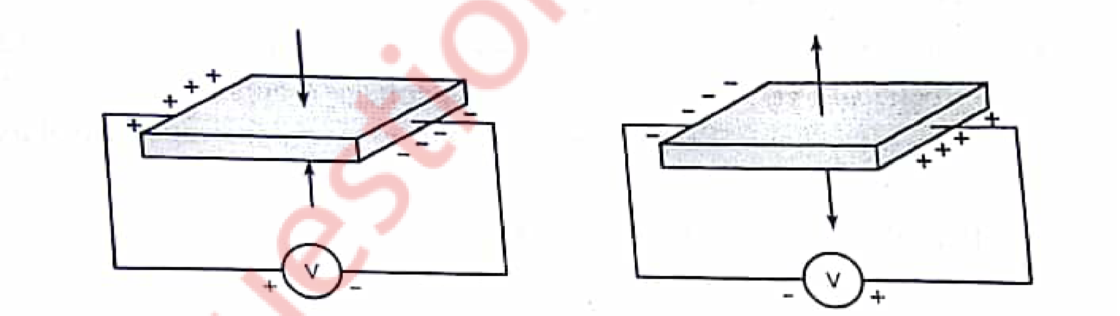
$S' = 2\times100 \text{ m}^2 = 200 \text{ m}^2$

$$T_2 = 0.161 \times \frac{3000}{(0.1 \times 1300)+(0.66 \times 200)} = 1.84 \text{ sec}$$

Answer :- Change in reverberation time = 1.85 sec.

Q4](c) State the piezoelectric effect. With neat circuit diagram explain the principle and working of piezoelectric oscillator. (5)

Ans:- *The piezoelectric crystals e.g., quarts , tourmaline etc have a very special characteristics. Thin slices of these crystals develop a potential difference across the two opposite faces when subjected to a mechanical stress in a perpendicular direction. This is known as DIRECT PIEZOELECTRIC EFFECT. If the direction of the mechanical stress is reversed the potential difference changes its polarity as:-*



PIEZOELECTRIC EFFECT:

Construction:-

- *Piezoelectric oscillator consists of two circuits interacting with each other by means of mutual inductance between inductors L, L1L1, and L2L2.*
- *A DC supply is connected to a tank circuit consisting of a variable capacitor (C) and an inductor L2L2.*
- *The tank circuit is connected to collector terminal of an NPN transistor.*
- *The base terminal of the transistor is connected to another coil L2L2, which is connected to ground on the other end along with emitter terminal of transistor and negative terminal of the DC supply.*

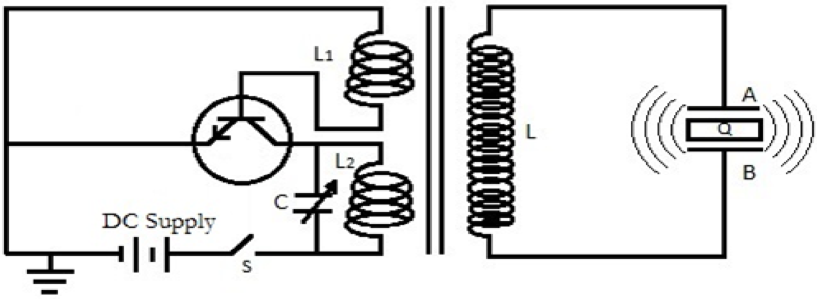


Fig. 7.1: Piezoelectric Oscillator

Working:-

- *A variable capacitor (C) and an inductor (L2)(L2) form a tank circuit.*
- *The frequency of the oscillations can be changed by changing the value of capacitance.*
- *When the circuit is closed, the current flows through the circuit and charges the capacitor.*
- *Then the capacitor starts discharging through the inductor, thus the electric energy is stored in the form of electric and magnetic field of capacitor and inductor respectively.*
- *Thus electric oscillations are produced in the tank circuit.*
- *The frequency of this oscillating electricity is given by*

  f=12πL2C√f=12πL2C
- *With the help of the other electronic components including a transistor, electrical oscillations are produced continuously.*
- *This is fed to the secondary circuit connected to Quartz crystal (Q).*
- *The oscillating electric field is converted to mechanical vibration of crystal owing to the piezoelectric effect.*
- *This vibration produces sound wave of the frequency equal to the frequency of vibration, which is the frequency of electric oscillations.*
- *In this way ultrasonic sound waves can be produced.*
- *Natural frequency of crystal is given by*

$$f = \frac{k}{2t}\sqrt{\frac{Y}{\rho}}$$

  - *t = Thickness of crystal slab*
  - *Y = Young's Modulus*
  - *ρ = Density*
  - *k = 1, 2, 3, ... (Integer Multiple)*
- *When the frequency of electric oscillations is equal to that of natural frequency of the crystal, resonance is achieved and the sound waves of maximum amplitude are produced.*

Q5](a) With energy band diagram , explain the variation of fermi energy level with impurity concentration in extrinsic semiconductor. (5)

Ans:- *Variation of Fermi level with impurity concentration*

- *At low impurity concentration the impurity atoms do not interact with each other. Hence, the extrinsic carriers have their own discrete energy levels.*
- *With the increase in impurity concentration the interaction of the impurity atoms start and the Fermi level varies in the following way.*

1. IN n-TYPE SEMICONDUCTOR:-

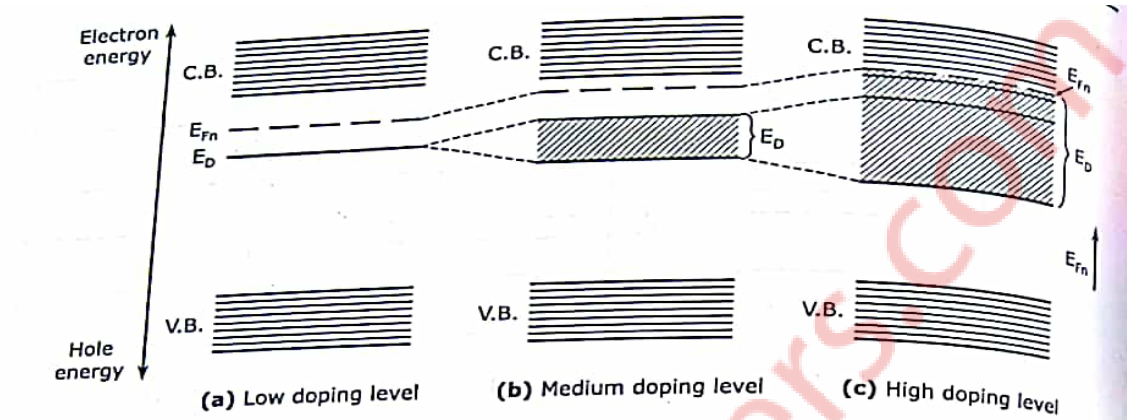
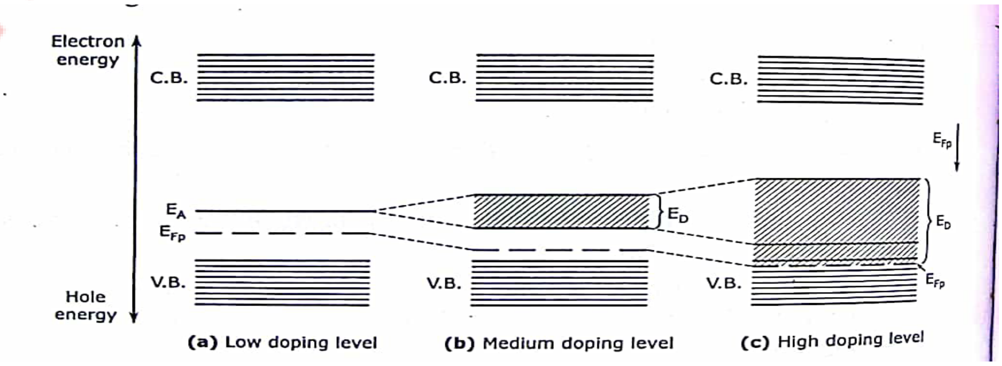


Figure 3.18 : Variation of Fermi level with carrier concentration in n type semiconductor.

- *As the impurity atoms interacts the donor electron are shared by the neighbouring atoms.*
- *This results in splitting of the donor level and formation of the donor band below the conduction band.*
- *With the increase in impurity concentration the width of the band increases. At one stage it overlaps with the conduction band.*
- *As the donor band widens the forbidden gap decreases. In the process the Fermi level shifts upwards and finally enters the conduction band as shown:-*

2. IN p-TYPE SEMICONDUCTOR.

- *With the increase in the impurity concentration the impurity atoms interact. As a result the acceptor level splits into acceptor band which gradually widens with doping level increment.*
- *Finally the acceptor level enters the valence band. In this process the Fermi level shifts downwards and at high doping level it enters the valence band.*
- *With the widening of the acceptor band the forbidden gap decreases as seen:-*

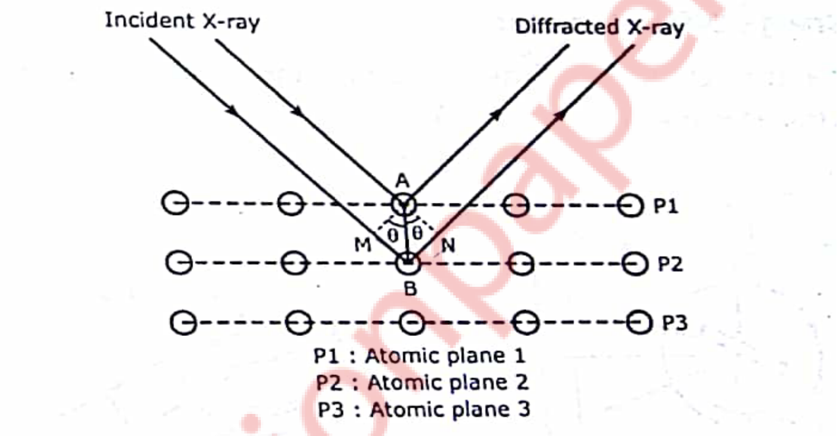


Q5](b) Explain with example how to determine crystal structure by Bragg's X-ray spectrometer. (5)

Ans:- *W.L Bragg's explained the phenomenon of X-ray diffraction from a single crystal shown as follows*

When a beam of X-rays is incident on a crystal it is scattered by individual atoms of the rich atomic planes. Thus, each atom become a source of scattered radiation. The atomic planes responsible for the X-ray diffraction are called BRAGG'S PLANES. Therefore the sets of Braggs planes constitute the crystal grating. Bragg's scattering or Bragg's diffraction is also referred as Braggs reflection. Bragg derived a law called Bragg's law to explain the X-ray diffraction effect.

Here a beam of X-ray is incident on a set of parallel planes of a crystal. The rays makes a glancing angle θ *and are practically reflected from different successive planes. The phase relationship of the scattered rays can be determined from their path differences. Here two parallel X-rays are reflected from two consecutive planes PI and P2. The path differences between then as shown*



$$\delta = MB + BN = 2MB = 2AB\sin\theta$$

Here AB = d, the interplanar spacing of the crystal. Hence,

$$\delta = 2d\sin\theta$$

The two diffracted rays reinforce each other when they interfere constructively when their path difference δ *is equal to* $n\lambda$

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

This is called Bragg's law.

Q5](c) Obtain one dimensional time dependent time independent Schrodinger equation. (5)

Ans:- *For one dimensional case, the classical wave is described by the wave equation*

$$\frac{dy^2}{dx^2} = \frac{1}{v^2} \times \frac{d^2y}{dt^2}$$

where y is the displacement and v is the velocity of the wave travelling in a direction. The displacement of the particle at any instant 't' , at any point 'x' in space

$$y(x, t) = Ae^{j(kx-\omega t)}$$

$$\text{where } \omega = 2\pi\vartheta \quad \text{and} \quad k = 2\pi/\lambda$$

in analogy with this the wave function which describes the behaviour of the matter particle at any instant 't', at any point 'x' in space can be written as

$$\Psi(x,t) = Ae^{j(kx-\omega t)}$$

$$\text{Where ,} \quad \omega = 2\pi\vartheta = 2\pi\frac{E}{h} = \frac{E}{\hbar}$$

$$\text{And} \quad k = \frac{2\pi}{\lambda} = \frac{2\pi}{h}\times p = \frac{p}{\hbar}$$

The total energy of the particle is given by

$$E = \text{kinetic energy + potential energy}$$

$$= \frac{1}{2}mv^2 + V = \frac{(mv)^2}{2m} + V$$

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

Operating this on the wave function Ψ(x, t) it is found that

$$E\Psi(x,t) = \frac{p^2}{2m}\Psi(x, t) + V\Psi(x, t)$$

Differentiating equation with respect to 'x' and 't' it is obtained that

$$\frac{\partial^2\Psi(x, t)}{\partial x^2} = -p^2Ae^{j(kx-\omega t)} = -k^2\Psi(x, t)$$

$$\text{Hence} \quad \frac{p^2}{\partial t}\Psi(x, t) = -jA\omega e^{j(kx-\omega t)} = -j\omega\Psi(x, t)$$

Hence the final equation is as follows:-

$$j\hbar\frac{\partial\Psi(x, t)}{\partial t} = -\frac{\hbar}{2m}\times\frac{\partial^2\Psi(x, t)}{\partial x^2} + V\Psi(x, t)$$

$$\text{Or} \quad -\frac{\hbar}{2m}\times\frac{\partial^2\Psi(x, t)}{\partial x^2} + V\Psi(x, t) = j\hbar\frac{\partial\Psi(x, t)}{\partial t}$$

The first and the second term on the left hand side represents the kinetic and potential energies respectively of the particle and the right hand side represents the total energy.

This is called as the one dimensional time dependent Schrodinger equation.

ONE DIMENSIONAL TIME INDEPENDENT SCHRODINGER EQUATION.

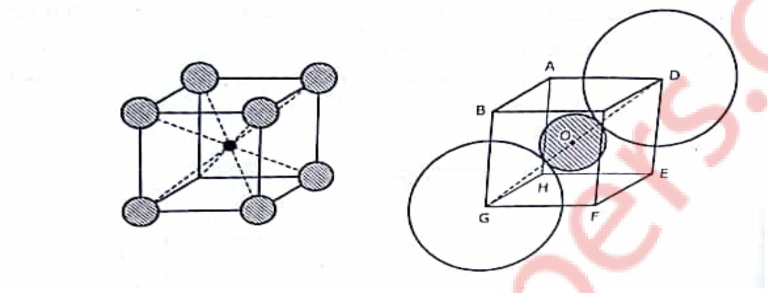
$$-\frac{\hbar^2}{2m}\times\frac{d^2\Psi(x)}{dx^2} + V(x)\Psi(x) = E\Psi(x)$$

Q6](a) Define ligancy and critical radius ratio. Calculate critical radius ratio for ligancy 8. (5)

Ans:- *Simple cubic diatomic structure.*

The centres of the right anions from a simple cubic structure with the cation located example of this configuration is CsCl structure in which the Cl^- ions are situated at the eight corners of the cube and the Cs^+ ion is found at the body centre.

In critical condition the eight corner anions touch the central cation along the body diagonals. The eight anions touch each other along the cube edges.



The body diagonals pass through two opposite corner anions and the central cation. Here a = $2r_A$ *and GD =* $\sqrt{3}a = 2(r_C + r_A)$.

Therefore , $\frac{r_C}{r_A} = 0.732$

Q6](b) What is the significance of wave function ? derive the expression for energy eigen values for the free particle in one dimensional potential well. (5)

Ans:- *Wave represents the propagation of a disturbance in a medium. A wave function which describes the behaviour of a matter wave as a function of position and time. It has no direct physical significance as it is not an observable quantity. However , the values of the wave function is related to the probability of finding the matter particle at a given point in space at a given time.*

In classical physics it is known that

The intensity of radiation is directly proportional to the square of Amplitude of the electromagnetic wave.

In an analogy in quantum mechanics it can be written that.

The density of matter particle is directly proportional to the square of Amplitude of the matter wave.

An one dimensional potential well is a potential energy function mathematically given by.

$V(x) = 0 \quad$ at $0 \leq x < L$

$\quad = \infty \quad$ at $x \leq 0$ and $x \geq L$

The potential energy is zero inside the well and infinite at the boundaries. A particle trapped inside the infinitely high potential well can propagate along x-axis and gets reflected from the boundary walls at x = 0 and x = L, but can never leave the well. Such a state is called bound state.

With zero potential energy the particle behaves as a free particle inside the well. Therefore the schodinger equation reads.

$$\frac{\hbar^2}{2m}.\frac{d^2\Psi(x)}{dx^2} = E\Psi(x)$$

$$\frac{d^2\Psi}{dx^2} + \frac{2mE}{\hbar^2} = 0$$

$$\frac{d^2\Psi}{dx^2} + k^2E(x) = 0$$

The behaviour of the particle describe by the solution of equation (+x) and the term Be^{-jkx} *represents the motion in the backward (-x) direction. Here A and B are constants.*

$$\boxed{\Psi(x) = Ae^{jkx} + Be^{-jkx}}$$

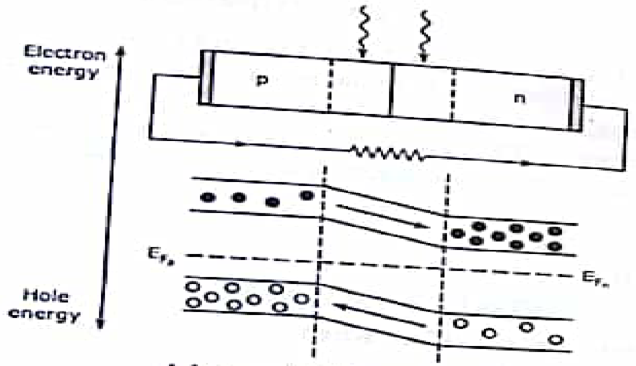
Q6](c) What is photovoltaic effect? Explain the principle and working of solar cell. (5)

Ans:- :- *PHOTOVOLTAIC EFFECT:-*

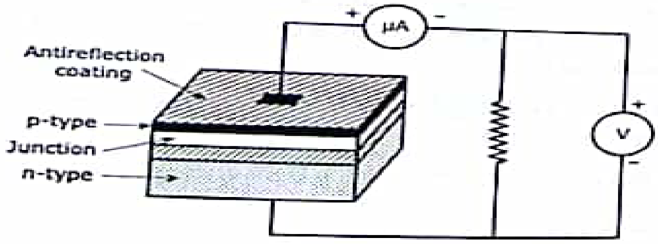
In photoelectric effect when radiation is incident on a metal surface electron are ejected. In photovoltaic effect, certain materials being exposed to radiation generates electron hole pairs available for conduction. As a result a voltage is developed across the material. The radiation energy E= $h\vartheta$ *is required to be greater then the band gap energy* E_g *of the material. This is a phenomenon in which light energy is converted into electrical energy.*

SOLAR CELL.

- *Solar cell is a semiconductor device that converts solar energy into electrical energy. This is a p-n junction diode with very doping level. Solar cells have a flat shape with a very thin top layer. So that the incident solar energy can reach the junction area.*
- *As the solar radiation is incident on the device due to the radiation energy* $E = h\vartheta \geq E_g$ *electron hole pairs are generated in p and n region.*
- *In the energy band structure of the solar cell in fig it is seen that the conduction band is lower in the region than that in the p region. Hence , the generated electrons of the conduction band of p region travel to the conduction band of n region which is at a lower electron energy level. Similarly the holes created in the valence band of the n region move to the valence band of the p region at a lower hole energy level.*



(a) Energy band structure of a solar cell



(b) Solar cell circuit

Figure 3.30

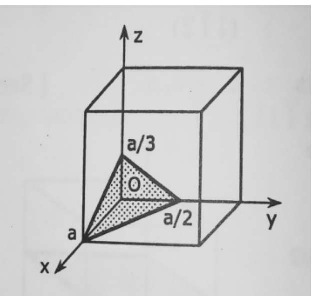
- *This diffusion of electrons and holes through the junction constitutes the current .*
- *The top surface of the solar cell is coated with an antireflection film to maximize the utilization of the incident solar energy by the junction .*
- *A solar cell does not need a power supply. It generates power.*
- *Materials used for solar cell are different types pf semiconductor, single crystal , polycrystal, thin silicon wafers etc*

APLLIED PHYSICS 1

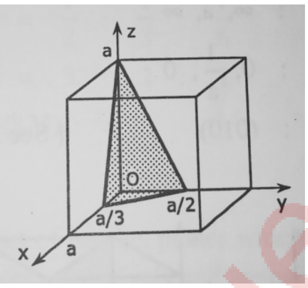
(CBCGS DEC 2018)

Q1](a)Draw (123), (321), (102).
(3)

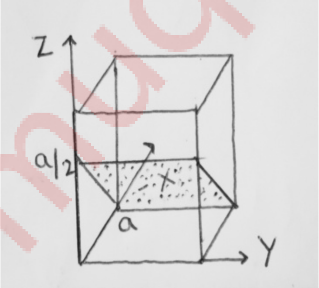
Ans) *(123)*



(321)



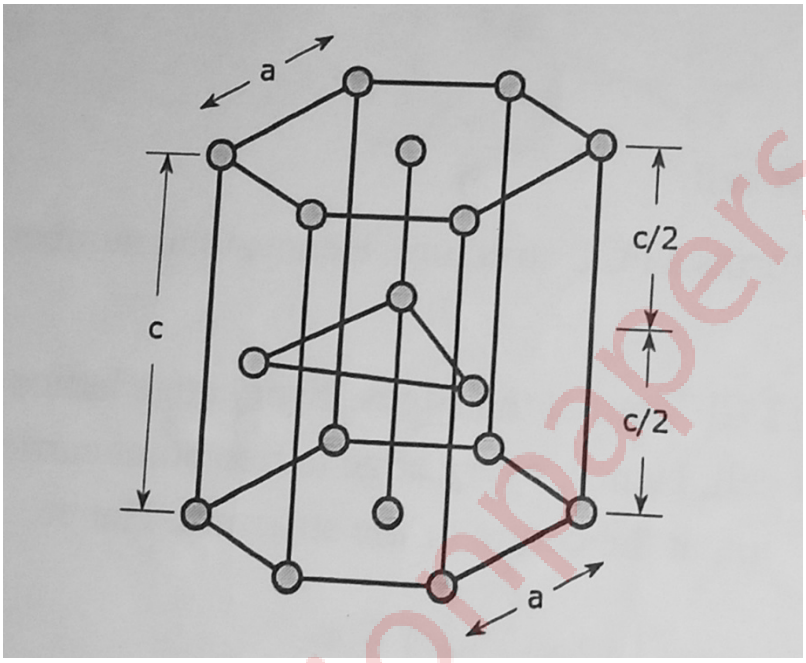
($\bar{1}$02)



Q1](b) Explain with diagram HCP unit cell based on lattice parameters.
(3)

Ans)*Here,* $a = b \neq c$

And, $\alpha = \beta = 90°$, $\gamma = 120°$



Every unit cell is structured as follows

- *In the bottom layer the central atomic surrounded by six other identical atoms.*
- *In the middle layer at height c/2 three atoms are positioned.*

In the top layer, at height C atomic distribution is similar to that of the bottom layer

---

Q1](c) State properties of matter waves.
(3)

Ans)

- *These waves are neither mechanical nor electromagnetic waves these are hypothetical waves*
- *Matter waves with different de Broglie wavelengths travel with different velocities whereas electromagnetic waves of all wavelengths travel with the same velocity C.*

- *The de Broglie wavelength depends on the kinetic energy of the matter particle .*
- *Matter waves travel faster than light.*
- *Matter waves can travel through vacuum or any other medium.*
- *For particle at rest v=0, so* $\lambda = \infty$*, hence no matter waves are associated with particle at rest.*

Q1](d)Calculate electron & hole concentration in intrinsic Si at room temperature if its electrical conductivity is $4\text{x}10^{-4}$ **mho/m. Given that mobility of electron =** $0.14 m^2$**/V-sec and mobility of holes=0.04** m^2**/V-sec.**
(3)

Ans)***Data***: $\mu_e = 0.14 m^2/\text{V-sec}$,$\mu_h = 0.040\ m^2/\text{V-sec}$, $\sigma = 4\times10^{-4}$ mho/m

Formula: $\sigma_i = n_i(\mu_e+\mu_h).e$

Calculations: $n_i = \sigma_i / e(\mu_e+\mu_h)$

$= 4\times10^{-4} / 1.6\times10^{-19}(0.14+0.040)$

$n_i = 1.388\times 10^{16}/m^3$

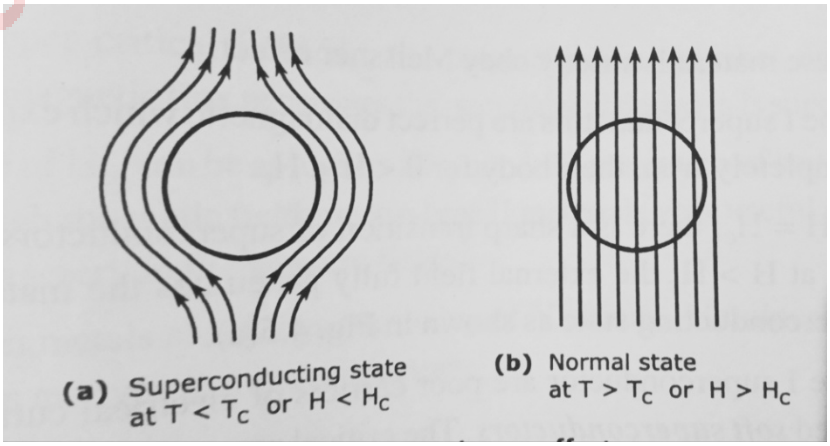
Answer: *Carrier concentration=*$1.388\times 10^{16}/m^3$

Q1](e) Explain Meissner Effect with the help of diagram. **(3)**

Ans:-

Superconducting material kept in a magnetic field expels the magnetic flux out its body when cooled below the critical temperature and exhibits perfect diamagnetism.This is called ***MEISSNER EFFECT.***

- *It is found that as the temperature of the specimen is lowered to Tc,the magnetic flux is suddenly and completely expelled from it.The flux expulsion continues for T<Tc.The effect is reversible.*



(a) Superconducting state at $T < T_C$ or $H < H_C$

(b) Normal state at $T > T_C$ or $H > H_C$

- *When the temperature is raised from below T_c. The flux density penetrates the specimen again at T=Tc and the material turns to the normal state.*

Q1](f) A conference room has a total volume of 2000 m3. The magnitude of total absorption within the conference room is 100 Sabin. Calculate the reverberation time.

(3)

Ans)*Data*: *$V=2000m^3$, a= 100 sabin*

Formula:*$T=0.161\times V/a$*

Calculations: *$T= 0.161\times V/a$*

$T=(0.161\times 2000)/100$

$=3.22$ sec

Answers:*Reverberation time = 3.22 sec.*

Q1](g) Discuss any three applications of Ultrasonic waves.
(3)

Ans) *Non destructive testing:*

- *Big concrete slabs, big metals castings like guarders can easily be tested for cracks, cavoties or any other flaws by using ultrasonic waves. When ultrasonic waved are passed through a flawless metal or concrete block it should go to the bottom of the block from where it is reflected back.*
- *If there is a flaw e.g., a crack or a hole or an impurity the ultrasonics waves get reflected from the flaw due to the change in medium. By measuring the time interval between sending and receiving the ultrasonic signal in both the caeses the flow cam be detected and located. The detection of such flaws prior to the failure while in use is of great practical importance.*

Emulsification:

- *Using cavitation effect immiscible liquids like oil and water or mercury and water can be transformed into stable emulsions.*

Medical applications:

Ultrasonic waves are used in

- *Ultra Sonography*
- *Ultrasonic imaging*
- *Dental cutting*
- *Ultrasonic Tomography*

Q2](a) State Heisenberg's Uncertainty Principle. Show that electron doesn't exist in the nucleus. Find the accuracy in the position of an electron moving with speed 350 m/ sec with uncertainty of 0.01%. (8)

Ans) *Heisenberg's uncertainty principle states that one cannot measure position and moment of the moving particle exactly. Thus, the inaccuracies* Δx *and* Δp *in the simultaneous determination of the position 'x' and momentum 'p' respectively of a particle are related as*

$$\Delta x \cdot \Delta p \geq \hbar$$

Where $\hbar = h/2\pi$, *h being Planck's constant.*

<u>Non existence of electron inside the nucleus</u>.

If the electromagnetic is inside the nucleus of radius of the other of 10^{-15} *m, the maximum uncertainty in the position of electron will be of the order of its radius.*

$$\therefore \Delta x_{max} = 10^{-15}$$

From the limiting condition of Heisenberg's uncertainty principle,

$$\Delta x_{max} \cdot \Delta p_{min} \geq \hbar$$

$\Delta p_{min} = \hbar/\Delta x_{max} = 6.63\times10^{-34}/2\times3.14\times10^{-15} = 1.055\times10^{-19}$ *kg-m/sec.*

Now, $\Delta p_{min} = m\Delta v_{min}$

Hence, $\Delta v_{min} = \Delta p_{min}/m = 1.055\times10^{-19}/9.1\times10^{-31}$

$= 1.159\times10^{11}$ *m/s* $> c$

As $\Delta v_{min} < v \quad v > 1.159\times10^{11}$ *m/a* $> c$

Therefore, the electron behaves as a relativistic particle.

The relativistic energy of the electron is

$$E = \sqrt{m_o^2c^4+p^2c^2}$$

Since,the actual momentum of the electron $p >> \Delta p_{min}, p^2c^2 >> m_o^2c^2$*,the rest* *mass energy of the electron the value of which is 0.511 MeV.Hence,*

$$E=pc$$

Assuming $p=\Delta p_{min}$*,the least energy that an electron should posses within a nucleus is given by*

$$E_{min}= \Delta p_{min}\cdot c= 1.055x10^{-19}x3x10^{8}$$

$$= 3.165x10^{-11}\ J \qquad E_{min}=3.165\times10^{-11}/1.6\times10^{-19} = 197\ MeV$$

In reality,the only source of generation of electron within a nucleus is the process of decay.The maximum kinetic energy possessed by the electrons during β-decay is about 100 KeV.This shows that an electron can not exist within a nucleus.

Numerical Solutlon :

Data: $v=350\ m/sec,\ \Delta v/v=0.01\%$

Formula: $\Delta x\cdot\Delta p\geq \hbar$

Calculations: $\Delta x.\ m.\ \Delta v \geq \hbar$

$\Delta v = 350\times 0.01/100 =0.035$

$\Delta x \geq \hbar/m\Delta v \geq 6.63\times10^{-34}/2\times3.14\times9.1\times10^{-31}\times0.035$

$\geq 3.314 \times 10^{-3}\ m$

Answer:*Minimum uncertainty in position is* $3.314\times10^{-3}\ m$

Q2](b) Show that for intrinsic semiconductors of the Fermi level lies midway between the conduction band and the valence band. With the help of diagram explain effect of impurity concentration on Fermi level of N type semiconductor.
(7)

Ans)

- *At any temperature T > 0K is an intrinsic semiconductor, a number of electrons are found in the conduction band and the rest of the valence electrons are left behind in the valence band.*
- *Let there be* n_C *number of electrons in the conduction band and* n_V *number of electrons in the valence band.*

  Hence, the total number of electrons in the intrinsic semiconductor is

  $$N = n_C + n \quad .... (1)$$

At $T = 0$ K all N electrons occupy energy states in the valence band.

- Out of these total N number of valence electrons Amy NC number of electrons cam reach the conduction band.

The probability of occupancy of an energy level in the conduction band can be written from equation (1) as

$$f(EC) = \frac{1}{1+e^{(Ec-Ef)/kT}}$$

where E_C is the potential energy of a rest electron in conduction band.

- Here, E_C is the minimum energy required for the electron to reach the bottom level of the conduction band. The extra energy is converted to its kinetic energy with which it moves freely in the conduction band at any energy level.
- Hence, the number if electrons found in the conduction band is

$$n_C = Nf(E_C) = \frac{N}{1+e^{(Ec-Ef)/kT}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

- Similarly, any n_V number if valence electrons from the total of N electrons can bring left behind in the valence band.
- The probability of occupancy of a level in the valence band is given by

$$f(E_V) = \frac{1}{1+e^{-(Ef-Ev)/kT}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

as (E_V-E_F) is negative.

- Hence, the number of electrons in the valence band can bring written as

$$nV = NF(E_V) = \frac{N}{1+e^{-(Ef-Ev)/kT}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

- Substituting equations (2) and (4) in (1), it is found that.

$$N = \frac{N}{1+e^{(Ec-Ef)/kT}} + \frac{N}{1+e^{-(Ef-Ev)/kT}}$$

$$[1+e^{(Ec-Ef)/kT}][1+e^{-(Ef-Ev)/kT}] = 2+e^{-(Ef-Ev)/kT}+e^{(Ec-Ef)/KT}$$

$$1+e^{(Ec-Ef)/kT} +e^{-(Ef-Ev)/kT} +e^{(Ec-2Ef+Even)/kT} = 2+ e^{-m(Ef-Ev)/kT}+ e^{(Ec-Ef)/kT}$$

$$e^{(E_c-2E_f+E_v)/kT} = 1$$

$$E_C - 2E_F + E_V/kT = 0$$

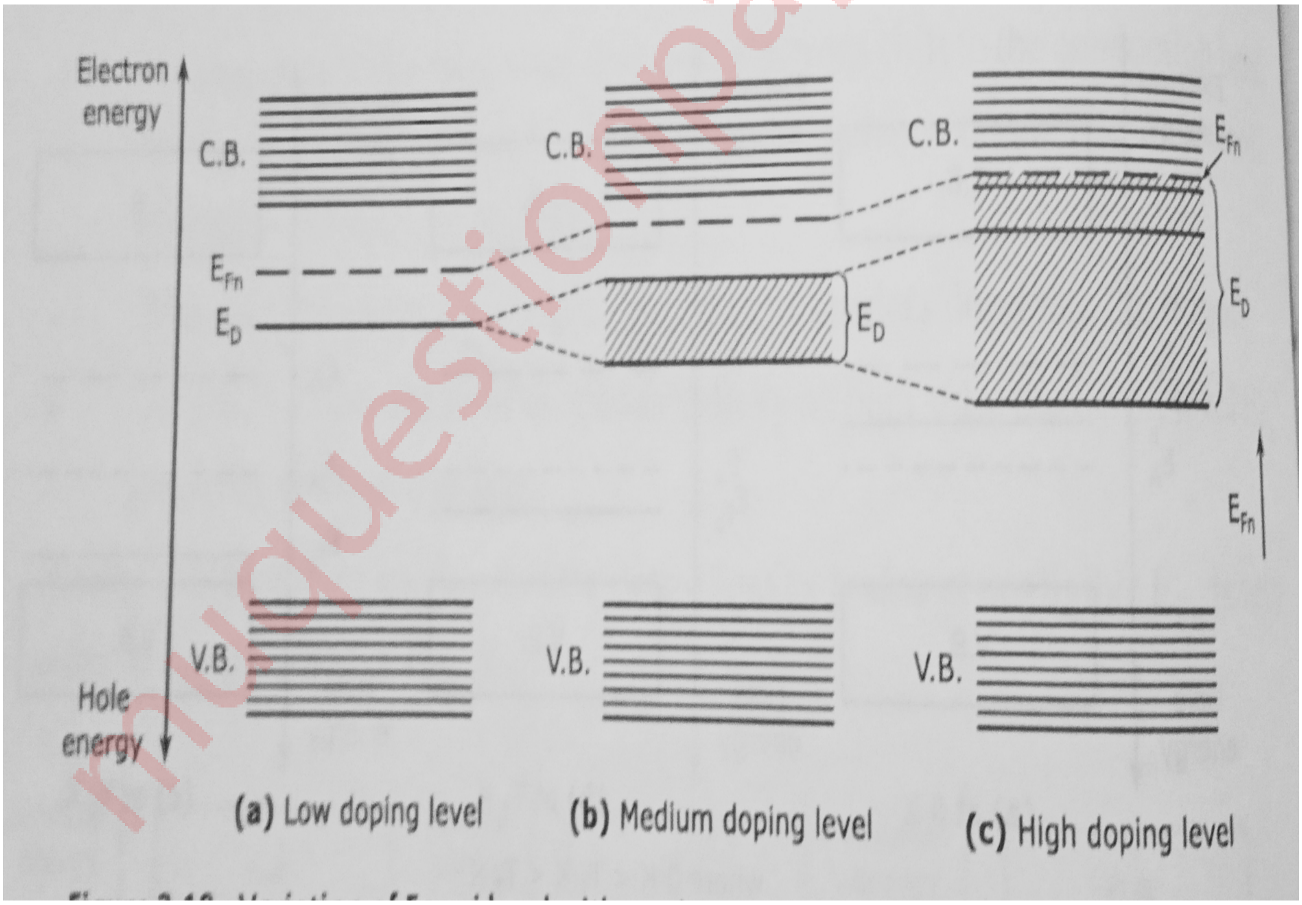
$$E_C + E_V = 2E_F$$

$$E_F = \frac{E_C + E_V}{2}$$

Thus the Fermi energy level lies in the middle of the forbidden energy gap in an intrinsic semiconductor.

Variation of Fermi Level with impurity concentration*:*

- *At low impurity concentration the impurity atoms do not interact with each other.Hence, the extrinsic carriers have their own discrete energy levels.*
- *With the increase in impurity concentration the interaction of the impurity atoms start and the Fermi level varies in the following way.*
- *As the impurity atoms interacts the donor electron are shared by the neighbouring atoms.*

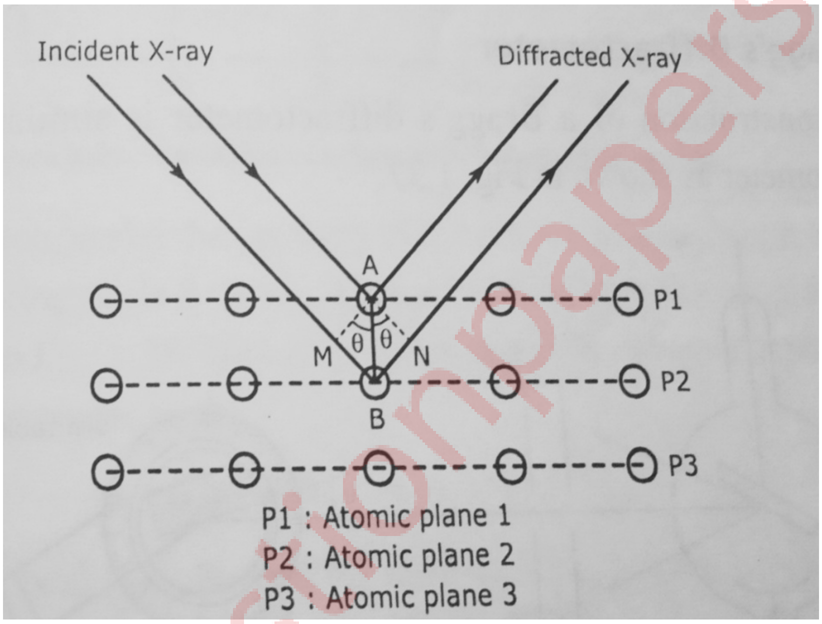


- *This results in splitting of the donor level and formation of the donor band below the conduction band. With the increase in impurity concentration the width of the band increases. At one stage it overlaps with the conduction band. As the donor band* *widens the forbidden gap decreases.In the process the Fermi level shifts upwards and finally enters the conduction band as shown:*

Q3](a) Derive Bragg's condition for X-ray diffraction. Monochromatic X rays are incident on a crystal. If the first order rejection is observed at an angle of 3.4°, at what angle would second order reflection expected.
(8)

Ans)

W.L.Bragg's explained the phenomenon of X-ray diffractionn from a single crystal shown as follows



When a beam of X-rays is incident on a crystal it is scattered by individual atoms of the rich atomic planes.Thus,each atom become a source of scattered radiation.The atomic planes responsible for the X-ray diffraction are called BRAGG'S PLANES. Therefore,the sets of Braggs planes constitute the crystal grating. Bragg's scattering or Bragg's diffraction is also referred as Braggs reflection. Bragg derived a law called Bragg's law to explain the X-ray diffraction effect. Here a beam of X-ray is incident on a set of parallel planes of a crystal.The rays makes glancing angle θ and are practically reflected from different successive planes.The phase relationship of the scattered rays can be determined from their path differences.Here two parallel X-rays are reflected from two consecutive planes P_1 and P .The path differences between them as shown

$$\delta = MB + BN = 2MB = 2AB\sin\theta.$$

Here AB = d,the interplanar spacing of the crystal

Hence, $\delta = 2d\sin\theta$

The two diffracted rays reinforce each other when they interfere constructively when their path

difference δ is equal to $n\lambda$

Hence, $2d\sin\theta = n\lambda$ *is called as Bragg's Law*

***Numerical solution**:*

Data: $\theta_1 = 3.4°$

***Formula**:* $2d\sin\theta = n\lambda$

***Solution**: From equation,* $\sin\theta \propto n$

Hence, $\sin\theta_1/\sin\theta_2 = n_1/n_2$

$\sin(3.4)/\sin\theta_2 = 1/2$

$\sin\theta_2 = 0.1186$

$\theta_2 = 6.8113°$

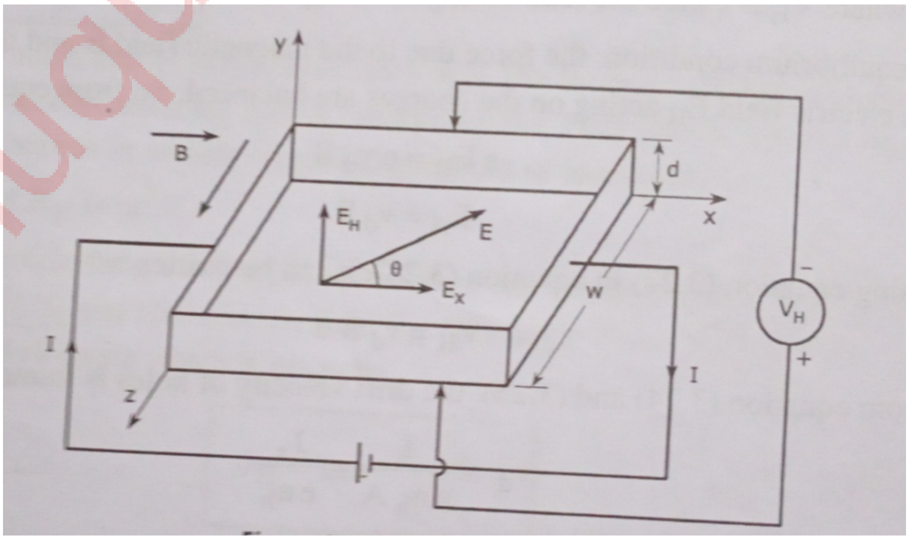
***Answer**: Hence, second order reflection is expected at 6.8113°*

Q3](b) Derive an expression for Hall voltage and Hall coefficient with neat labelled diagram. (7)

Ans) *If a current carrying conductor or semiconductor is placed in a transverse magnetic field,a potential difference is developed across the specimen in a direction perpendicular to both the current and magnetic field.The phenomenon is called HALL EFFECT.*

As shown consider a rectangular plate of a p-type semiconductor of width 'w' and thickness 'd' placed along x-axis.When a potential difference is applied along its length 'a' current 'I' starts flowing through it in x direction.

As the holes are the majority carriers in this case the current is given by



$I=n_hAevd$……………………………(1)

where n_h=density of holes

$A = w\times d$ = cross sectional area of the specimen

v_d = drift velocity of the holes.

The current density is

$J=I/A=n_hev_d$…………………….(2)

The magnetic field is applied transversely to the crystal surface in z direction.Hence the holes experience a magnetic force

$F_m=ev_dB$ ……………………………(3)

in a downward direction.As a result of this the holes are accumulated on the bottom surface of the specimen.

Due to this a corresponding equivalent negative charge is left on the top surface.The separation of charge set up a transverse electric field across the specimen given by

$E_H=V_H/d$ …………………………..(4)

Where V_H is called the HALL VOLTAGE and E_H the HALL FIELD.

In equilibrium condition,the force due to the magnetic field B and the force due to the electric field E_H acting on the charges are balanced. So from the equation (3)

$eE_H=ev_dB$

$E_H=v_dB$……………………………….(5)

Using equation (4) in the equation (5)

$V_H=v_dBd$ ……………………….(6)

From equation (1) and (2),the drift velocity of holes

$v_d=I/en_hA=J_x/en_h$ …………………….(7)

Hence,hall voltage can be written as

$$\boxed{\begin{aligned}VH&=IB_d/en_hA\\&=J_xBd/en_h\end{aligned}}$$

An important parameter is the hall coefficient defined as the hall field per unit current density per unit magnetic induction and is written as

$$\boxed{R_h=V_HA/IB}$$

Q4](a) Differentiate between Type-I & Type - II Superconductors.

(5)

Ans)

Sr.No.	*Type I superconducters*	*Type II superconductors*
1.	*They exhibit complete Meissner effect.*	*They exhibit partial Meissner effect.*
2.	*There are perfect diamagnetics.*	*They are not perfect diamagnetics.*
3.	*These are known as soft superconductors.*	*They are known as hard superconductors.*
4.	*They have only one critical magnetic field.*	*They have two critical magnetic fields.*
5.	*These material undergo a sharp transition from the superconducting state to the normal state at the critical magnetic field.*	*These materials undergo a gradual transition from the superconducting state to the normal state between the two critical magnetic fields.*
6.	*The highest value of critical magnetic field is 0.1 WB/m*^{2}	*The upper critical magnetic filed can be of the order of 50 Wb/m*^{2}
7.	*Application are very limited.*	*They are used to generate very high magnetic fields.*
8.	*Examples: Lead, Tin, Mercury, etc*	*Examples: Alloys like Nb-Sn, Nb-Ti, etc.*

Q4](b) Discuss in details any three factors affecting acoustics of a hall with their remedies.

(5)

Ans) *(1)**Defect***-**Echo**

Echo is a sound wave reflected from a parallel hard smooth surface. Excessive echo affects the acoustics of the hall.

***Design**:A splayed (fan shaped) floor plan and the covering of interior surfaces with suitable absorbent material minimize the defect and distribute the sound energy uniformly throughout the hall.*

(2) ***Defect***-**Echelon Effect**

Successive echo of a sound from a set of regularly spaced parallel and smooth surfaces cause Echelon effect which makes the original sound unintelligible.

Design *: The steps inside the hall should be covered with absorber like carpets.*

(3) ***Defects*** *:* **Reverberation**

The persistence of sound in a room due to multiple reflection from the walls,thefloor and the ceiling for some time,is called reverberation.

Design*:Though excessive reverberation distorts the original sound a small amount of reverberation is desirable in a concert hall since it improves the quality of music. The reverberation is optimized by placing and fixing sound absorbing material in the hall. This way the reverberation time is controlled to a desired value.*

Q4](c) A quartz crystal of thickness 1 mm is vibrating at resonance. Calculate its fundamental frequency. (Assume that for quartz, $Y= 7.9\times 10^{10}$ N/m^2 and $\rho = 2.650$ gm/cc. (5)

Ans) ***Data****:* $t_1 = 1\ mm= 10^{-3}\ m,\ \ Y = 7.8 \times 10^{10}\ N/m^2,$

$\rho\ = 2.650\ gm/cc = 2650\ kg/m^3$

Formula*:* $f= 1/2t \bullet \surd Y/\rho$

Calculations*:* $f = 1/2\times 10^{-3}\ \surd\ 7.9\times 10^{10}/2650 = 2.73\ MHz$

Answer*:Frequency = 2.73 MHz*

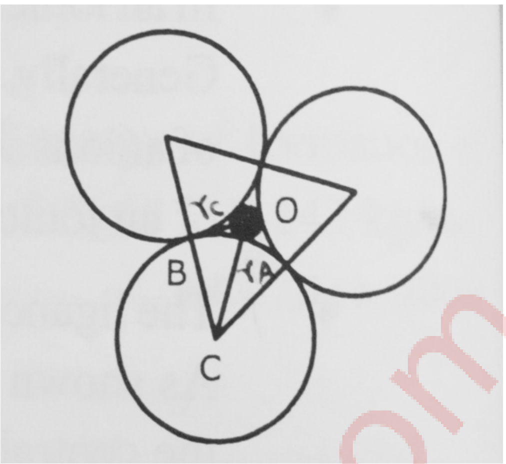
Q5](a) Define Ligancy. Find the value of critical radius ratio for Ligancy 3. (5)

Ans*)In an ionic solid, the actions are positioned at alternate lattice points. Generally,cations are smaller than anyone in size. in a crystal,thr number of anions surrounding a cation is called as Ligancy.*

Ligancy 3*:Triangular configuration*

The arrangement is triangular since a triangle is formed if the centres of the neighbouring anions are joined.In critical condition all the neighbouring anions and the central cation are in contact with each other,as shown in figure,

Here, $BC=r_A$ *and* $OC=r_A+r_C$ *and* $\angle\ BCO=30^0$



In the Δ OBC,we get

$BC/CO=\cos 30^0$

or $r_A/r_C+r_A = \sqrt{3}/2$

or $r_C+r_A/r_A = 2/\sqrt{3}$

The critical radius ratio is thus

$r_C/r_A = 0.155$

Q5](b) For an electron passing through potential difference 'V', show that its wavelength is; (5)

$\lambda=12.26/\sqrt{V}$ A°.

Ans) *The wavelength of an electron with kinetic energy E is given by*

$\lambda=h/\sqrt{2mE}$ .... (1)

On the other hand, the kinetic energy of an electron passing through potential difference'V' is,

$1/2\ mv^2 = eV$

Hence, $E=eV$ *Thus, replacing E with eV in equation (1), we get,*

$\lambda=h/\sqrt{2meV}$ .... (2)

Substituting values of,

$h = 6.63 \times 10^{-34}$ kg-m/s

$m = 9.1 \times 10^{-31}$ kg

$e = 1.6 \times 10^{-19}$ coulomb

in equation (2), we get,

$\lambda = 1.226 \times 10^{-19} /\sqrt{V}$ metre

$\lambda = 12.26 / \sqrt{V}$ A°

Q5](c) What is the probability of an electron being thermally excited to conduction band in Si at 27°C.The band gap energy is 1.12 eV. (5)

Ans) ***Data***: $T = 27°C = 300\ K$, $E_g = 1.12\ eV$

$K = 1.38 \times 10^{-23}$ J/K $= 86.25 \times 10^{-26}$ eV/K

Formula: $f(E_C) = 1/1+e^{(Ec-Ef)/kT}$

Calculations: *Since an intrinsic semiconductor. Hence,*

$E_C - E_F = E_G/2 = 0.56$ eV

$f(E_C) = 1/1+ \exp[0.56/86.25\times 10^{-6}\times 300] = 3.9 \times 10^{-10}$

Answer:*Probability* $= 3.9 \times 10^{-10}$

Q6](a) Explain Point defects in crystals. (5)

Ans) *In any crystal, at all temperatures above absolute zero, there are always some free atoms present which lodge themselves anywhere other them their scheduled lattice sites. This give rise to point defects.*

Point defects can be classified into the following categories:

Vacancy defects: *This is a defect in which an atom is missing from a regular lattice site, l. Such vacancies arise in close packed structures, i.e., metallic structures.*

Interstitial defects: *An interstitial defect is an imperfection in which an atom that has moved from its*

regular lattice dates lodges itself in the interstices i. e., the void space.

Substitutional impurity: *When a regular atom leaves behind a vacancy and goes to the interstices the vacant lattice site can be occupied by a foreign atom.*

Interstitial impurity: *This is the kind of imperfection when a foreign atom lodges itself in the interstices. Thus can oxide only when the foreign atomism substantially smaller than the host atom.*

Schottky defect: *In an ionic crystal, a pair of vacancies arise which leas to missing of one Casio and one anion from the regular lattice sites. This is known as Schottky defect in which the charge neutrality is maintained.*

Frankel defect: *The cations are v smaller than anions. In ionic crystals if a cation leaves its regular lattice site and lodges itself in the interstices it is called Frenkel defect. It is a combination of a cation vacancy and one intersticial defect.*

Q6](b)Show that group velocity of matter waves associated with a particle is equal to the particle velocity($V_{group}=V_{particle}$) (5)

Ans)

Consider a particle of rest mass m, moving with a vclocity,v,which is very large and comparable to c with v <c.Its mass is given by the relativistic formula,

$m= mo /\sqrt{1-(v^2/c^2)}$ ....(1)

Let ω be the angular frequency and k be the wave number of the de Broglie wave associated with the particle.Here v is the frequency and λ is the wavelength of the matter wave. Hence,it can be written that

$\omega = 2\pi v = 2\pi(mc^2/h)$

$\omega = 2\pi/h \cdot m_o c^2/\sqrt{1-(v^2/c^2)}$............(2)

And $k = 2\pi/\lambda = 2\pi p/h = 2\pi mv/h$

$k = 2\pi/h \cdot m_o v/\sqrt{1-v^2/c^2}$

- *The wave velocity is the the phase velocity given by*

  $v_p = \omega/k = c^2/v$..................(3)

- *Since the wave packet is composed of waves of slightly different wavelength and velocities, the group velocity is written as*

  $v_g = d\omega/dk$

- *This can be calculated using equation (1) and (2) as*

$$v_g = \frac{dw/dv}{dk/dv}$$

$$= [d/dv(c^2/\sqrt{1-(v^2/c^2)})]\cdot[d/dv(v/\sqrt{1-(v^2/c^2)})]^1$$

$v_g = v$

This shows that a matter particle in motion is equivalent to a wave packet moving with group velocity v_g *whereas the component waves move with phase velocity,* v_p.

Q.6](c) Explain the principle, construction and working of Light Emitting Diode. (5)

Ans) ***Principle****: The recombination process:*

- *In a forward biased p-n junction through electrons and holes diffuse through the junction in opposite directions. In this process they recombine with each other in the depletion region and release some energy called the recombination energy.*
- *According to energy band structure, during the recombination process the electron*

come back to the valence band and fulfil the gap called a hole. This is accompanied by the release of some energy equal to the band gap energy E_g.

- *For ordinary semiconductors like Ge and Si the bandgap energies are 1.12 eV and 0.63 eV respectively. In these solids the recombination energy is heat energy.*
- *However, if E_g ranges from 1.7eV to 3.0 eV, according to $E = hv = hc/\lambda$, the emission takes place within the visible region. This is possible if the direct band AGP ionic crystals like Gallium Arsenide (GaAs), Gallium Arsenide Phosphide (GaAsP) and Gallium Phosphide (GaP) are used as the diode material. In this case the recombination energy is emitted as optical energy.*
- *The wavelength of the emitted light is given by*

$$\lambda = hc/E_g = 1.24/E_g(eV) \quad \mu m$$

- *The colours of the emitted light are as follows:*

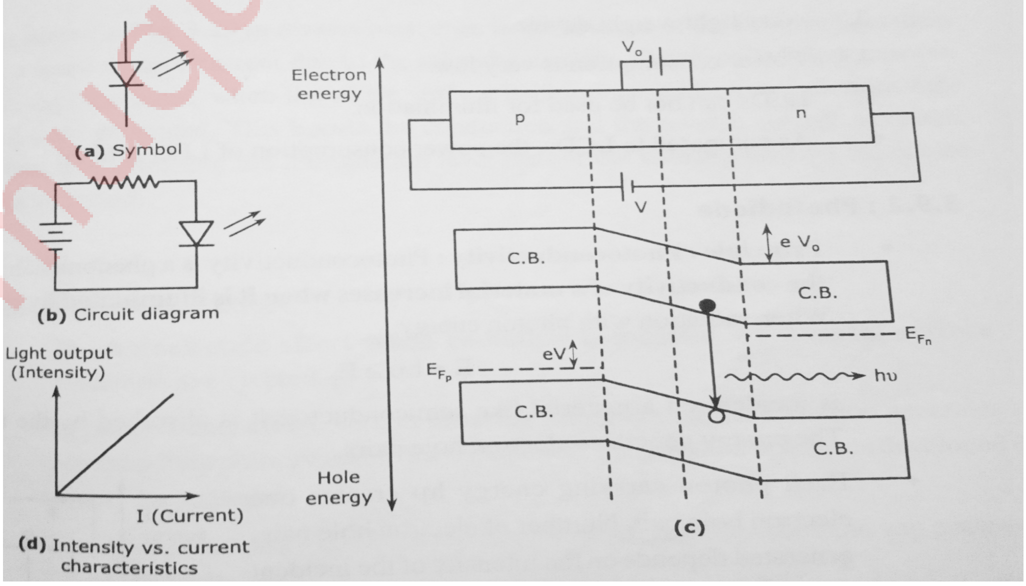
(1) GaAs, GaP, GaAsP for red, orange, yellow and green light.

(2) ZnS and SiC for blue,

(3) GaN for violet.

Construction and working:

- *A light emittingdiode is always forward biased and the forward voltage across a LED is Typical forward LED voltage ranges from 1.2 V to 3.2 V depending on the device.*
- *The symbol of LED and a typical LED circuit are shown in Fig.(a)and (b)respectively.The energy band diagram showing the recombination process is shown in Fig.(c).The intensity of the light output of an LED is directly proportional to the forward current which is shown in Fig.(d).*
- *The materials used for LED operate at low voltages and current typically at 1.5 V and 10 mA. Hence, LEDs are low price device which cannot be used for illumination*



purposes.

- *The LEDs have very low reverse break down voltage, typically, 3V.Therefore, LEDs should never be reverse biased which will cause damage to it.*

APPLIED PHYSICS I

CBCGS MAY 2019

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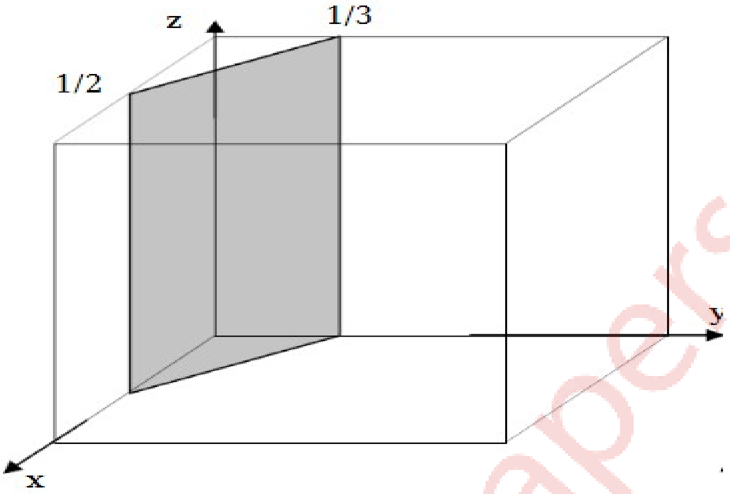
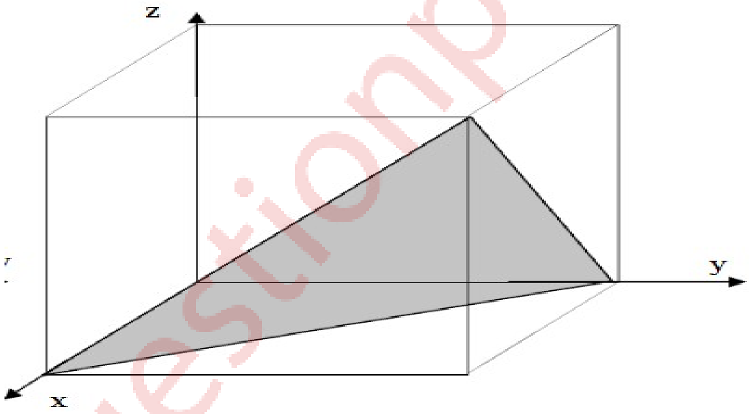
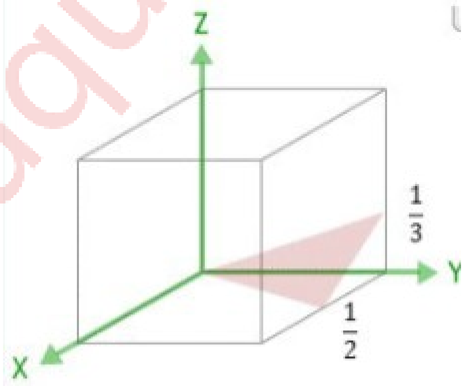
a.Draw the following for a cubic unit cell. [$\acute{1}\,\acute{2}\,\acute{3}$] **, [2 0 0],** [$\acute{2}\,\acute{3}$ **0] .** **(3M)**

Ans :







b. Show that the Fermi energy level lies at the centre of the band gap in intrinsic semiconductors. (3M)

Ans : At any temperature T > 0 K

n_e = Number of electrons in conduction band .

n_v = Number of holes in valence band

We have $n_e = N_c e^{\frac{-(E_C - E_f)}{KT}}$ where N_c = Effective density of states in conduction band

And $n_v = N_v e^{\frac{-(E_F - E_V)}{KT}}$ where N_v = effective density of states in valence band

For best approximation $N_c = N_v$.

For intrinsic semiconductor

$n_c = n_v$.

$$N_C . e^{\frac{-(E_C - E_F)}{KT}} = N_V . e^{\frac{-(E_F - E_V)}{KT}} .$$

$$\frac{e^{\frac{-(E_c - E_F)}{KT}}}{e^{\frac{-(E_F - E_V)}{KT}}} = \frac{N_C}{N_V} .$$

$$e^{\frac{-(E_C - E_F - E_F + E_V)}{KT}} = \frac{N_V}{N_C} .$$

$$e^{\frac{-(E_C + E_V - 2E_F)}{KT}} = \frac{N_V}{N_C}$$

As $N_V = N_C = 1$.

$$e^{\frac{-(E_C + E_V - 2E_F)}{KT}} = \frac{N_V}{N_C} .$$

Taking ln on both sides

$$\frac{-(E_C + E_V - 2E_F)}{KT} = 0 .$$

$\therefore (E_C + E_V) = 2 E_F$.

$$\therefore E_F = \frac{E_C + E_V}{2} .$$

Thus, the Fermi level in an intrinsic semiconductor lies at the center of forbidden energy gap .

c. The mobility of hole is 0.025 m^2 / V.s. What would be the resistivity of p-type Si sample if its Hall coefficient is 2.25 $\times 10^{-5}$ m^3/c . (3M)

Given : $\mu = 0.025\ m^2/Vs$, $R_H = 2.25 \times 10^{-5}\ m^3/c$.

To find : Resistivity (ρ) .

Formula : $\rho = \dfrac{R_H}{\mu}$.

Solution : $\rho = \dfrac{2.25X10^{-5}}{0.025}$.

$\rho = 9 \times 10^{-4}$ ohm-m .

---

d. Explain de broglie's hypothesis of matter waves and deduce the expression for λ. (3M)

Ans : Interference, diffraction requires wave nature for their explanation. In photo-electric effect Einstein visualized the incident light as a sort of particles which he called photons and accounted for the emission of electrons as due to the collision between these photons and electrons bound to the metal. During the collision, the photon transfers all its energy to the electrons which results in the emission of photo electrons. Here the behaviour of light is same as that of a particle.

Louis De Broglie put forward the dual behaviour in terms of hypothesis which states "If the radiation behaves as particle under certain circumstances, then one can even expect that, entities which ordinarily behave as particles to exhibit properties attributed to only waves under appropriate circumstances.

Consider a wave of frequency ν

$$E = h\nu .$$

It can also be represented as

$$E = mc^2 .$$

$$\therefore h\nu = mc^2 .$$

Now p= momentum associated with photon which travels in free space .

$$p = mc = \frac{mc^2}{c} = \frac{h\upsilon}{c} = \frac{h}{\lambda}$$

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

---

e. Explain reverberation of sound. (3M)

Ans : 1. Reverberation means the prolonged reflection of sound from walls, floor or roof of a hall.

2. It is persistence of sound even after the sources of the sound has stopped.

3. The time gap between the initial direct note and the reflected note upto a minimum audibility level is called reverberation time.

4. When a source emits sound, the waves spread out and the listener is aware of the commencement of sound when the direct waves reach his ears.

5. Subsequently, the listener receives sound energy due to reflected waves also.

6. If the note is continuously sounded, the intensity of sound at the listener's ears gradually increases.

7. After sometime, a balance is reached between the energy emitted per second by the source and energy lost or dissipated by walls or other materials.

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f. Explain Meissner Effect with the help of diagram . (3M)

Ans : 1) A superconducting material kept in a magnetic field expels the magnetic flux out of its body when cooled below the critical temperature and exhibits perfect diamagnetism. This effect is called **'Meissner effect'**

2) Refer fig. 4.4.1(a), where a specimen is subjected a magnetic field. The specimen is in normal state. We find that magnetic field penetrates the specimen.

3) Refer Fig. 4.4.1(b), now the specimen is cooled below its Tc, the superconductor expels field lines from its body. This is Meissner effect.

4) Refer Fig. 4.4.1(c), when the field is switched off magnetic field will not be trapped by the superconductor cooled below Tc.

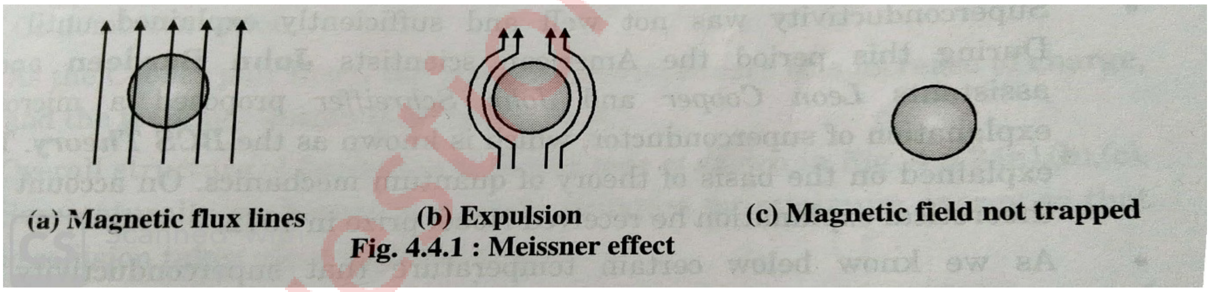

Fig. 4.4.1 : Meissner effect

5) As specimen expels the magnetic flux, it is exhibition of perfect diamagnetism, susceptibility is found out to be -1. Let see it mathematically.

For normal state, magnetic induction inside the specimen is given by

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

Where μ_0 = absolute permeability

H = external field applied

M = Magnetization produced within specimen .

At $T < T_C$, $B = 0$ i.e. superconducting state

$$\therefore \mu_0(H+M) = 0$$

$$\text{Susceptibility} = \frac{M}{H} = -1 .$$

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g. Discuss any three applications of Ultrasonic waves . (3M)

Ans : The applications of Ultrasonic waves are :

1) Echo Sounding :
   a) Ultrasonic generator will send repeated pulses towards the target and the reflection from target is collected by a transducer and displayed on CRO screen along with the sent impulse .
   b) From the difference in time between pulse sent and collected, one can find the distance as velocity of ultrasound is known .

   Distance of the target = $\frac{vt}{2}$ where v= velocity , t= time difference

   This principle is used for depth sounding of water , detection of submerged objects and SONAR .
   c) In sea water, the velocity of ultrasound is given by

   $$v = 1510 + 1.14\ S + 4.21\ t - 0.037\ t^2.$$

   where S = Salinity of sea water , t = temperature in $^\circ$ C, v = velocity in m/sec .
2) Cavitation :
   a) When ultrasonic waves of very high frequency pass through the liquid, formation of small bubbles, called micro bubbles takes place .
   b) This is because excessive stress on the liquid breaks it apart and a bubble is formed .The bubbles are highly unstable and they soon collapse producing a high vacuum within .
   c) Due to this action, implosion takes place .The area surrounding the bubble has a tremendous pressure .
   d) The particles in the vicinity of these bubbles are strongly pulled towards the centre of the bubbles. This process of creating cavity is called cavitation .
   e) It is used in

      → Emulsification of two immiscible liquids like water and oil .

      → To prepare dairy products, sauces and gravies, synthetic creams .

      → Dispersion of metals in the molten materials to obtain uniform alloying.

Q2)a) Derive Bragg's equation for X-ray diffraction in crystals. Calculate the glancing angle on a plane (1 0 0) of rock salt having lattice constant 2.814 A° corresponding to first order Bragg's diffraction maximum for X-rays of wavelength 1.541 A°. (8M)

Ans : A monochromatic X-ray beam when made incident on them at an angle which is called as glancing angle, and showed that constructive interference takes place between the rays scattered by the atoms only when a condition called Bragg's Law is satisfied.

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

Where d = interplanar spacing and n= integer .

When the condition for constructive interference is satisfied, a sudden jump in the intensity is observed.

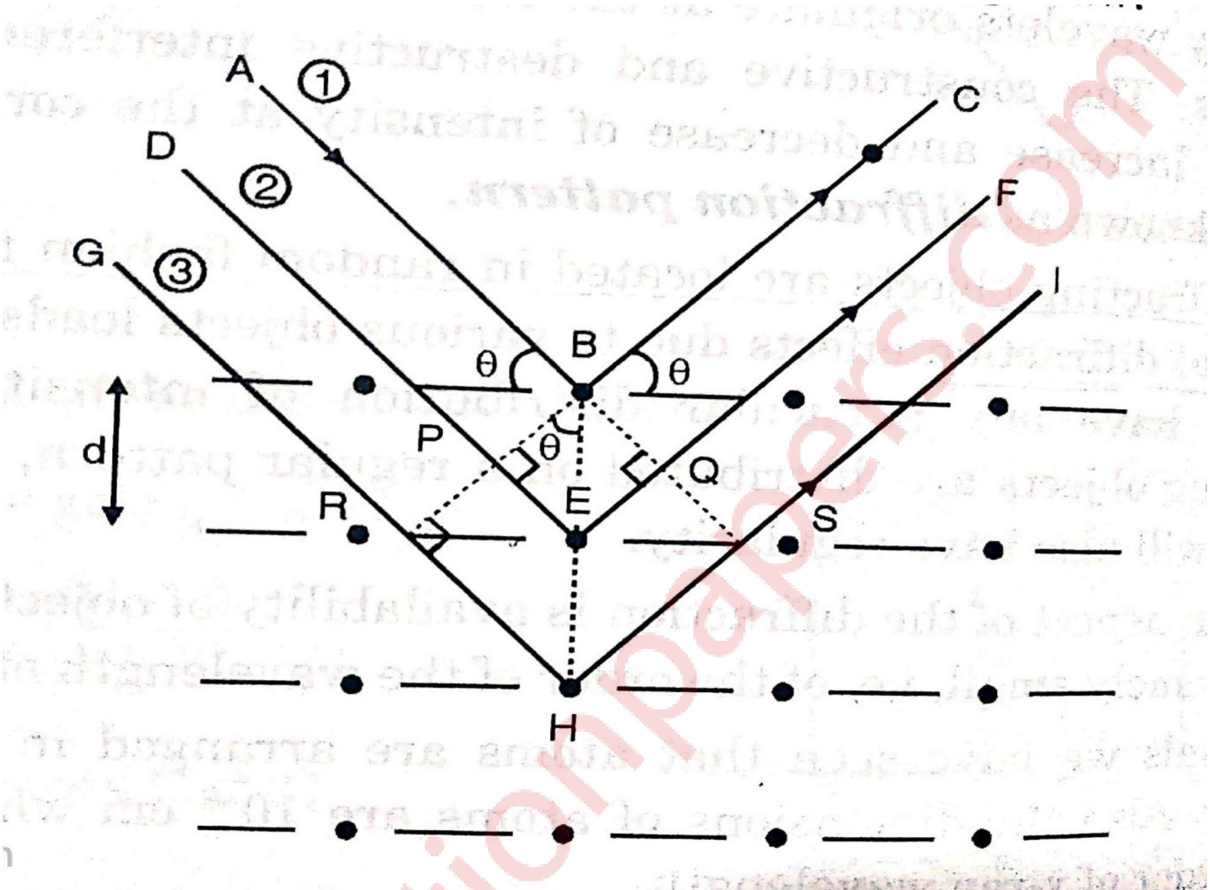


Fig. 1.7.1 : Bragg's law

In the figure, we have Bragg's plane with atoms shown with dots. An ordered or regular arrangement of atoms has been depicted. Let the interplanar spacing be D. A monochromatic and parallel beam of X-rays at glancing angle θ is made incident on planes. Ray AB will get scattered at point B on the first plane. Rays DE and GH which are parallel to AB will also experience scattering at points E and H respectively at second and third plane. The scattering due to atoms on crystal plane is in all directions.

Among the scattered rays select rays BC and EF which are parallel to each other. It is assumed that they have path difference Δ = nλ and produce constructive interference. Bragg's Law provides the condition at which Δ= nλ .Lets obtain the value of path difference Δ.

Draw perpendiculars BP and BQ to the rays DE and EF. No one can say that upto BP, path covered by both the incident rays is the same. So as BQ onwards parallel rays BC and EF covers the same distance.

Hence Path difference between rays 1 and 2 is

Δ = PE + EQ

From Δ BPE and Δ BQE, PE = BE sinθ and

EQ = BE sinθ

$$\Delta = \text{BE}\sin\theta + \text{BE}\sin\theta = 2\text{BE}\sin\theta = 2\text{d}\sin\theta \ (\text{BE} = \text{d}).$$

As constructive interference is taking place,

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

The same logic can be extended for rays 2 and 3.Hence if rays 1 and 2 gives constructive interference and rays 2 and 3 also give constructive interference, then rays 1 and 3 will also provide the same.In this case, path difference between rays 1 and 3 will be

$$\Delta' = 4d\sin\theta = 2(2d\sin\theta) = 2\Delta \quad \text{i.e. integer multiple of } \Delta \ .$$

Numerical : (1 0 0) ≡ (h k l) , a = 2.814 Å , n = 1 , λ = 1.514 Å

$$d = \frac{a}{\sqrt{h^2+k^2+l^2}} = \frac{1.514}{\sqrt{1^2+0^2+0^2}} = 1.514 \ \text{Å} \ .$$

nλ = 2dsinθ .

$$1X2.814 = 2X1.514X\sin\theta \ .$$

$$\therefore \sin\theta = \frac{2.814}{2X1.514} = 0.0929 \ .$$

$$\therefore \theta = \sin^{-1}(0.929) = 6.833^{\circ} \ .$$

Ans : The glancing angle measures 6.833° .

Q2)b) What is Hall Effect? Derive an expression for Hall Voltage. How can mobility be determined by using Hall Effect .? (7M)

Ans : 1. If a metal or semiconductor, carrying a current I is placed in a transverse magnetic field B, an electric field E is induced in the direction perpendicular to both I and B. This phenomenon is known as Hall Effect and the electric field or voltage induced is called Hall Voltage (V_H) . The physical process of hall effect is as follows. Consider a specimen along positive x-direction.

2. The current flowing through the specimen is in the positive x-direction and the magnetic field is in the positive z-direction. The force exerted on charge carriers, that is, on electrons is downward. The electrons move downward and thus voltage H (Hall Voltage) is developed with upper surface as positive and lower as negative.

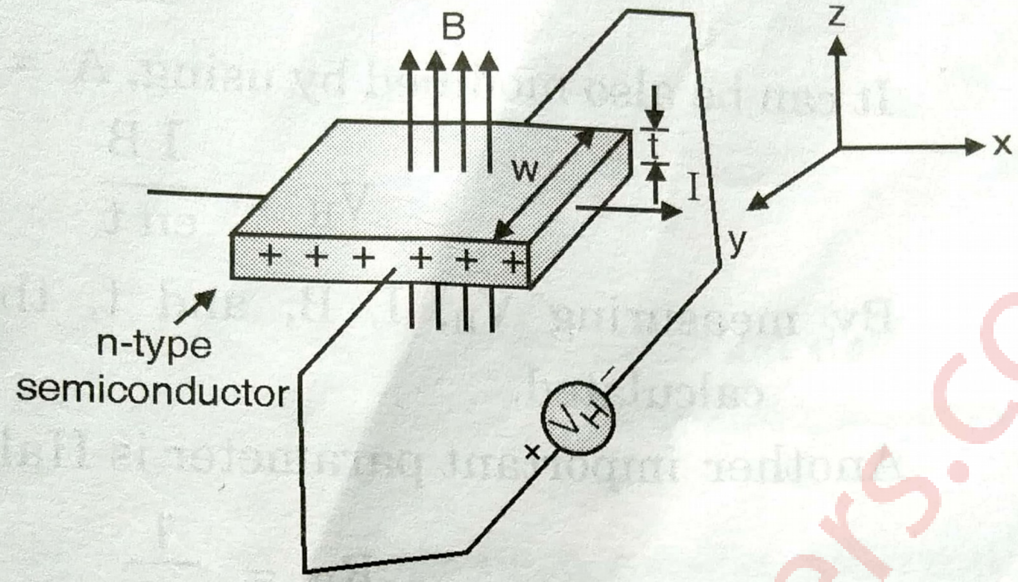


Fig. 3.14.1 Hall effect

3. If the specimen is assumed to be of n-type, then magnetic force experienced by electrons will be towards -Y direction as it is applied transversely.

∴ Magnetic Force F = e v B .

4. Holes present in specimen will experience the same force but in positive Y direction. Hence electrons and holes will be separated.

5. This develops potential difference between both the surface denoted by V_H , called as Hall Voltage.

$$\therefore E_H = \frac{V_H}{w} .$$

The current is given by I = n A e v where v = drift velocity .

6. In equilibrium condition, the force due to magnetic field B and the force due to electric field E_H acting on the charge are balanced .

$\therefore e E_H = evB$.

Or $E_H = vB$.

$\therefore V_H = Bvw$.

$v = \frac{I}{enA} = \frac{J}{en}$. where $J = \frac{I}{A}$.

Hence Hall Voltage is written as

$$V_H = \frac{IBw}{enA} = \frac{Bw}{en}.J$$

It can be modified by using A = w X t

$$V_H = \frac{IB}{ent} \;.$$

By measuring V_H , I , B and t , the charge density ($n_h e$ or $n_e e$) can be calculated .

The Hall Coefficient R_H is defined as

$$R_H = \frac{1}{pe}$$ (for p-type semiconductor)

$$R_H = \frac{1}{ne}$$ (for n-type semiconductor)

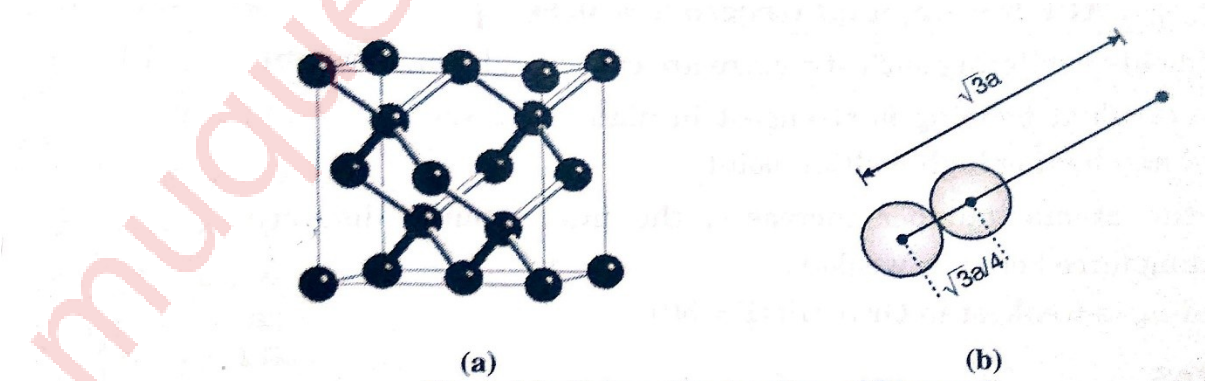
$$R_H = \frac{V_H t}{BI} \;.$$

As $\sigma = \mu ne$, $\mu = \sigma R_H$ where μ is mobility , σ is conductivity .

If the conductivity and Hall coefficient are measured, then the mobility can be determined .

Q3)a) Derive the relation between density and lattice constant for a cubic crystal. Calculate the lattice constant, atomic radius and packing factor for Chromium having BCC structure. Given density of Chromium is 5.98 gm/cc and atomic weight is 50. (8M)

Ans : 1. Let us considered the example of diamond cubic structure. The diamond lattice can be described as being built up from two identical interpenetrating FCC sub lattice one of which is displaced from the other by 1/4th of the length along body diagonal.



(a) (b)

Fig. 1.4.1 : Schematic structure of Diamond

2. The atomic basis is two atoms per lattice point, i.e. each lattice point corresponds to two identical atoms, one located at (0, 0, 0) and other at $\left(\frac{1}{4},\frac{1}{4},\frac{1}{4}\right)$.

3. The four corner atoms are at diagonally opposite points in the respective planes. With this arrangement, two carbon atoms one at the center of the tetrahedron and the other at the corner, form the basis.

4. In a diamond structure, eight atoms are at eight corners, six face centered atoms at the centers of each of the six faces and four atoms are positioned on the way along the body diagonal inside the unit cell, in such a way that each of them is linked tetrahedrally with one corner and three face centered atoms.

Number of atoms / unit cell is 8 .

The length of body diagonal = $\sqrt{3}a$ and $\frac{1}{4}$ of body diagonal = 2 r .

$$\therefore \frac{\sqrt{3}a}{4} = 2r \ .$$

$$\therefore r = \frac{\sqrt{3}a}{8} \ .$$

APF (Atomic Packing Factor)

APF for diamond structure = $\frac{(Number\ of atoms\ per\ unit\ cell)\ X\ (Volume\ of\ one\ electron)}{Volume\ of\ unit\ cell}$.

$$= \frac{8X\frac{4}{3}\pi r^3}{a^3} = \frac{8X\frac{4}{3}\pi\left(\frac{\sqrt{3}a}{8}\right)^3}{a^3} = 0.34 \ .$$

APF for diamond structure = 0.34 .

Element exhibiting such structure are carbon, silicon, germanium, gray tin. The covalent bonding is strongest in diamond crystal (Z=6) so it is very hard and having high melting point. As the atomic number increases, the inter atomic distances increases, binding force becomes weaker. Bonding is weakest in Gray tin (Z = 50) .

Numerical : $\rho = 5.98$ gm/cc , M = 50 g .

We know that $\rho a^3 = \frac{nM}{N}$ where n is No. of atoms/unit lattice , N is Avogadro's Number .

$$\therefore a^3 = \frac{nM}{N\rho} \ .$$

$$\therefore a^3 = \frac{2X50}{6.022X10^{23}X5.98} \ .$$

$\therefore a = 3.028X10^{-8}$ = 30.28 Å

Since it is BCC lattice , $a = \frac{4r}{\sqrt{3}}$.

$\therefore$ $r = \frac{\sqrt{3}a}{4}$ = 1.311 Å

Since It is a BCC cubic lattice, the APF is 68% .

Q3)b) Explain the formation of P-N junction in equilibrium with energy band diagram and explain its conduction process in forward bias . (7M)

Ans : 1. For unbiased p-n junction, no current flows through the junction. This also happens when junction is in thermal equilibrium. It implies that drift of minority carriers is counter balanced by the diffusion of majority carriers of equal number.

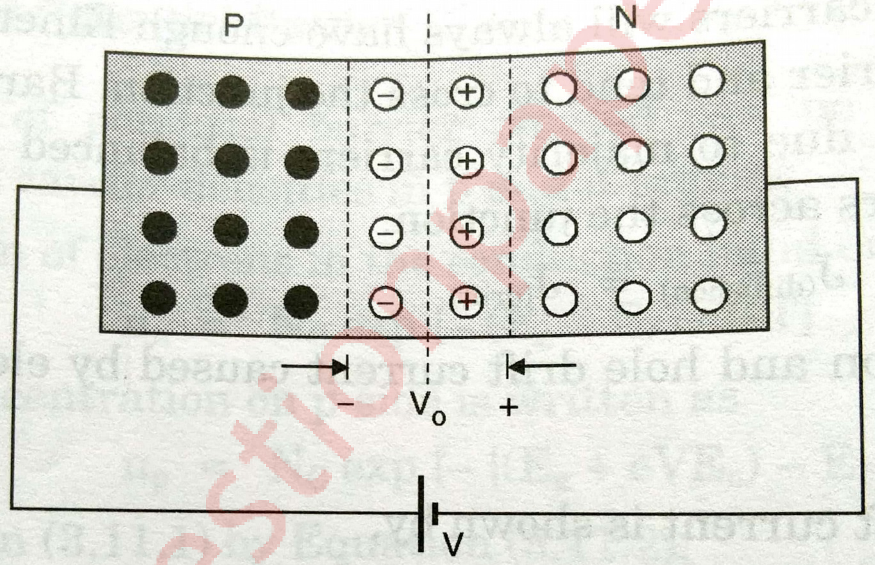


Fig. 3.13.1

2. A few majority carriers will always have enough Kinetic energy to overcome the built in barrier and tend to cross the junction. Barrier height is adjusted till the current due to majority carriers is balanced by the current due to minority carriers across the junction.

$\therefore$ $J_{(diffusion)} = J_{(drift)}$.

Let electron and hole drift current be caused by electric field (hence drift current)

$\therefore$ Net drift current is shown by ,

$J_{drift} = J_{hn} + J_{ep}$.

For n and p region and due to minority carriers .

Similarly ,

$$J_{(diffusion)} = J_{hp} + J_{en} \quad .$$

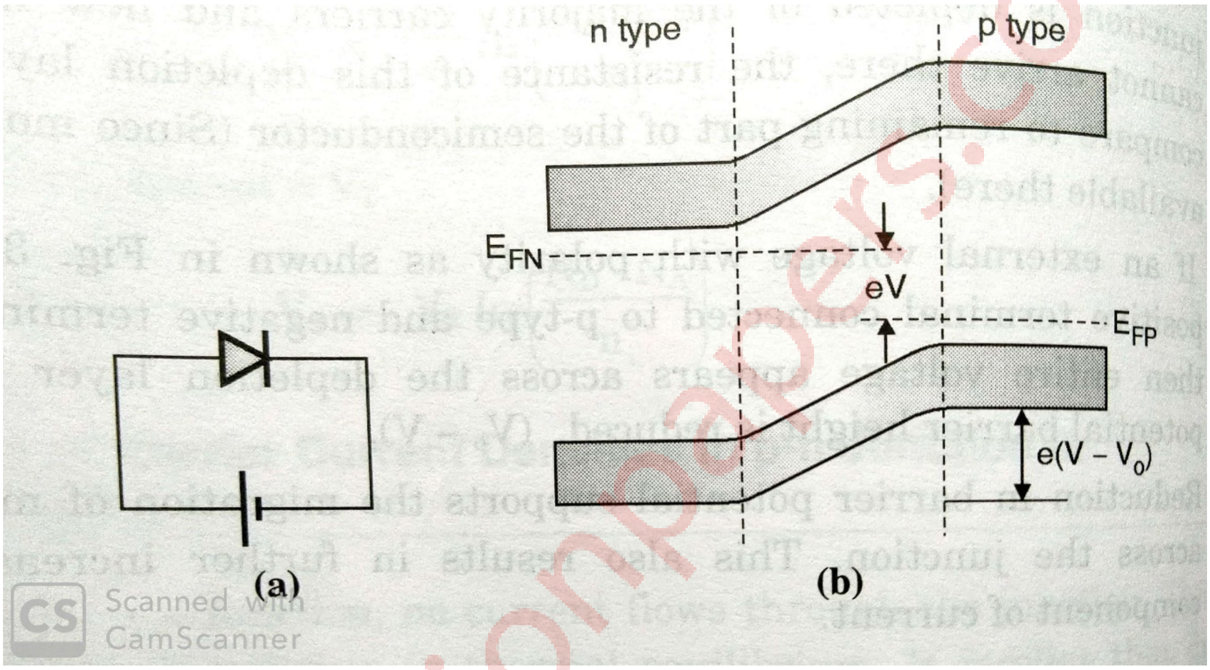
Therefore there cannot be a net built up of electrons or holes on either side with time due to electrical neutrality on both sides.

Hence at equilibrium

$$J_{hp} - J_{hn} = 0 \qquad \text{and} \qquad J_{en} - J_{ep} = 0$$

$$\therefore J_{hp} = J_{hn} \qquad \text{and} \qquad J_{en} = J_{ep} \quad \text{at equilibrium .}$$

Forward Biasing



a. A potential barrier results due to immobile ions at p-n junction. Since a junction is depleted of the majority carriers and new majority carriers cannot arrive there, the resistance of this depletion layer is very high as compared to the remaining part of the semiconductor (Since mobile carriers are available there).

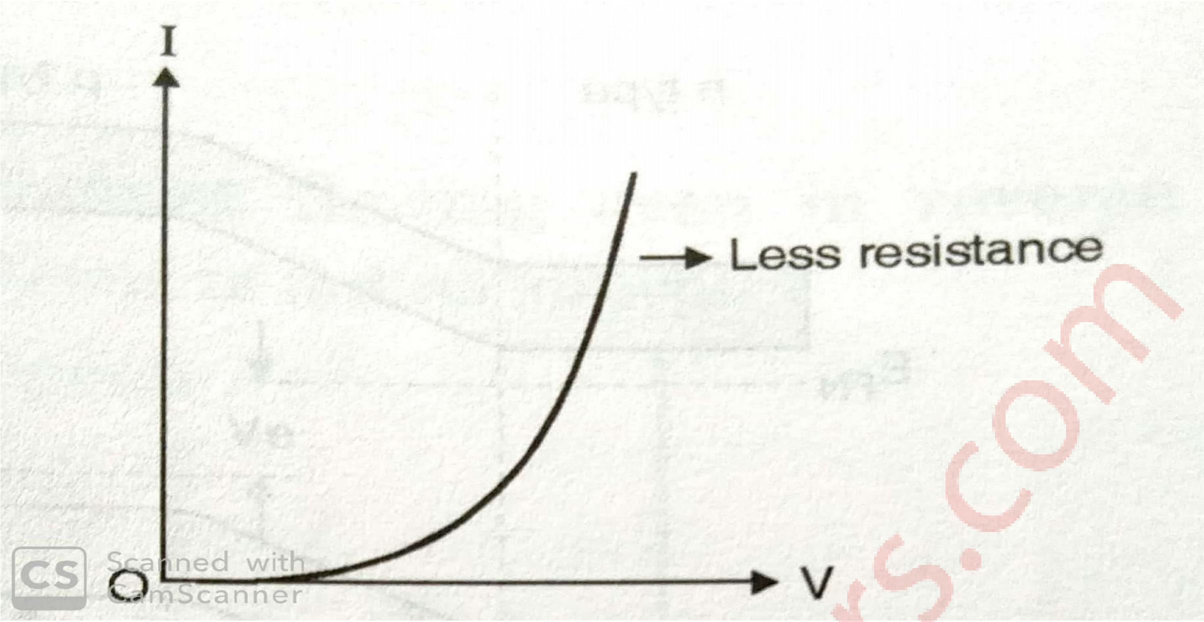
b. If an external voltage with polarity as positive terminal connected to p-type and negative terminal with n-type, then entire voltage appears across the depletion layer and hence the potential barrier height is reduced, $(V_0 - V)$.

c. Reduction in barrier potential supports the migration of majority carriers across the junction. This also results in further increase in diffusion component of current .

d. Increase in the current can also be termed as reduction of resistance at PN junction.

e. With increase in forward voltage across PN junction, reduces the resistance and more current flows.

f. Minority carriers are not affected in this process hence current due to minority carriers remains unaffected.



g. Effect of forward biasing on band structure can be understood by considering the simple fact that negative terminal connected to n-side increases electron energy and positive terminal connected to p-side increases hole energy. This in turn provides upward shift to all energy levels on the n-side and lowers the energy level on p-side.

h. Fermi level which was same for P and N side in unbiased junction, now gets separated by eV and becomes E_{FN} and E_{FP} .

Q4)a) Differentiate between Type-I and Type-II Semiconductors . (5M)

Type I	Type II
1. Type I semiconductors exhibit only one critical field .	1. Type II semiconductors exhibit two critical fields namely lower critical field and higher critical field .
2. The critical magnetic field value is very low .	2. The critical magnetic field value is high .
3. Type I semiconductors are explained on the basis of BCS Theory .	3. There is no fixed theory developed to explain it .
4. Type I semiconductors exhibit perfect and complete Meissner Effect .	4.Type II semiconductors donot exhibit perfect and complete Meissner Effect .
5. These materials have limited technical applications because of very low field strength value .	5. These materials have wider technological applications because of very high field strength value .
6. Examples : Pb, Hg, Zn, etc .	6. Examples : Nb_3Ge, Nb_3Si, $Y_1Ba_2Cu_3O_7$, etc .

Q4)b) Discuss in detail any three factors affecting acoustics of a hall with their remedies . (5M)

Ans : The three main factors affecting the acoustics of a hall are :

1. Shape of the hall :

a. It is one of the most important parameter to be considered for acoustically correct hall.

b. As the reflections are created by roof and side walls, they should be designed in such a way that echoes are not allowed to generate.

c. In place of parallel walls, splayed side walls are preferred. Curved surface on walls, ceilings or floor produce concentration of sound into particular region and absence of sound in other regions. Hence curved surface must be designed with proper care.

2. Use of absorbents :

a. Once the construction of hall is completed certain errors are found or the hall requires further correction as far as acoustics are concerned.

b. As the reflections from rear wall are of no use. It must be covered with absorbents, so as the ceiling.

c. False ceiling provided in large halls solves this problem effectively. The floor needs to be covered with carpet so as unwanted reflections and the noise created by audience is suppressed.

d. Even audience and auditorium act as absorbents. If more people are present in the hall, then more sound is absorbed.

3. Reverberation :

a. Reverberation time must be maintained in such a way that it does not remain too short or too large i.e. nearly 0.5 seconds for lecture hall, around 1.2 for concert hall and around 2 for cinema halls.

b. Proper use of absorbing materials, sufficient people as audience, presence of open windows, presence of furniture, etc are the major components which decide the reverberation time.

c. Calculated use of such components will be helpful to either increase our or decrease the reverberation time.

Q4)c) Calculate the de Broglie wavelength of alpha particles accelerating through a potential difference of 150 volts. Given mass of Alpha particles is 6.68 X 10^{-27} Kg. (5M)

Given : V = 150 Volts , m = 6.68 X 10^{-27} Kg .

To find : λ .

Formula : $\lambda = \frac{h}{\sqrt{2meV}}$.

$$\lambda = \frac{6.626X10^{-34}}{\sqrt{2X6.67X10^{-27}X2X1.6X10^{-19}X150}}$$ = 8.28 X 10^{-13} m .

Q5)a) Find the accuracy in the position of an electron moving with speed 350 m/sec with uncertainty of 0.01 % . (5M)

Given : v = 350 m/sec , $\frac{\Delta v}{v} = 0.01\% = \frac{0.01}{100} = 10^{-4}$.

To find : Δx .

Formula : $\Delta x.\Delta p \geq \frac{h}{2\pi}$.

Solution : Momentum of electron = p = mv .

$$\Delta p = m\Delta V = mv\frac{\Delta v}{v} = 9.11X10^{-31}X350X10^{-4} = 3.189X10^{-32}$$.

Using Heisenberg's Uncertainity Formula :

$$\Delta x.\Delta p \geq \frac{h}{2\pi}$$

$$\therefore \Delta x \geq \frac{h}{2\pi}.\frac{1}{\Delta p}$$.

$$\therefore \Delta x \geq \frac{6.63X10^{-34}}{2\pi X3.189X10^{-32}}$$.

$$\therefore \Delta x \geq 3.309X10^{-3} \text{ m}$$.

Ans : The accuracy in the position of electron is 3.309 X 10^{-3} m .

Q5)b) A quartz crystal of thickness 1 mm is vibrating at resonance. Calculate its fundamental frequency. [Assume that for quartz, Y=7.9 X 10^{10} N/m^2 and ρ=2.650 gm/cc]. (5M)

Given : t = 1 mm = 10^{-3} m , Y = 7.9 X 10^{10} N/m^2 , ρ = 2.650 gm/cc .

To find : η .

Formula : $\eta = \frac{k}{2t}\sqrt{\frac{Y}{\rho}}$.

Solution : For fundamental frequency, consider first harmonic i.e. k = 1 .

$$\eta = \frac{1}{2X10^{-3}}\sqrt{\frac{7.9X10^{10}}{2.65}}$$.

$$\eta = 8.633X10^{7}\,Hz$$.

Ans : The fundamental frequency of the crystal is 8.633 X 10^7 Hz .

Q5)c) Calculate electron and hole concentration in intrinsic Si at room temperature if its electrical conductivity is 4 X 10^4 mho/m .Given that mobility of electron=0.14 m^2/V-sec and mobility of holes=0.04 m^2/V-sec . (5M)

Given : σ = 4 X 10^4 mho/m , μ_e = 0.14 m^2/V-sec , μ_p = 0.04 m^2/V-sec .

To find : concentration of electron (n) , concentration of hole (p) .

Formula : $\sigma_e = ne\mu_e$, $\sigma_p = pe\mu_p$.

Solution :

$$\sigma_e = nX1.6X10^{-19}X0.14 .$$

$$4X10^4 = nX1.6X10^{-19}X0.14 .$$

$$n = 1.786X10^{24}/m^3 .$$

$$\sigma_p = pX1.6X10^{-19}X0.04 .$$

$$4X10^4 = pX1.6X10^{-19}X0.04 .$$

$$\therefore p = \frac{4X10^4}{1.6X10^{-19}X0.04} .$$

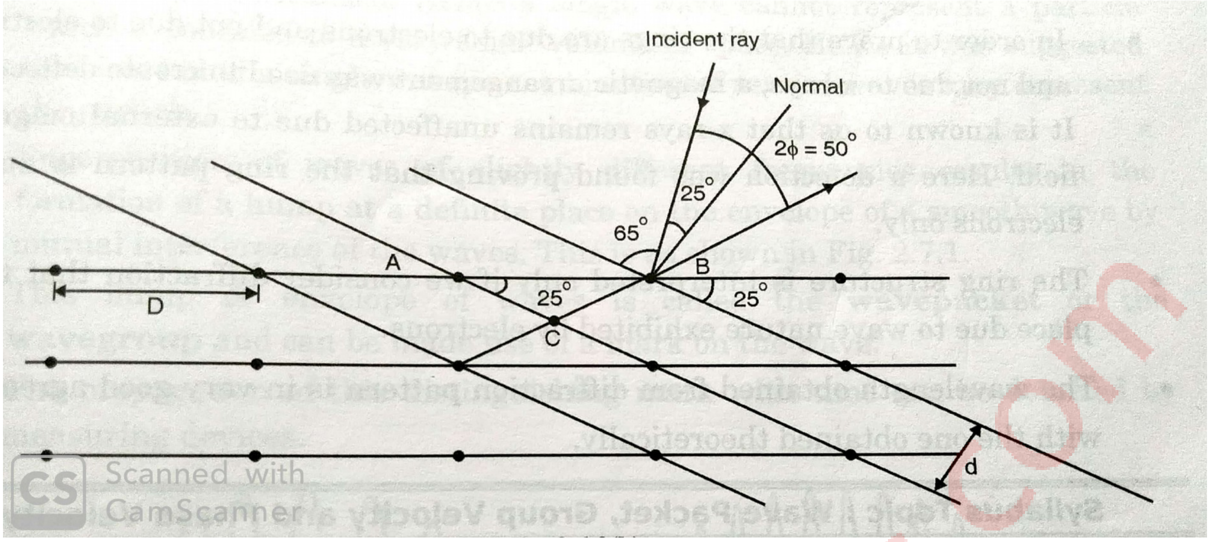
$$\therefore p = 6.25X10^{24}/m^3 .$$

Q6)Write short notes on the following :

a. Davisson-Germer Experiment . (5M)

Ans : 1) This experimental set-up is a modified spectrometer and work on diffraction of electron in form of a beam by a crystal . 1. Electrons are obtained by a heated filament and accelerated by a potential difference of 'V' volts. These electrons are directed towards a Ni crystal which is kept on prism table of spectrometer.

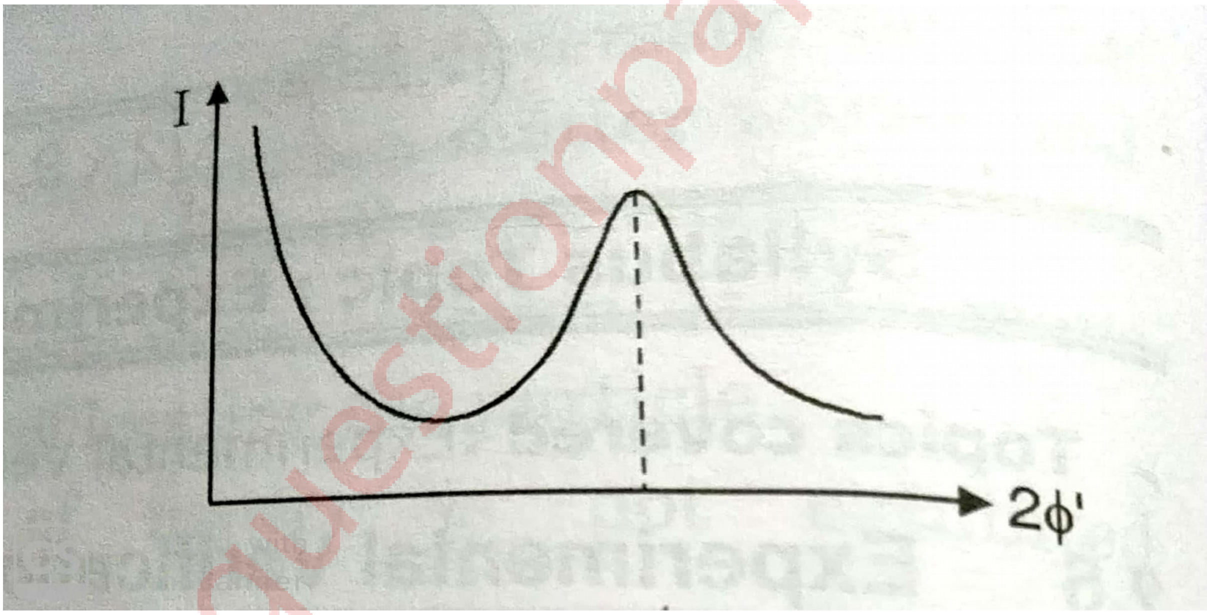
2. Since electrons are considered as beam and expected to experience diffraction, a detector is replaced for telescope. The detector can be rotated on a circular path around the crystal.



3. As expected, the electrons acting like a wave were diffracted in a particular direction which is in accordance with Bragg's Law.

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

4.The maximum strength of diffracted wave is obtained at angle $2\Phi' = 50°$ and accelerating potential V = 54 Volts.



5. In the figure above, the intensity which represents number of diffracted electrons is found to have a peak at $2\Phi' = 50°$, this is analogous to x-ray diffraction from periodically arranged atoms of crystal. This behaviour cannot be explained by considering particle nature of electrons. If particle nature is accepted then we can consider only reflection not interference or diffraction.

6. In Bragg's Law, angle θ represents glancing angle = $90 - \Phi' = 90° - 25° = 65°$.The interplanar spacing is given by d = 0.909 °A.

7. In ΔABC, AB = D = 2.15 °A (Inter atomic spacing)

BC = d = Inter planar spacing

$$\therefore \sin 25^\circ = \frac{d}{D}$$.

d = D sin 25° = 2.15 X sin 25

d = 0.909 °A .

This can be explained using the figure of atomic arrangement of Ni crystal.

8. For the given value of d and θ we can write Bragg's Law for n = 1 ,

1 X λ = 2 d sinθ = 2 X 0.909 X sin 65 .

$$\therefore \lambda = 1.65 A^\circ$$.

From theoretical value obtained from de Broglie 's law we have

$$\therefore \lambda = \frac{12.25}{\sqrt{V}} = 1.67 A^\circ$$.

Hence experimental value which is obtained by considering electron as wave is verified with theoretical value. This confirms de Broglie's hypothesis according to which particle and wave nature are equivalent to each other.

---

b. Maglev **(5M)**

Ans : 1. Maglev trains are an application of frictionless bearings based upon Meissner Effect.

2. Maglev stands for Magnetically Levitated vehicles.

3. They are used in transportation by being set afloat above a guide way.

4. The utility of such levitation is that in the absence of contact between moving and stationary systems the friction is eliminated. This brings great speeds with low energy consumption.

5. The train has a superconducting magnet built into its base.

6. There is Aluminum guide way over which the vehicle will set afloat by magnetic levitation.

7. The magnetic levitation is brought about by enormous repulsion between two highly powerful magnetic field by superconducting magnet and Aluminum guide way. Wheels have no role to play when vehicle is lifted up.

8. The track is made up of large number of segments and the flow of currents through the coils could be related to the position and speed of the vehicle.

9. Prototype of such vehicle has achieved speed of 400 kmph.

c. Bragg's spectrometer (5M)

Ans : 1. Bragg's Spectrometer is an instrument based upon Bragg's Law .This is a modified form of ordinary spectrometer to suit the use of x-rays.

2. A monochromatic x-ray beam obtained from x-ray tube is made to pass through slits S_1 and S_2 and which are made up of lead. The fine beam is then made to fall on the crystal C fixed on a crystal mount exactly at the center of circular turn table.

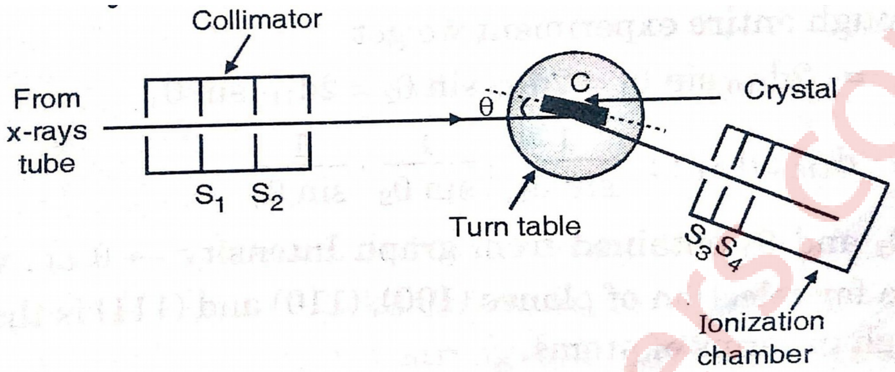


Fig. 1.8.1 : Schematic diagram of Bragg's spectrometer

3. The x-rays reflected are collected by ionization chamber is sturdy, the turn table is rotated till we get a sharp increase in the intensity.

4. The sudden increase in the intensity of x-ray suggests that Bragg's Law is satisfied at the given angle θ of the incident beam.

5. The peak in ionization current which represents the intensity occurs more than once as is varied because Bragg's Law states nλ = 2dsinθ i.e. for n=1,2,3, …. We have $\theta_1,\theta_2,\theta_3$, ……

6. If the intensity (or ionization current) is plotted against glancing angle then we get the graph using which we find the angles $\theta_1,\theta_2,\theta_3$, …… where peak occurs .

7. Determination of crystal structure (for cubic crystals) :

Here the crystal face used for reflecting the x-rays can be so cut that it remains parallel to one set of planes, then to another and so on when placed at center of the turn table on Bragg's spectrometer with x-rays of known λ incident upon it. For a given plane used as reflecting surface, find the corresponding d using .

$$n\lambda = 2d\sin\theta \quad \text{(take n=1)} \quad .$$

8. Similarly find value of d for other planes as well .

For cubic structure we select three planes viz (1 0 0), (1 1 0), (1 1 1) .

As λ is same through entire experiment we get

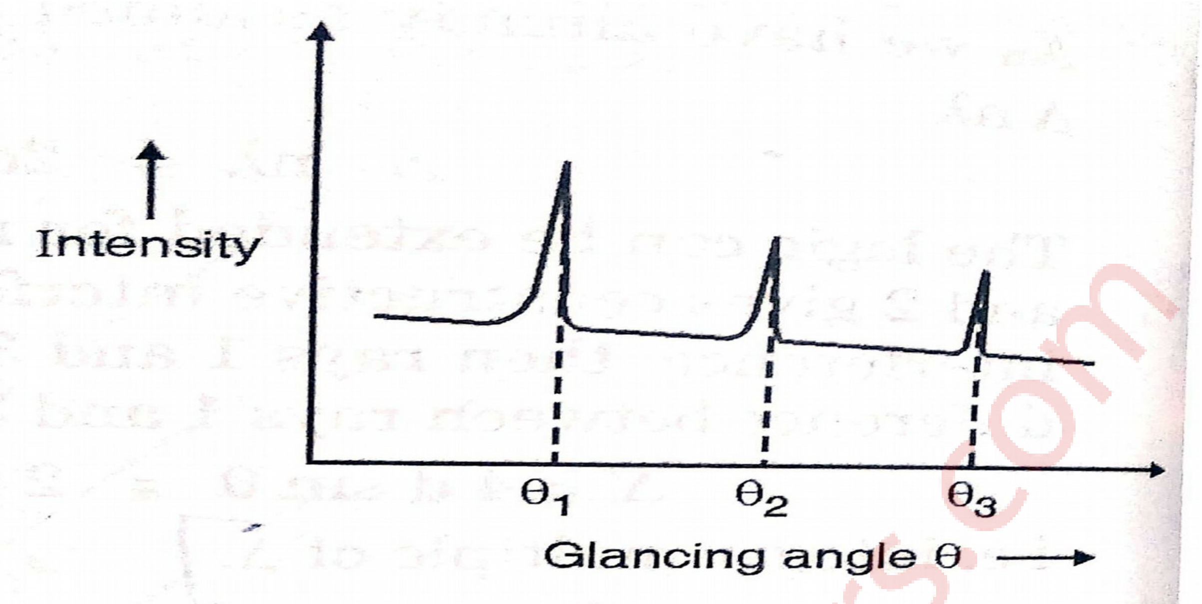


Fig. 1.8.2 : Variation of ionisation current

$$\lambda = 2d_{100}\sin\theta_1 = 2d_{110}\sin\theta_2 = 2d_{111}\sin\theta_3 .$$

$$\therefore d_{100} : d_{110} : d_{111} = \frac{1}{\sin\theta_1} : \frac{1}{\sin\theta_2} : \frac{1}{\sin\theta_3} .$$

Where θ_1, θ_2 and θ_3 obtained from graph intensity → θ i.e. where the peak occurs.

Experimentally obtained values of θ_1, θ_2 and θ_3 will provide us d_{100}, d_{110} and d_{111} .By comparing their ratio with Equation, one can determine crystal structure .

---

d. Crystal defects **(5M)**

Ans : Any deviation from a perfect periodic arrangement of atoms or molecules is called imperfections or crystal defects. The crystal defects are classified into five types :

1. Lattice vibrations
2. Point defect or zero dimension defect
3. Line defect or one dimensional defect
4. Planar or surface or two dimensional defect
5. Volume defect or three dimensional defect.

Point defects are of six types :

a. Vacancy defect

b. Interstitial

c. Substitutional impurities.

d. Interstitial impurities

e. Schottkey defect

f. Frankel defect

Vacancy defect :

a. Vacancy is produced due to the removal of an atom from its regular position in the lattice. The removed atom does not vanish. It travels to the surface of the material. For low concentration of vacancies, a relation is

$$n = Ne^{\frac{-E_V}{KT}}$$

Where n = Number of vacancies

N = Total number of atoms

T = Temperature in K .

E_V = Average energy required to create a vacancy .

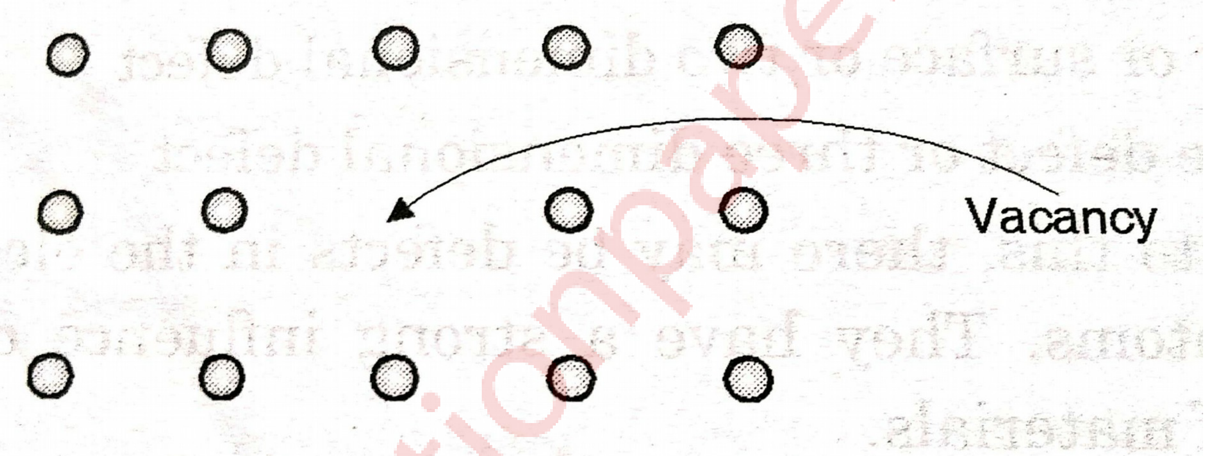


Fig. 1.10.1 : Vacancy

b. Interstitial :

An extra atom of the same type is fitted into the void between the regularly occupied sites. Since in general the size of atom is larger than the void into which it is fitted, so the energy required for interstitial formation is higher than that of vacancy formation .

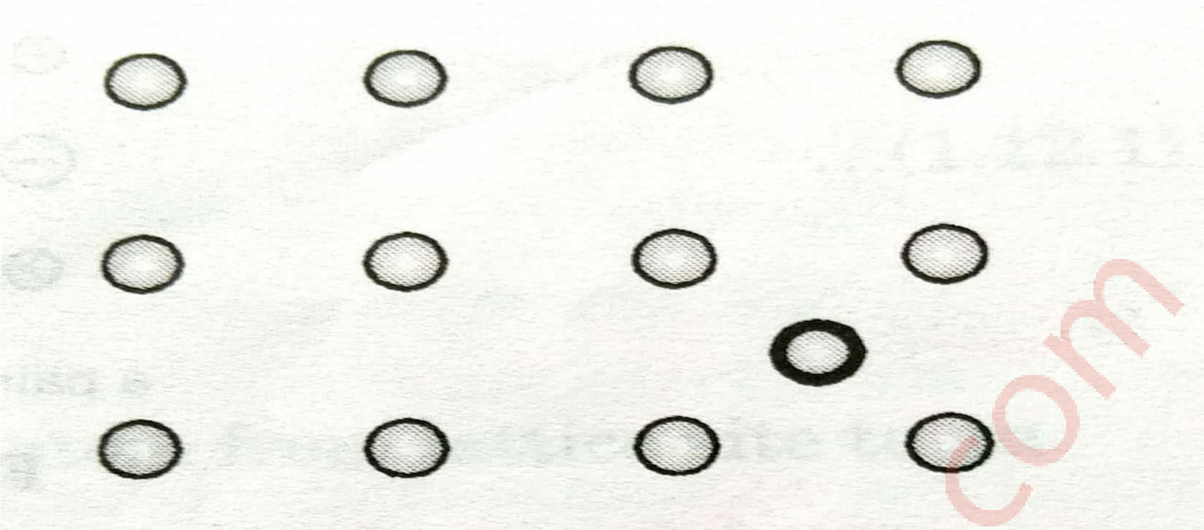


Fig. 1.10.2 : Interstitial

c. Substitutional impurities :

In this, a foreign atom is found occupying a regular site in a crystal lattice.

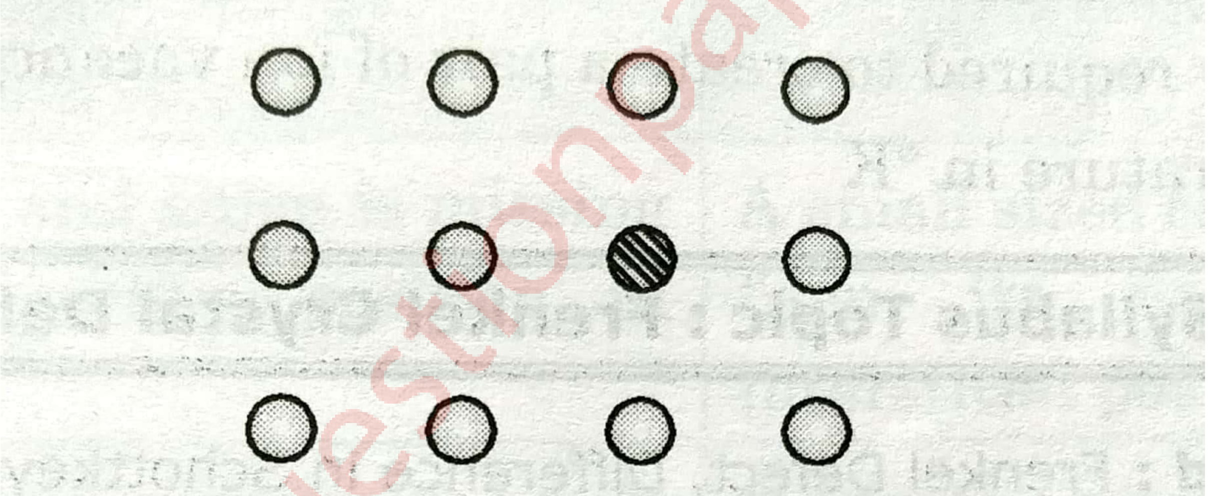


Fig. 1.10.3 : Substitutional impurity

d. Interstitial impurities :

Here a foreign atom is found at non regular site.

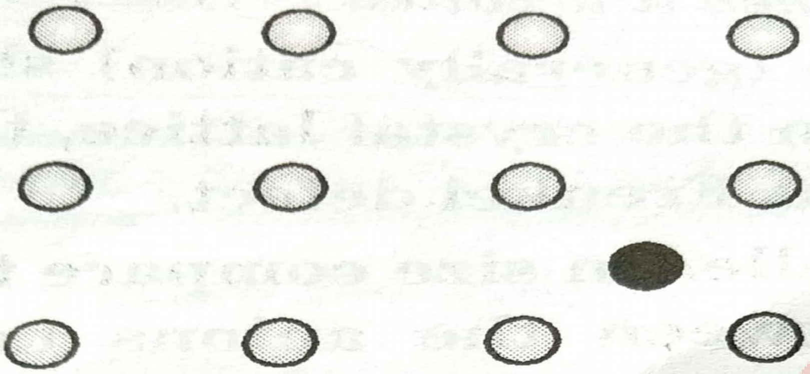


Fig. 1.10.4 : Interstitial impurity

e. Schottkey defect :

The point imperfection in ionic crystals occurs when a negative ion vacancy is associated with a positive ion vacancy. It is therefore a localized vacancy pair of positive and negative ions. This type of defect maintains the crystal electrically neutral, it is called as Schottkey defect.

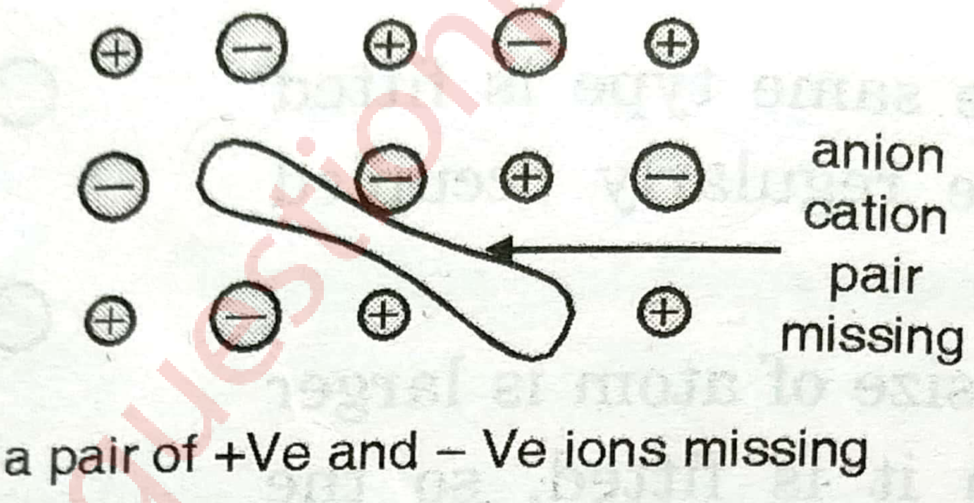


Fig. 1.11.1 : Schottkey defect

For ionic crystals, numbers of pair ion production is

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

Where N = Number of lattice site where $N = (N_C N_A)^{\frac{1}{2}}$

k = Boltzman constant

E_P = Energy required to create a pair of ion vacancy inside crystal lattice .

T = Temperature in Kelvin .

f. Frenkel defect :

Frenkel defect occurs when an ion (generally cation) shifts from its position to interstitial position in the crystal lattice, then a vacancy is created. The defect is known as Frenkel defect.

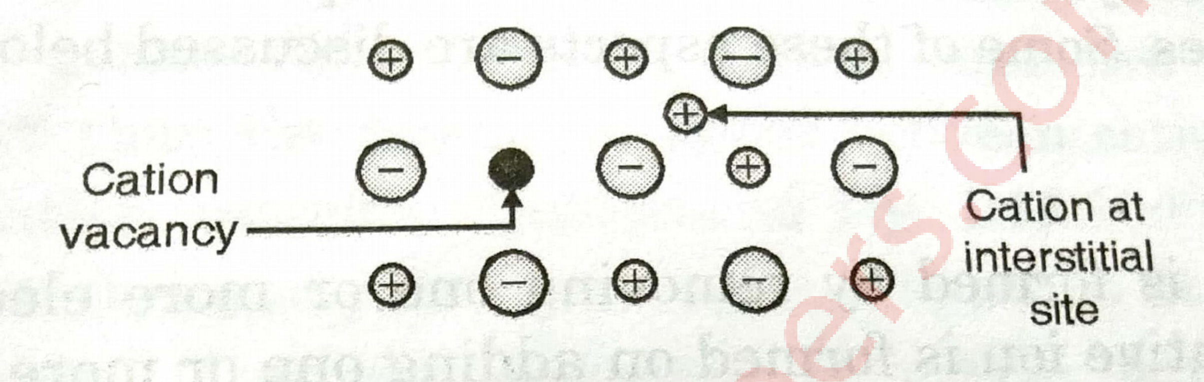


Fig. 1.12.1 : Frenkel defect

This defect can occur in ionic crystal when,

I) The anion is much larger than cation.

II) The ion has low co-ordination number.

Number of Frenkel defects creation is

$$n = (NN')e^{\frac{-E}{2KT}}.$$

Where N = Number of lattice site

N' = Number of interstitial site

E = Energy required to remove an atom from its lattice site to an interstitial position .

QP CODE: 77300

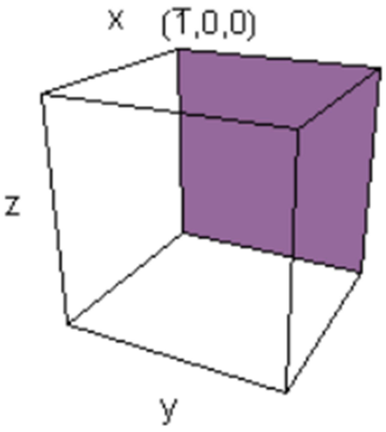
PHYSICS SOLUTION

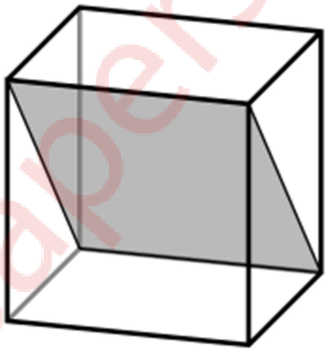
SEM – 1 (Rev- 2019’C’ Scheme DEC – 2019)

Q1] Attempt any five questions from the following **(15)**

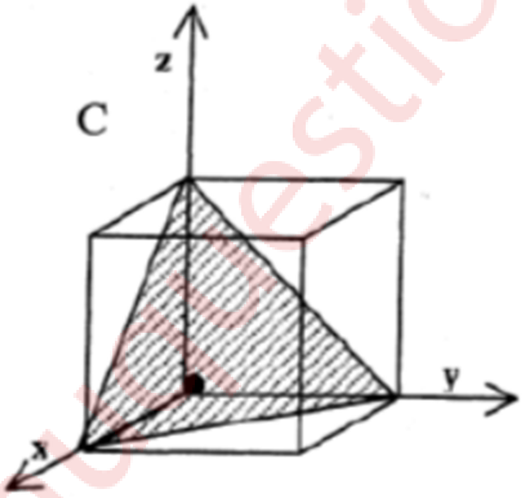
a) Draw $(\mathbf{0\ 0\ 2}), (\bar{\mathbf{1}}\ \mathbf{0\ 0}), (\mathbf{0\ 1\ 1})$

Solution :-





(011)



(0 0 2)

(b) Explain any three properties of matter waves.

Solution :-

(1) Matter wave represents the probability of finding a particle in space.

(2) Matter waves are not electromagnetic in nature.

(3) de-Brogile or matter wave is independent of the charge on the material particle. It means, matter wave of de-Broglie wave is associated with every moving particle (whether charged or uncharged).

(4) Practical observation of matter waves is possible only when the de-Broglie wavelength is of the order of the size of the particles.

(5) Electron microscope works on the basis of de-Broglie waves.

(6) The phase velocity of the matter waves can be greater than the speed of the light.

(7) Matter waves can propagate in vacuum, hence they are not mechanical waves.

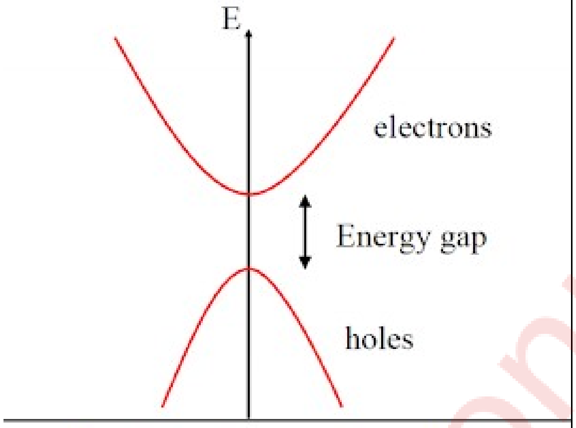
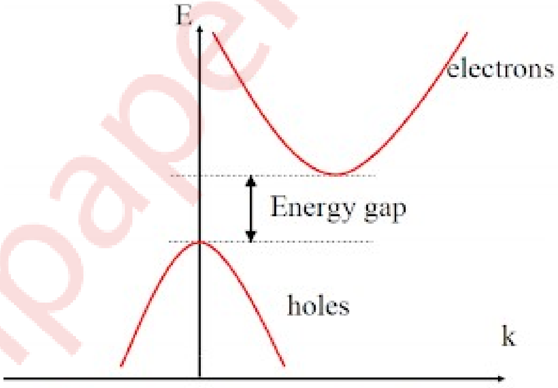
(8) The number of de-Broglie waves associated with nth orbital electron is n.

(9) Only those circular orbits around the nucleus are stable whose circumference is integral multiple of de-Broglie wavelength associated with the orbital electron.

(c) Differentiate between Direct and Indirect band gap semiconductor.

Solution:-

Direct band gap semiconductor	Indirect band gap semiconductor
A direct band-gap (DBG) semiconductor is one in which the maximum energy level of the valence band aligns with the minimum energy level of the conduction band with respect to momentum.	An Indirect band-gap (IBG) semiconductor is one in which the maximum energy level of the valence band and the minimum energy level of the conduction band are misaligned with respect to momentum.
In a DBG semiconductor, a direct recombination takes place with the	In case of a IBG semiconductor, due to a relative difference in the

release of the energy equal to the energy difference between the recombining particles.	momentum, first, the momentum is conserved by release of energy and only after the both the momenta align themselves, a recombination occurs accompanied with the release of energy.
The probability of a radiative recombination is high.	The probability of a radiative recombination is comparatively low.
The efficiency factor of a DBG semiconductor is higher. Thus, DBG semiconductors are always preferred over IBG for making optical sources.	The efficiency factor of a IBG semiconductor is lower.
Example, Gallium Arsenide (GaAs).	Example, Silicon and Germanium
 Direct bandgap semiconductors	 Indirect bandgap semiconductors

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(d) Explain any three conditions for Sustained Interference.

Solution:-

To obtain well defined interference patterns, the intensity at points corresponding to destructive interference must be zero, while intensity at the point corresponding to constructive interference must be maximum. To accomplish this the following conditions must be satisfied.

- The two interfering sources must be coherent, that is, they must keep a constant phase difference.

- The two interfering sources must emit the light of the same wavelength and time period. This condition can be achieved by using a monochromatic common original source, that is, the common source emits light of a single wavelength.

- The amplitudes or intensities of the interfering waves must be equal or very nearly equal so that the minimum intensity would be zero.

- The separation between the two coherent sources must be as small as possible so that the width of the fringes is large and are separately visible.
- The two sources must be narrow or they must be extremely small. A broad source is equivalent to a large number of fine sources. Each pair of fine sources will give its own pattern. The fringes of different interference patterns will overlap.

- The distance between the two coherent sources and the screen must be as large as possible so that the width of fringes is large and are separately visible.

- The two interference waves must be propagated along the same direction so that their vibrations are along a common line.

(e) A source is emitting 150W of red light of wavelength of 600nm. How many photons per second are emerging from the source.

Solution :-

$$E = \frac{hc}{\lambda} = \frac{(6.626\times10^{-34})\times(3\times10^{8})}{600\times10^{-9}} = 3.313\times10^{-19}J$$

$$E = 3.313\times10^{-19}J$$

Each photons carry 3.313×10^{-19}J of energy

A 100W source means that it output 100 Joules of energy every second

No of photons emitted = total energy output in one second/ energy carried per photon

$$n = \frac{150}{3.313\times10^{-19}} = 4.527\times10^{20}$$

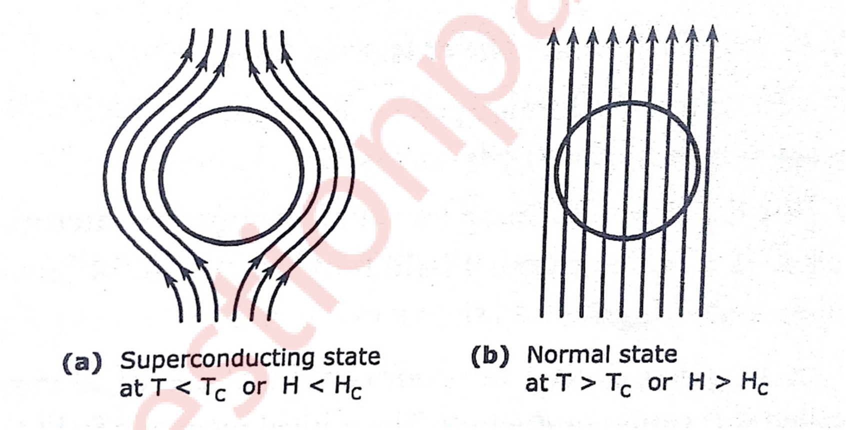
Answer :- $\mathbf{4.527 \times 10^{20}}$

(f) Explain the Meissner effect with application.

Solution :-

A superconducting material kept in a magnetic field expels the magnetic flux out its body when cooled below the critical temperature and exhibits perfect diamagnetism. This is called MEISSNER EFFECT.

- It is found that as the temperature of the specimen is lowered to T_c, the magnetic flux is suddenly and completely expelled from it. The flux expulsion continues for $T < T_c$. The effect is reversible.
- When the temperature is raised from below T_c. The flux density penetrates the specimen again at $T = T_c$ and the material turns to the normal state.



(a) Superconducting state at $T < T_c$ or $H < H_c$

(b) Normal state at $T > T_c$ or $H > H_c$

- For the normal state the magnetic induction inside the specimen is given by:
  $B = \mu_o(H + M) = \mu_O(1 + \chi)H$……………………………………….(1)

Here H is the applied magnetic field , m is the magnetization produced within the specimen , is χ the susceptibility of the material and μ_o is the permeability of free space.

- At $T < T_c$ as seen above
  B = 0

$M = -H$

And thus $\chi = \frac{M}{H} = -1$

- The specimen is therefore a perfect diamagnetic. The diamagnetism produces strong repulsion to the external magnets.
- This effect is used to identify a superconductor , in levitation effect and suspension effect.

(g) Explain Magento Resistance with application.

Solution :-

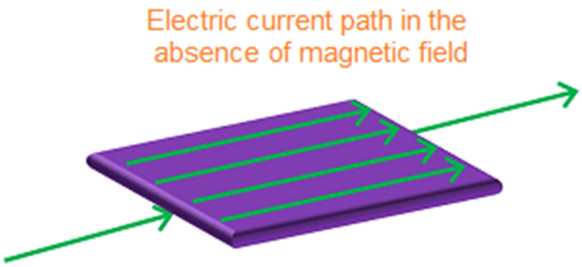
Magneto resistor definition

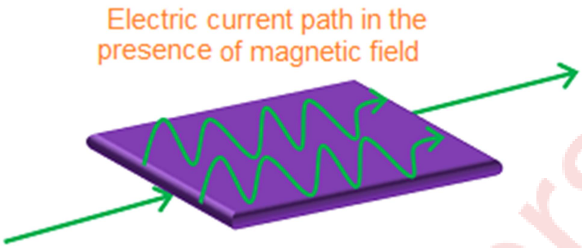
Magneto resistor is a type of resistor whose resistance changes when an external magnetic field is applied. In other words, the flow of electric current through the magneto resistor changes when an external magnetic field is applied to it. Magnetic field is the region present around a magnetic object within which other objects experience an attractive or repulsive force.

Magneto resistive effect is the property of some materials, which causes them to change their resistance under the presence of magnetic field. This magneto resistive effect occurs in materials such as semiconductors, non-magnetic metals, and magnetic metals.

An Irish mathematical physicist and engineer William Thomson first discovered this magneto resistive effect in 1856. He observed that resistance of the pieces of iron increased when the electric current is flowing in the same direction as the magnetic force or magnetic field and the resistance is decreased when the electric current is flowing at 90° to the magnetic field or magnetic force.

After that, he performed the same experiment with nickel and he found that the resistance of the nickel is affected in the same manner but the magnitude of this magnetic field was much greater than before. This effect is called Anisotropic Magneto Resistance (AMR).





Applications of magneto resistors

The various applications of magneto resistors include:

- Bio-sensors
- Hard disk drives
- Magnetic field sensors
- Magneto resistors are used in electronic compass for measuring earth's magnetic field.
- Magneto resistors are used for measuring electric current.

Q2] A) show that Non-Existence of electron in the Nucleus, Find the uncertainty in the position of electron. The speed of an electron is measured to be 4×10^3 m/s to an accuracy of 0.002% (8)

Solution :-

Initially assume that an electron is a part of a nucleus. The size of a nucleus is about 1 fermi = 10^{-15}m if an electron is confined within a nucleus the uncertainty in its position must not be greater than the dimension of the nucleus i.e., 10^{-15}m. hence, $\Delta x_m = 10^{-15}$m

From the limiting condition of Heisenberg's uncertainty principle given in the equation it can be written as

$$\Delta x_m . \Delta p_{mi} = \hbar$$

$$\Delta p_{mi} = \frac{\hbar}{\Delta x_{mi}} = \frac{6.63 \times 10^{-34}}{2 \times 3.14 \times 10^{-15}} = 1.055 \times 10^{-19} \text{kg-m/sec}$$

$$\text{Now , } \Delta p_{mi} = m\Delta v_{mi}$$

$$\text{Hence , } \quad \Delta v_{mi} = \frac{\Delta p_{mi}}{m} = \frac{1.055 \times 10^{-19}}{9.1 \times 10^{-31}} = 1.159 \times 10^{11} \text{m/s} > c$$

$$\text{As , } \Delta v_{mi} < v , \ v > 1.159 \times 10^{11} \text{m/s} > c$$

Therefore the electron inside the nucleus behaves as a relativistic particle.

The relativistic energy of the electron is $E = \sqrt{m_o^2 c^4} + \sqrt{p^2 c^2}$

Since the actual momentum of the electron p>> $\Delta p_{mi}. p^2. c^2 \gg m_o^2. c^2$, the rest mass energy of the electron the value of which is 0.511 MeV. Hence, E= pc

Assuming p = Δp_{mi} the least energy that an electron should posses within a nucleus is given by

$$E_{mi} = \Delta p_{mi} . c$$

$$= 1.055 \times 10^{-19} \times 3 \times 10^{8}$$

$$= 3.165 \times 10^{-11} \text{J}$$

$$E_{mi} = \frac{3.165 \times 10^{-1}}{1.6 \times 10^{-19}} = 197 \text{ MeV.}$$

In reality the only source of generation of electron with in a nucleus is the process of β-decay. The maximum kinetic energy possessed by the electrons during β-decay is about 100KeV. This shows that an electron can not exist within a nucleus.

NUMERICAL:-

Given Data :- V $= 4 \times 10^3$ m/sec , $\frac{\Delta v}{v} = ?$ $\Delta x = 0.002\%$

Formula :- $\Delta x . \Delta p \geq \hbar$

Calculations :- $\Delta x . m . \Delta p \geq \hbar$

$$\Delta x \geq \frac{\hbar}{m\Delta v}$$

$$\Delta v = \frac{6.63 \times 100 \times 10^{-34}}{0.002 \times 2 \times 3.14 \times 9.1} = 0.58 \times 10^{-30}$$

Uncertainty :-

$$\frac{\Delta v}{v} = \frac{(0.58 \times 10^{-30})}{4 \times 10^3} = 1.45 \times 10^{-34}$$

Therefore uncertainty in position = $\mathbf{1.45 \times 10^{-34}}$

Q2] B) Define the Fermi energy level, show that in intrinsic semiconductor Fermi level is at the centre of Forbidden energy gap. Draw the position of Fermi level in intrinsic, P type and N type semiconductor. (7)

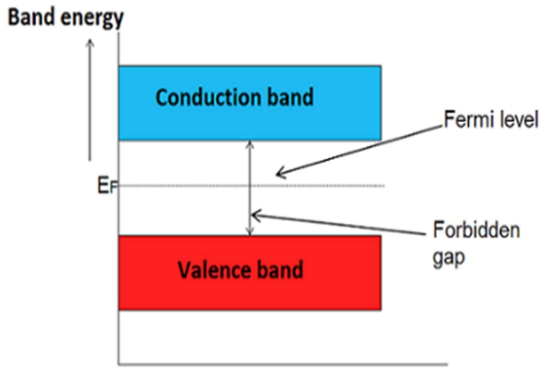
Solution :-

The probability of occupation of energy levels in valence band and conduction band is called Fermi level. At absolute zero temperature intrinsic semiconductor acts as perfect insulator. However as the temperature increases free electrons and holes gets generated.

In intrinsic or pure semiconductor, the number of holes in valence band is equal to the number of electrons in the conduction band. Hence, the probability of occupation of energy levels in conduction band and valence band are equal. Therefore, the Fermi level for the intrinsic semiconductor lies in the middle of forbidden band.

Fermi level in the middle of forbidden band indicates equal concentration of free electrons and holes.

The hole-concentration in the valence band is given as



$$p = N_V e^{\frac{-(E_F - E_V)}{K_B T}}$$

The electron-concentration in the conduction band is given as

$$n = N_c e^{\frac{-(E_C - E_F)}{K_B T}}$$

Where K_B is the Boltzmann constant

T is the absolute temperature of the intrinsic semiconductor

N_c is the effective density of states in the conduction band.

N_v is the effective density of states in the valence band.

The number of electrons in the conduction band is depends on effective density of states in the conduction band and the distance of Fermi level from the conduction band.

The number of holes in the valence band is depends on effective density of states in the valence band and the distance of Fermi level from the valence band.

For an intrinsic semiconductor, the electron-carrier concentration is equal to the hole-carrier concentration.

It can be written as

$$p = n = ni$$

Where P = hole-carrier concentration,   n = electron-carrier concentration and n_i = intrinsic carrier concentration

The fermi level for intrinsic semiconductor is given as,

$$E_F = \frac{E_C+E_V}{2}$$

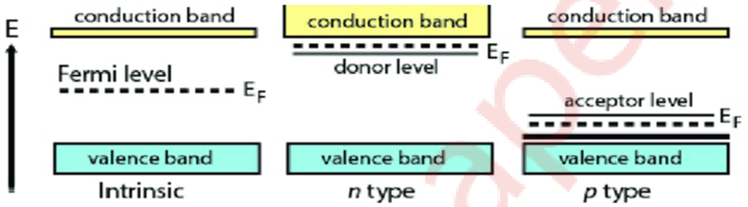
Where E_F is the fermi level

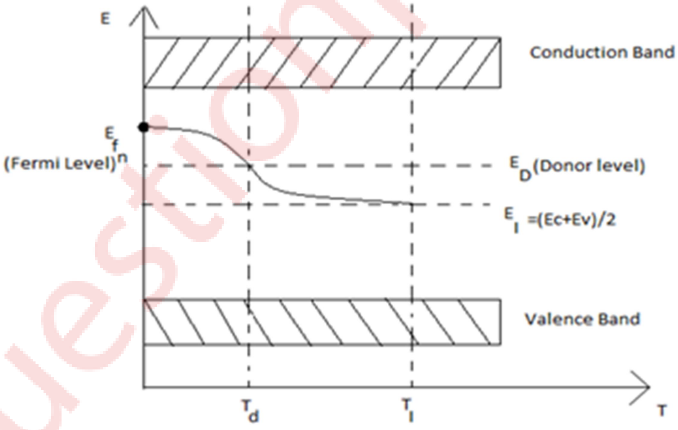
E_C is the conduction band

E_V is the valence band

Therefore, the Fermi level in an intrinsic semiconductor

lies in the middle of the forbidden gap.





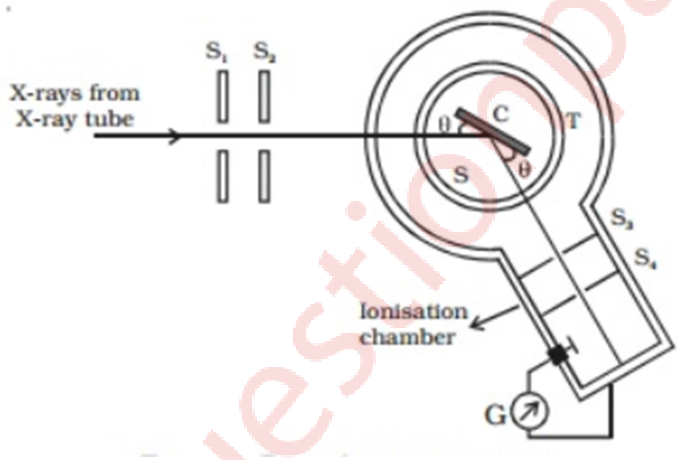
For n-type

Q3] A) Explain with diagram Bragg's X ray Spectrometer. Calculate the interplaner spacing between the family of planes (1 1 1) in crystal of lattice constant 3A° (8)

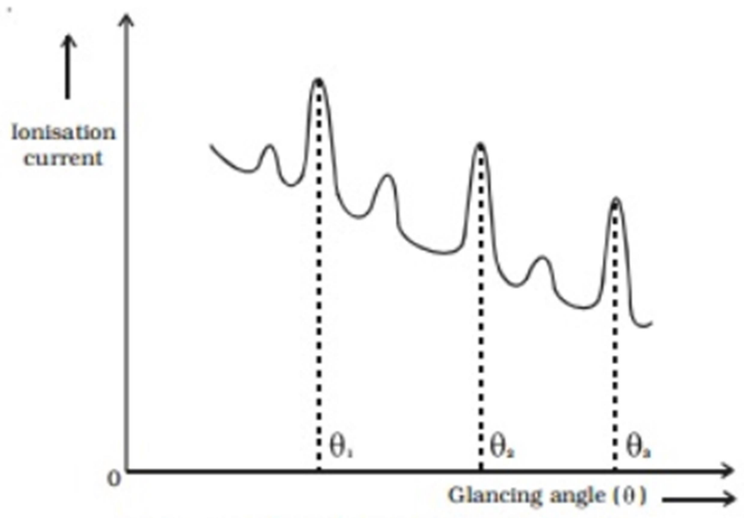
Bragg's spectrometer used to determine the wavelength of X - rays is shown in Fig. Bragg's spectrometer is similar in construction to an ordinary optical spectrometer.

X-rays from an X-ray tube are made to pass through two fine slits S_1 and S_2 which collimate it into a fine pencil. This fine X-ray beam is then made to fall upon the crystal 'C' (usually sodium chloride crystal) mounted on the spectrometer table. This table is capable of rotation about a vertical axis and its rotation can be read on a circular graduated scale S. The reflected beam after passing through the slits S_3 and S_4 enters the ionization chamber. The X-rays entering the ionization chamber ionize the gas which causes a current to flow between the electrodes and the current can be measured by galvanometer G. The ionization current is a measure of the intensity of X-rays reflected by the crystal.

The ionization current is measured for different values of glancing angle θ. A graph is drawn between the glancing angle θ and ionization current.



For certain values of glancing angle,the ionization current increases abruptly. The first peak corresponds to first order, the second peak to second order and so on. From the graph, the glancing angles for different orders of reflection can be measured. Knowing the angle θ and the spacing d for the crystal, wavelength of X-rays can be determined.



NUMERICAL :-

$(\mathrm{h\ l\ k}) = \ (1\ 1\ 1)$

$\mathrm{a} = 3\mathrm{A}°$

To find :-

Inter- planar distance (d)

Solution:-

We know that,

$$\mathrm{d} = \frac{\mathrm{a}}{\sqrt{\mathrm{h}^2+\mathrm{k}^2+\mathrm{l}^2}} = \frac{3}{\sqrt{1^2+1^2+1^2}} = \ \sqrt{3}$$

$\mathrm{d} = 1.732\mathrm{A}°$

Q3] B) Prove that the Diameter of the nth dark ring in Newton's ring setup is directly proportional to the square root of the ring number. In Newton's Rings reflected light of wavelength 5×10^{-5} cm. the diameter of the 10th dark ring is 0.5cm. calculate radius of curvature R. (7)

Solution :-

Let POQ be the plano-convex lens placed on a plane glass plate AB. Let R be the radius of curvature of the lens surface in contact with the plate.

Let p be the radius of a Newton's ring corresponding to the constant film thickness 't'. The path difference between the two interfering rays in the reflected system is

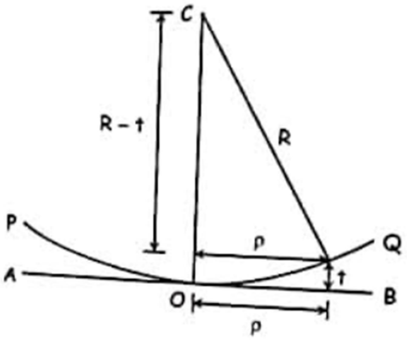
$$2\mu\cos(r+\theta)+\frac{\lambda}{2}$$

λ = wavelength of incident light

$\mu = 1$ for air film

$r = 0$ for normal incidence

$\theta = 0$ for large R



From diagram

$$R^2 = p^2 + (R-t)^2$$

$$p^2 = R^2 - (R-t)^2$$

$$p^2 = 2Rt - t$$

$t \ll R$ and hence we have

$$p^2 = 2Rt$$

Path difference between the interfering ray is $\frac{p^2}{R}+\frac{\lambda}{2}$

For dark rings :-

Path difference = $\frac{p^2}{R}+\frac{\lambda}{2} = (2n+1)\left(\frac{\lambda}{2}\right)$ (n=1,2,3 ....)

If D is the difference of Newton’s ring then $p = \frac{D}{2}$

$\frac{D_n^2}{4R} = n\lambda \qquad \text{where } D_n = \text{Diameter of } n^{th} \text{ dark ring}$

$D_n^2 = 4Rn\lambda$

$D_n \;\propto\; \sqrt{n}$

Hence the diameter of the dark ring is proportional to the square root of natural numbers.

NUMERICAL :-

$D_{10} \; = 0.5\text{cm}$

$\lambda = 5 \times 10^{-5} \;\text{cm}$

R = ?

$D_n = \sqrt{(2n - 1)(2\lambda R)}$

$D_{10} = \sqrt{(2 \times 10 - 1)(2\lambda R)}$

$0.5 = \sqrt{(2 \times 10 - 1)(2 \times 5 \times 10^{-5} \times R)}$

$0.5^2 = 19 \times 10 \times 10^{-5} \times R$

$R = 131.57\text{cm}$

Q4] A) Derive one dimensional time independent Schrodinger Equation (5)

Solution :-

We start with the one-dimensional classic wave equation,

$\frac{\partial^2 u}{\partial x^2} = \frac{1}{u^2}\frac{\partial^2 u}{\partial t^2}$

By introducing the separation of variables ,

$$u(x,t) = \psi(x)f(t)$$

We obtain $f(t)\frac{d^2\psi(x)}{\partial x^2} = \frac{1}{u^2}\psi(x)\frac{d^2f(t)}{dt^2}$

If we introduce one of the standard wave equation solutions for f(t) such as $e^{i\omega t}$ (the constant can be taken care of later in the normalization), we obtain

$$\frac{d^2\psi(x)}{\partial x^2} = \frac{-\omega^2}{u^2}\psi(x)$$

Now we have an ordinary differential equation describing the spatial amplitude of the matter wave as a function of position. The energy of a particle is the sum of kinetic and potential parts.

$$E^2 = \frac{p^2}{2m} + V(x)$$

Which can be solved for the momentum (p) to obtain

$$p = \{2m[E - V(x)]\}^{1/2}$$

Now we can use the de Broglie formula to get an expression for the wavelength

$$\lambda = \frac{h}{p} = \frac{h}{\{2m[E-V(x)]\}^{1/2}}$$

The term $\frac{\omega^2}{u^2}$ in equation can be written in terms of λ if we recall that

$$\omega = 2\pi v \text{ and } v\lambda = v$$

$$\frac{\omega^2}{u^2} = \frac{4\pi^2 v^2}{u^2} = \frac{4\pi^2}{\lambda^2} = \frac{2m[E-V(x)}{h^2}$$

When is almost always written in the form

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

A two-body problem can also be treated by this equation if the mass m is replaced with a reduced mass μ

Q4] B) Differentiate between Type I and Type II superconductor (5)

Solution :-

TYPE I SUPERCONDUCTOR	TYPE II SUPERCONDUCTOR
1. They exhibit complete Meissner effect	1. They exhibit partial Meissner effect.
2. These are perfect diamagnetics.	2. These are not perfect diamagnetics.
3. These are known as soft superconductors.	3. These are known as hard superconductors.
4. These materials undergoes a sharp transition from the superconducting state of the normal state at the critical magnetic field.	4. These materials undergoes a gradual transition from the superconducting state of the normal state at the critical magnetic field.
5. The highest value of critical magnetic field Is 0.1 wb/M2.	5. The upper critical field can be of the order of 50 wb/m2.
6. Applications are very limited.	6. They are used to generate very high magnetic field.
7. Examples:- lead tin, mercury, etc.	7. Examples:- alloys like Nb-Sn, Nb-D, Nb- Zr, etc.

Q4] C) Find Resistance of an intrinsic Ge rod of dimension(1cm long, 1mm wide and 1mm thick) at 300K. For Ge $\mathbf{n_i = 2.5 \times 10^{19}\ /m^3,\ \mu_n = 0.39\frac{m^2}{v} - s,\ \mu_p = 0.19\frac{m^2}{v} - s}$ (5)

Solution :-

$n_i = 2.5 \times 10^9\ /m^3$

$$\mu_e = 0.39\frac{m^2}{V}\sec$$

$$\mu_h = 0.91\frac{m^2}{V}\sec$$

$$T = 300°K$$

$$l = 10^{-2}m$$

$$A = bd = 10^{-6}m^2$$

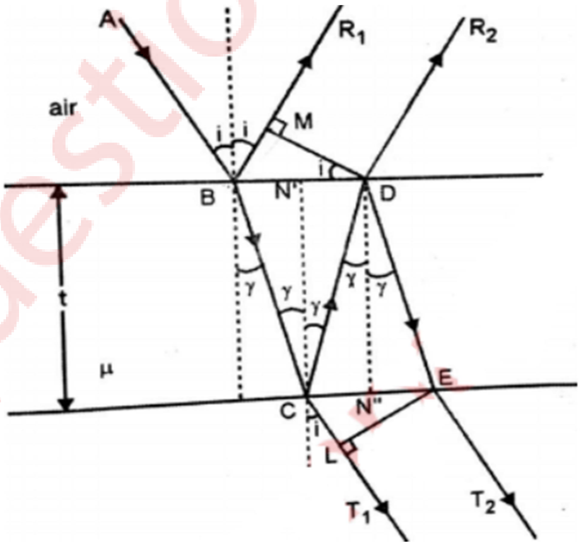
$$\sigma = n_i e(\mu_e + \mu_h) = (2.5 \times 10^9)(1.6 \times 10^{-1}\ )(0.39 + 0.19) = 2.32/\Omega m$$

$$\rho = \frac{1}{\sigma} = \frac{1}{2.3} = 0.431\Omega m$$

$$R = \rho\left(\frac{l}{A}\right) = (0.431\Omega m) \times \frac{10^{-2}}{10^{-6}} = 4.31 \times 10^3\Omega$$

Q5] A) Derive the condition for maxima and minima due to interference of light reflected from thin film of uniform thickness (5)

Solution :-



Consider a thin film of uniform thickness (t) and R.I (μ)

On Reflected side,

The ray of light R1 and R2 will interfere.

The path difference between R1 and R2 is,

$\Delta = \mu(BC + CD) - BG$

$BC = CD = \frac{t}{\cos r}$..........(1)

Now,

$BD = (2t) \tan r$ ....(2)

$BM = BD \sin i$

$BM = (2t) \tan r \sin i$

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

$BM = 2\mu t\left(\frac{\sin 2r}{\cos r}\right)$..........(3)

Substituting (i) and (iii) in Δ :

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

$= 2\mu t \cos r(1 - \sin 2r)$

$\Delta = 2\mu t \cos r$

For transmitted system :

The transmitted rays CT1 and ET2 are also derived from the same incident ray AB and hence they are coherent.

Path difference = $\triangle = \mu(CD + DE) - CL$

For constructive interference :

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

For destructive interference :

$2\mu t \cos r = (2n - 1)\lambda/2$

Q5] B) Explain Hall Effect. Derive the equation for Hall Voltage (5)

Solution :-

If a current carrying conductor or semiconductor is placed in a transverse magnetic field, a potential difference is developed across the specimen in a direction perpendicular to both the current and magnetic field. The phenomenon is called HALL EFFECT.

As shown consider a rectangular plate of a p-type semiconductor of width ‘w’ and thickness ‘d’ placed along x-axis. When a potential difference is applied along its length ‘a’ current ‘I’ starts flowing through it in x direction.

As the holes are the majority carriers in this case the current is given by

$$I = n_h A e v_d \quad \text{.................................(1)}$$

where n_h = density of holes

A = w × d = cross sectional area of the specimen

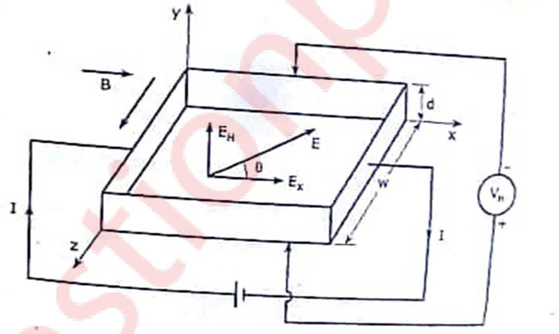


Figure 3.25 : Hall effect set up

v_d = drift velocity of the holes.

The current density is

$$J = \frac{I}{A} = n_h e v_d \quad \text{..........................(2)}$$

The magnetic field is applied transversely to the crystal surface in z direction. Hence the holes experience a magnetic force

$$F_m = e v_d B \quad \text{.................................(3)}$$

In a downward direction. As a result of this the holes are accumulated on the bottom surface of the specimen.

Due to this a corresponding equivalent negative charge is left on the top surface.

The separation of charge set up a transverse electric field across the specimen given by,

$$E_H = \frac{V_H}{d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where V_H is called the HALL VOLTAGE and E_H the HALL FIELD.

In equilibrium condition the force due to the magnetic field B and the force due to the electric field E_H acting on the charges are balanced. So the equation (3)

$$eE_H = ev_dB$$

$$E_H = v_dB \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Using equation (4) in the equation (5)

$$V_H = v_dB\,d \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

From equation (1) and (2), the drift velocity of holes is found as

$$v_d = \frac{I}{en_hA} = \frac{J}{en_h} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Hence hall voltage can be written as

$$\boxed{V_H = \frac{IBd}{en_hA} = \frac{J_xBd}{en_h}}$$

Q5] C) Calculate the lowest three energy states of an electron confined in potential well of width 10A° (5)

Solution :-

Potential well width :- 10 A°

L = 10 A° $= \quad 10 \times 10^{-10}\mathrm{m}$

Energy of electron in $\mathrm{n^{th}}$ level → $E_n = \frac{n^2h^2}{8mL^2} = n^2E_1$

$$E_1 = \frac{h^2}{8mL^2} = \frac{(6.63\times10^{-34})^2}{8\times9.1\times10^{-31}\times(10\times10^{-10})^2} = \frac{43.9569\times10^{-1}}{7280} = 6.0380\times10^{-20}\mathrm{J}$$

$$E_2 = n^2E_1 = 2^2E_1 = 2^2\times6.0380\times10^{-20} = 24.152\times10^{-20}\mathrm{J}$$

$$E_3 = n^2E_1 = 3^2E_1 = 3^2\times6.0380\times10^{-20} = 54.342\times10^{-20}\mathrm{J}$$

Q6] A) Explain multiferroics and its different types (5)

Solution :-

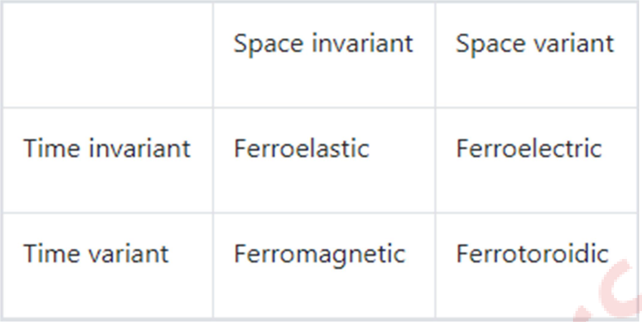
Multiferroics are defined as materials that exhibit more than one of the primary ferroic properties:

- ferromagnetism—a magnetisation that is switchable by an applied magnetic field,
- ferroelectricity—an electric polarisation that is switchable by an applied electric field, and
- ferroelasticity—a deformation that is switchable by an applied stress,

in the same phase. While ferroelecstric ferroelastics and ferromagnetic ferroelastics are formally multiferroics, these days the term is usually used to describe the magnetoelectric multiferroics that are simultaneously ferromagnetic and ferroelectric. Sometimes the definition is expanded to include non-primary order parameters, such as antiferromagnetism or ferrimagnetism. In addition other types of primary order, such as ferroic arrangements of magneotelectric multipoles of which ferrotoroidicity is an example, have also been recently proposed.

Besides scientific interest in their physical properties, multiferroics have potential for applications as actuators, switches, magnetic field sensors or new types of electronic memory devices.

Those materials which combine multiple ferroic properties such as ferromagnetism, ferroelectricity and ferroelasticity are known as multiferroics. Simultaneous coexistence of at least two ferroic properties takes place in the same phase in multiferroics. It has the feasibility of exhibiting coupling between ferroelectricity and magnetism which is known as the magnetoelectric effect (ME). This ME enables the external electric field to change magnetization .



	Space invariant	Space variant
Time invariant	Ferroelastic	Ferroelectric
Time variant	Ferromagnetic	Ferrotoroidic

1. **Type-I Multiferroics:**

This type of multiferroics are older, more numerous and are good ferroelectrics. Above room temperature, the critical temperatures of the magnetic and ferroelectric transitions can be well. In these materials, the coupling between magnetism and ferroelectricity is unfortunately weak. Different origin of ferroelectricity and magnetism in type-I multiferroic are mostly due to different active subsystems of a material.

2. **Type-II Multiferroics:**

Due to the recent discovery of a novel class of multiferroics, there is the biggest excitement as ferroelectricity exists only in a magnetically ordered state and is caused by a particular type of magnetism. A nonzero electric polarization occurs in the low temperature phase. For example CuFeO2 with $T_c = T_N$.

Q6] B) A soap film 4×10^{-5}cm thick is viewed at angle of 35° to normal. Calculate wavelength of light in the visible spectrum which will be absent from the Reflected light ($\mu = 1.33$) (5)

Solution :-

$\mu = 1.33 \qquad t = 4 \times 10^{-5}\text{cm}$

$\mathrm{i} = 35°$

$\mu = \frac{\mathrm{sini}}{\mathrm{sinr}}$

$\mathrm{sinr} = \frac{\mathrm{sini}}{\mu} = \frac{\mathrm{sin35}}{1.33} = 0.43$

$\mathrm{r} = 25.46$

$\mathrm{cosr} = 0.902$

Condition for darkness is $2\mu\mathrm{tcosr} = \mathrm{n}\lambda$

Substitute values of n as 1,2,3,4…… we will get corresponding wavelengths those wavelengths which fall in the visible spectra will remain absent.

$\mathrm{for\ n} = 1, \lambda_1 = 2 \times 1.33 \times 4 \times 10^{-5} \times 0.902 = 9597\mathrm{AU}$

$\mathrm{for\ n} = 2, \lambda_1 = 2 \times 1.33 \times 4 \times 10^{-5} \times \frac{0.902}{2} = 4798\mathrm{AU}$

$\mathrm{for\ n} = 3, \lambda_1 = 2 \times 1.33 \times 4 \times 10^{-5} \times \left(\frac{0.902}{3}\right) = 3199\mathrm{AU}$

$\mathrm{for\ n} = 4, \lambda_1 = 2 \times 1.33 \times 4 \times 10^{-5} \times \frac{0.902}{4} = 2399\mathrm{AU}$

$\mathrm{for\ n} = 5, \lambda_1 = 2 \times 1.33 \times 4 \times 10^{-5} \times \frac{0.902}{5} = 1919\mathrm{AU}$

So wavelength corresponding to 4798 and 3199 AU will remain absent in the visible spectra

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Q6] C) The Coefficient (Rh) of semiconductor is $3.22 \times 10^{-4}\mathrm{m}^3\mathrm{c}^{-1}$. Its resistivity is $9 \times 10^{-3}\Omega\mathrm{m}$. Calculate the mobility and concentration of carriers. **(5)**

Solution:-

Since $\mathrm{R_H}$ is positive the given specimen is p type material, $\mathrm{R_H} = \frac{1}{\mathrm{pe}}$

$(\mathrm{p}) = \frac{1}{\mathrm{R_H e}} = \frac{1}{3.22\times10^{-4}\times1.6\times10^{-19}} = 1.9 \times 10^{22}\mathrm{m}^{-3}$

$$\text{mobility}(\mu) = \sigma_H R_H = \frac{R_H}{\rho_H} = \frac{3.22\times10^{-4}}{9\times10^{-3}} = 0.3577 \times 10^{-1}\ \mathrm{m}^2\ /\mathrm{V}-\mathrm{s}$$
