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°

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.*

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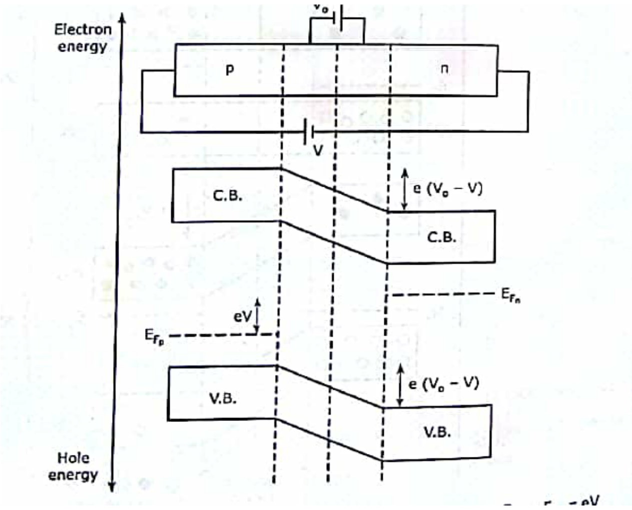
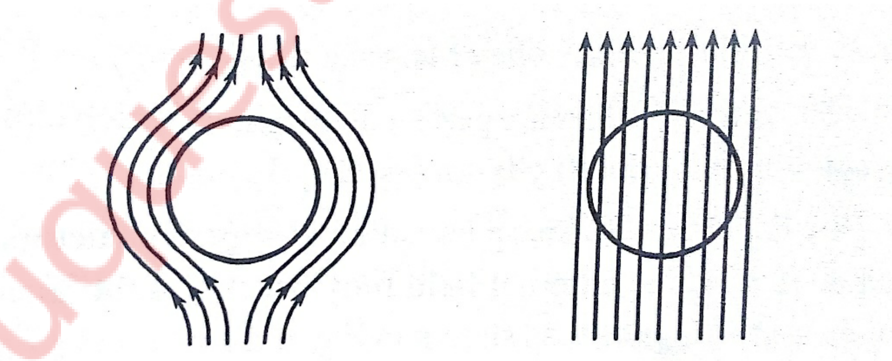


The height of the conduction hill reduces by the same amount eV and becomes e(V_o - V). Similarly the height of the valence hill becomes -e(V_o - V). This makes the charge flow through the junction easier.

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 is7.9 × 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

ρ = *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*

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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 ×10^{13}/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

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

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) 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

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

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

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

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

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

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

$$= 1.055 \times 10^{-19} \times 3 \times 10^{8}$$

$$= 3.165 \times 10^{-11} J$$

$$E_{mi} = \frac{3.165 \times 10^{-11}}{1.6 \times 10^{-19}} = 197\ MeV.$$

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

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 $= 3.8 \times 10^{-3} m$

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.*

$$N = n_c + n_V$$

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

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

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

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

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

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

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

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 :-*

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STRUCTURE:-

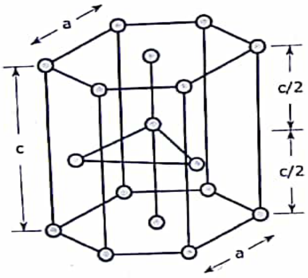

Figure 1.9 (a) : HCP structure

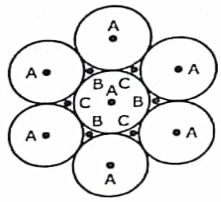

Figure 1.9 (b) : Atomic arrangement of HCP structure

- *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

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

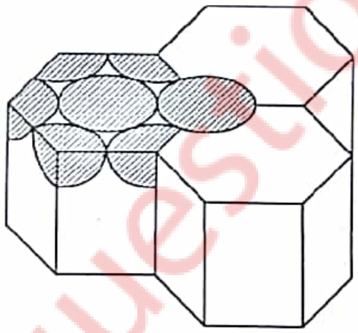

Figure 1.10 (a)

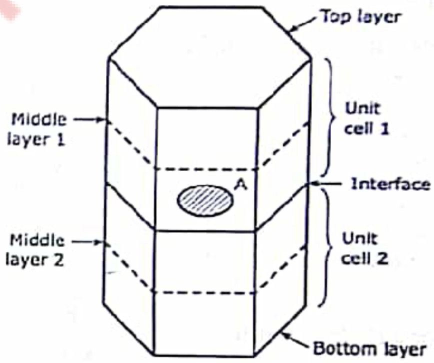

Figure 1.10 (b)

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.

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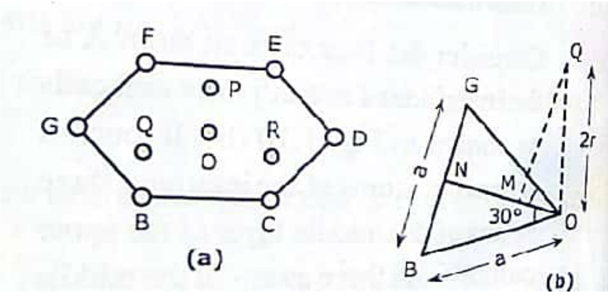
ATOMIC PACKING FRACTION:-

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.

$$OM = \frac{2}{3}ON = \frac{2}{3}a\cos30° = \frac{2}{3}a\frac{\sqrt{3}}{2} = \frac{a}{\sqrt{3}}$$

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

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

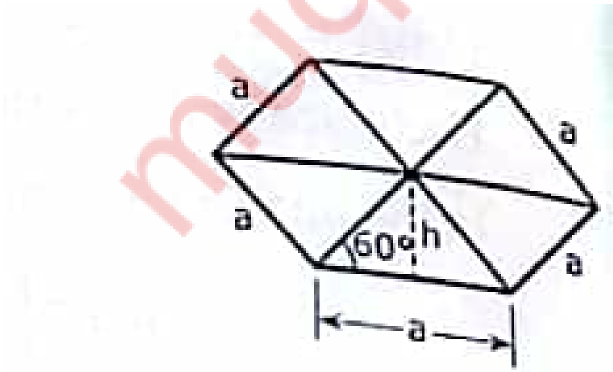


Figure 1.10 (d)

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

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.

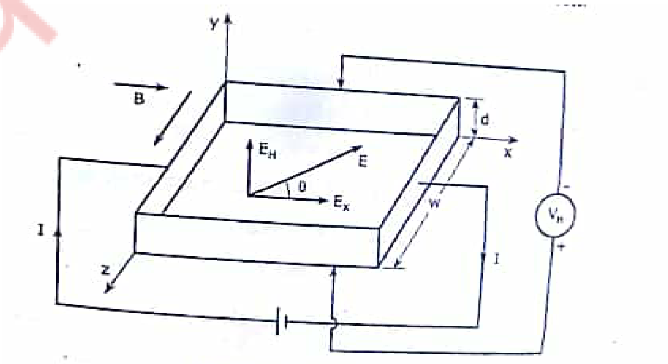


Figure 3.25 : Hall effect set up

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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

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,

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

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)*

$$eE_H = e v_d B$$

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

Using equation (4) in the equation (5)

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

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

$$v_d = \frac{I}{e n_h A} = \frac{J}{e n_h} \quad \text{..........................}(7)$$

Hence hall voltage can be written *as*

$$\boxed{V_H = \frac{IBd}{en.A} = \frac{J_x Bd}{en.}}$$

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

$$\boxed{R_H = \frac{E_H}{J_x B}}$$

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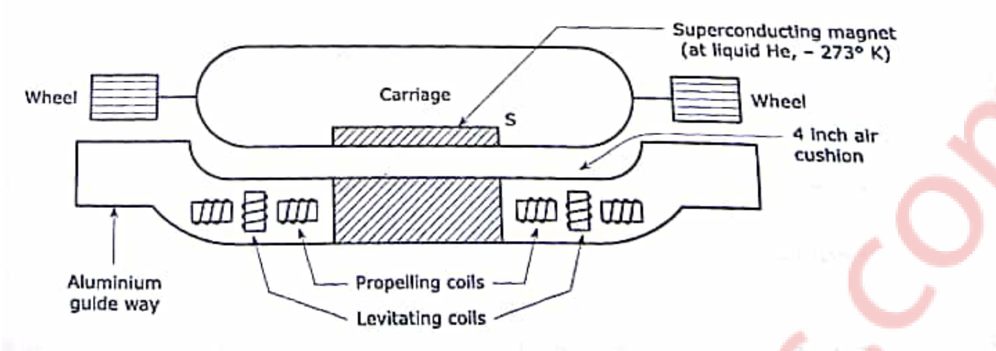
Q4](a) What is the working principle of maglev? Explain how it can acquire high speed? (5)

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*

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

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

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

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

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

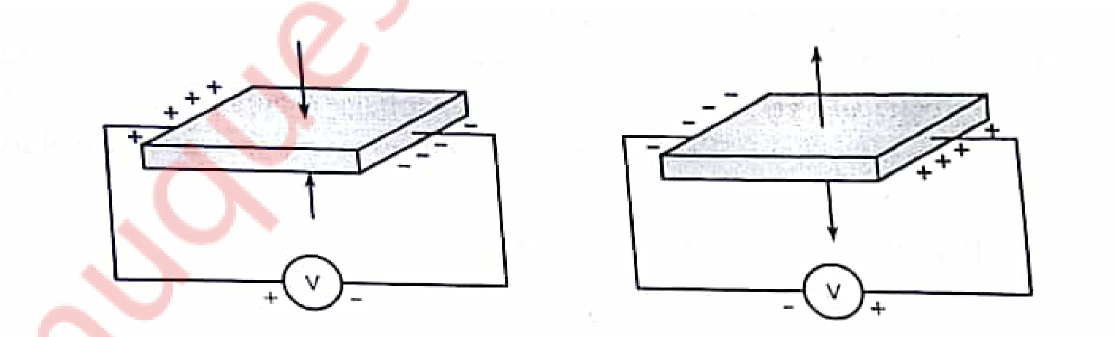
$S' = 2 \times 100\ m^2 = 200\ m^2$

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

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.*

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- *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.*

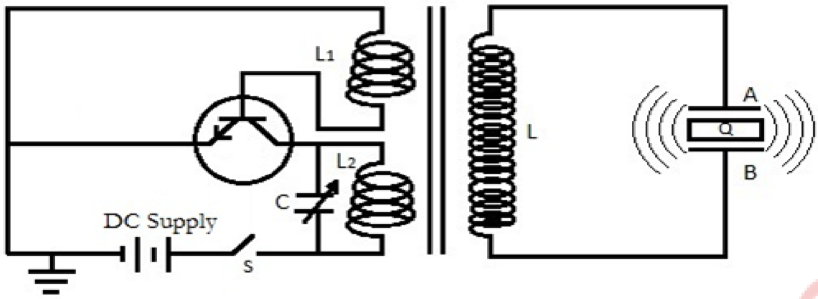

Fig. 7.1: Piezoelectric Oscillator

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.*

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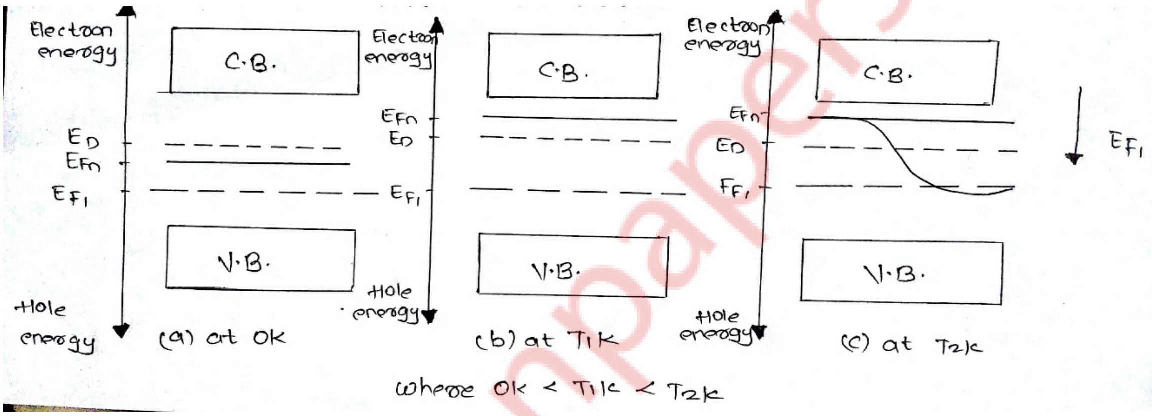
Q5](a) With energy band diagram ,explain the variation of fermi energy level with temperature in extrinsic semiconductor. ***(5)***

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.*

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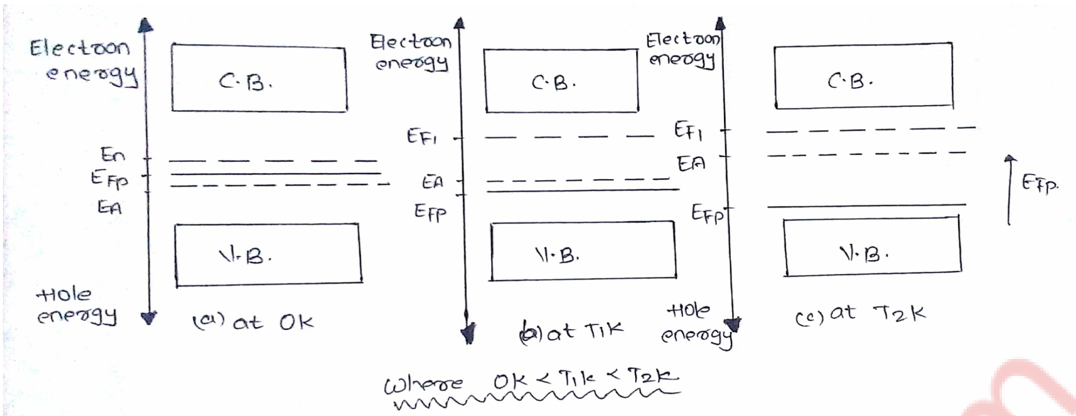
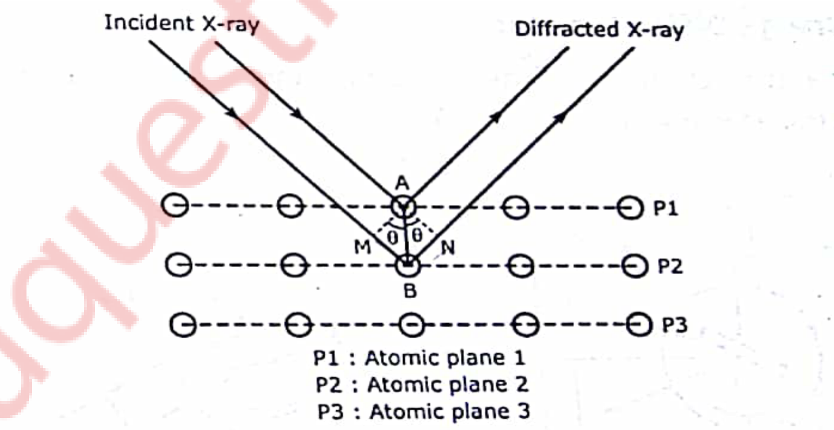


Q5](b) Explain with example how to determine crystal structure by Bragg's X-ray spectrometer. (5)

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 nλ

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

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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

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

where $\omega = 2\pi\vartheta$ *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 = 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

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

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:-

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

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

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.

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.*

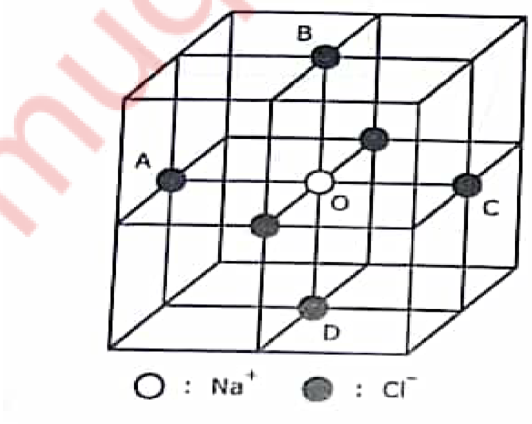
OCTAHEDRAL CONFIGURATION:

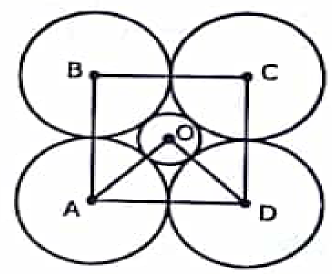
The octahedral configuration of neighbouring anions is found in NaCl structure. Here four anions A, B ,C and D are arranged at the corners of a square with the cation O at the centre of the square. Two more anions are situated in front and at the back of the cation. The centres of all six anions form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

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

Hence, $$\frac{BO}{BC} = \cos 45°$$

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





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The critical radius ratio here is,

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

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* $0 \leq x < L$

= ∞ *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.*

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

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.

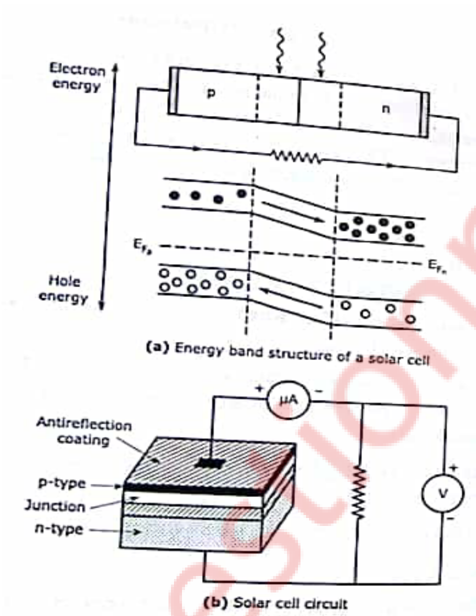

Figure 3.30

- *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*

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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*

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