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 :- $E = 75eV = 75 \times 1.6 \times 10^{-19} = 1.20 \times 10^{-17}$

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

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

$\lambda = \frac{h}{\sqrt{2mE}} = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.1 \times 10^{-31} \times 1.20 \times 10^{-17}}} = 1.41\ A°$

wavelength = $1.41\ A°$

frequency $= \frac{1}{\lambda} = 7.048 \times 10^9$.

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.
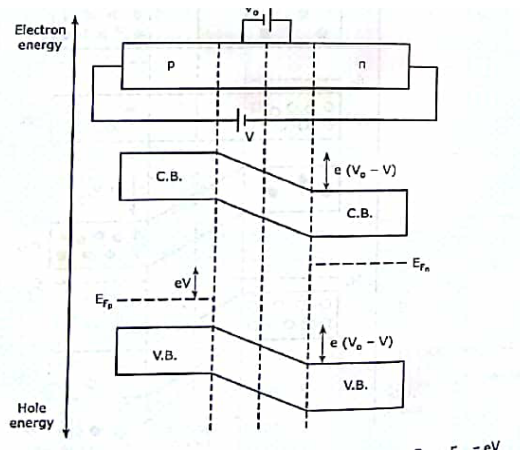

Q1](d) "Superconductor is a perfect diamagnetic", Explain. (3)

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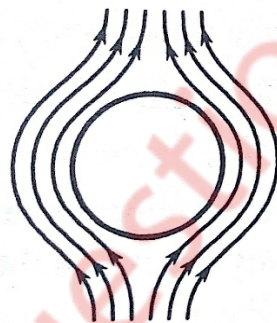
(a) Superconducting state
at $T < T_C$ or $H < H_C$
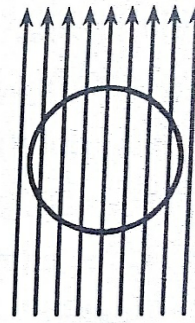
(b) Normal state
at $T > T_C$ or $H > H_C$

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

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

Here H is the applied magnetic field , m is the magnetization produced within the specimen , is χ the susceptibility of the material and μ_0 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.*

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 ,

$$L = -60 \ dB$$

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 $7.9 \times 10^{10} N/m^2$ 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   :- $f = \dfrac{1}{2t}\sqrt{\dfrac{Y}{\rho}}$

Calculations   :- f = $\dfrac{1}{2 \times 10^{-3}} \sqrt{\dfrac{7.9 \times 10^{10}}{2650}}$ = 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 = 2.5×10^{13}/cm^3 = 2.5×10^{19}m^3

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

Calculations :- $\sigma = 2.5 \times 10^{19}(0.36 + 0.17) \times 1.6 \times 10^{-19}$

= 2.12 mho/metre

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

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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.*
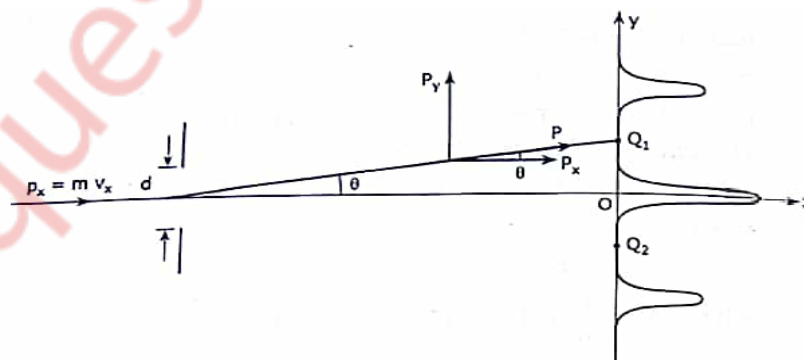
Figure 2.5 : Single slit electron diffraction

- *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* $\Delta p_y = p\dfrac{\lambda}{d}$ *.....................................(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*

$$\Delta y_m = d \qquad ....(4)$$

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

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

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

This verifies the uncertainty principle.

NUMERICAL:-

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

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

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

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

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

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

Therefore uncertainty in position = $3.8 \times 10^{-3} m$

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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°C = 303 K , E_g = 1.12eV,

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

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

Calculation :- Si is an intrinsic semiconductor. Hence ,

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

$$f(E_C) = \frac{1}{1+\exp[\frac{0.56}{86.25 \times 10^{-6} \times 303}]} = 4.9 \times 10^{-10}.$$

Answer   :- Probability = 4.9×10^{-10}.

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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:

● : Na^+
○ : Cl^-

(a) (b) (c)
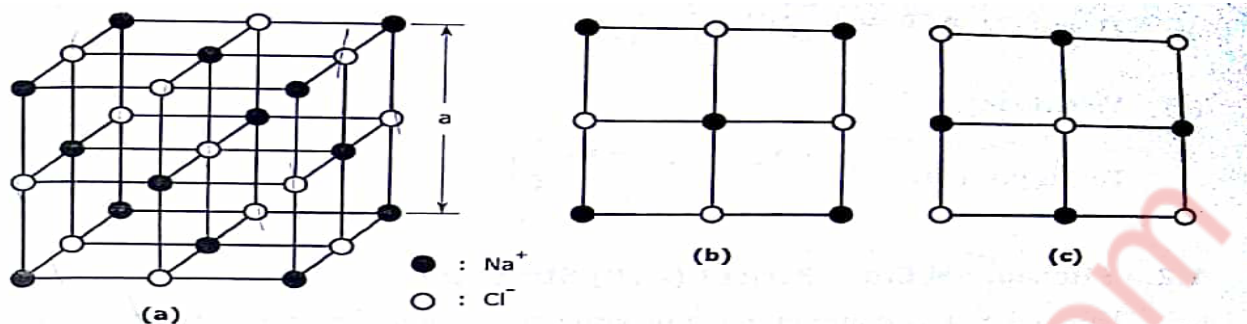
(a) Total number of molecule / unit cells

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)

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

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

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

(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   :- $r_C = 0.98 A°$, $r_A = 1.81 A°$

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

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

Answer :- APF = 0.66

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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

$$I = n_h A e v_d \quad \text{...............................(1)}$$

where n_h *= density of holes*
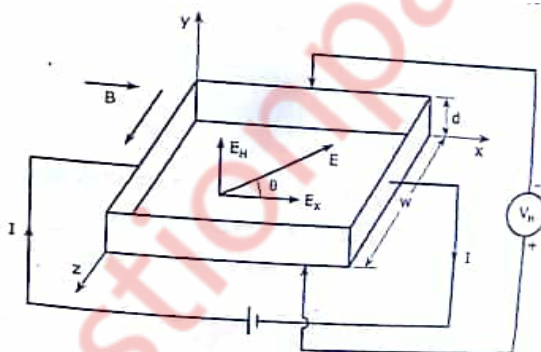
A = w × d = cross sectional area of the specimen

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,

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

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)

$$eE_H = ev_d B$$

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

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

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

Hence hall voltage can be written as

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

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

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

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.
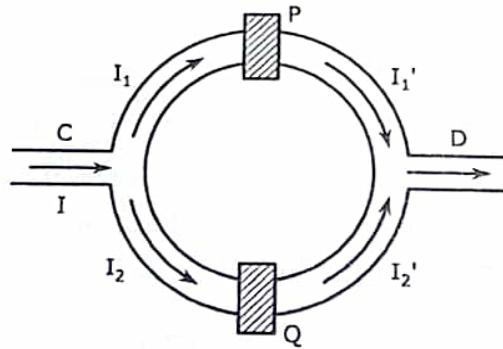
Figure 4.8 : SQUID

- 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 $150 m^2$ 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*

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

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

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

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

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

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

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

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:-*
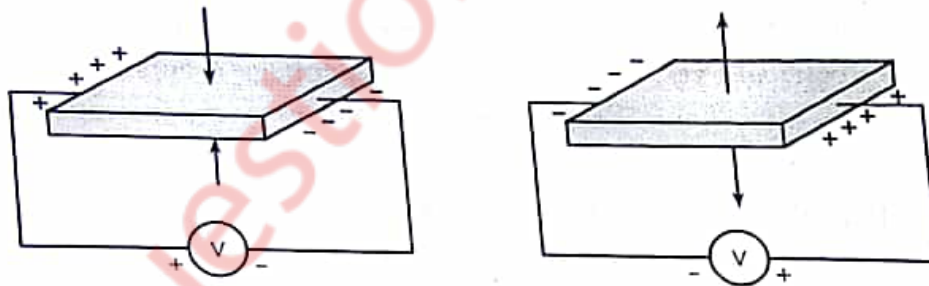
PIEZOELECTRIC EFFECT:

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.*
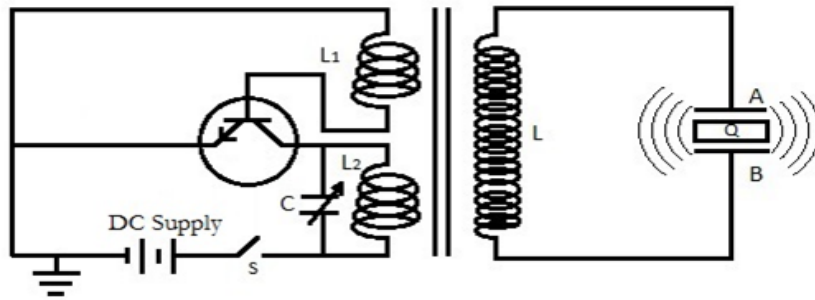
Fig. 7.1: Piezoelectric Oscillator

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*

  $f = \frac{1}{2\pi\sqrt{L2C}}$ 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*

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

    - o *t = Thickness of crystal slab*
    - o *Y = Young's Modulus*
    - o *ρ = Density*
    - o *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.*
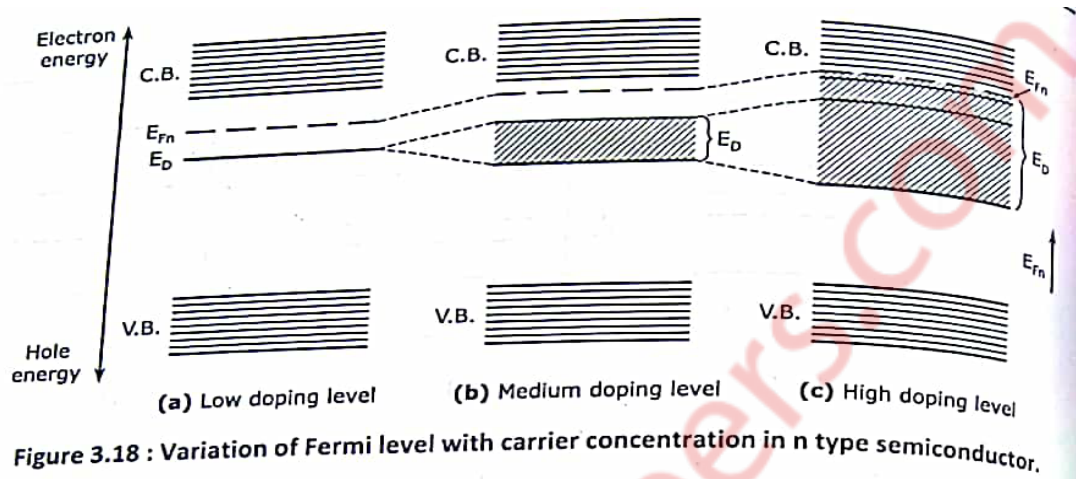

1. IN n-TYPE SEMICONDUCTOR:-

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:-*
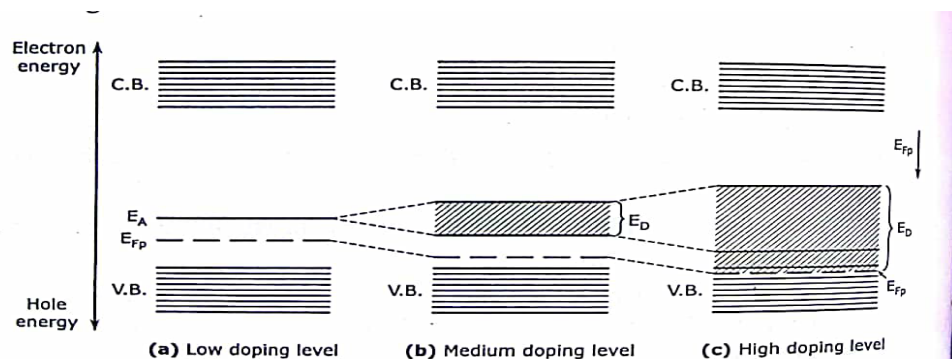

Q5](b) Explain with example how to determine crystal structure by Bragg's X-ray spectrometer. (5)

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

Incident X-ray   Diffracted X-ray

P1 : Atomic plane 1
P2 : Atomic plane 2
P3 : Atomic plane 3
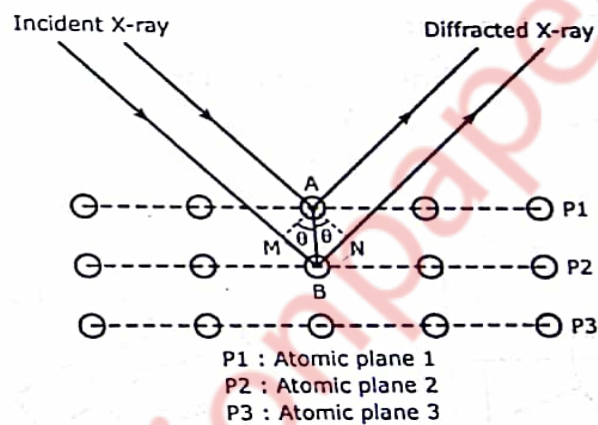
$$\delta = MB + BN = 2MB = 2AB\sin\theta$$

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

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

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

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

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

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

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

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

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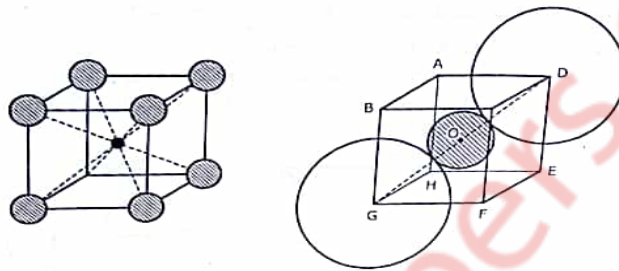
The body diagonals pass through two opposite corner anions and the central cation. Here a = $2r_A$ *and GD =* $\sqrt{3}a = 2(r_C + r_A)$.

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

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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.

$V(x) = 0$ *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.

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

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

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

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.

- *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
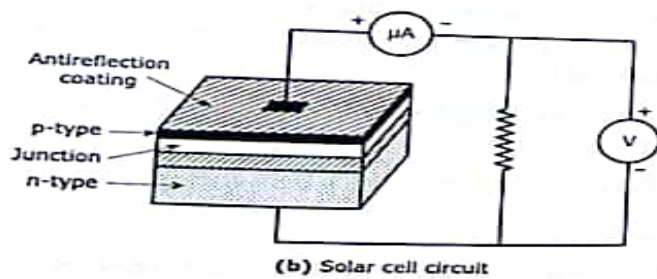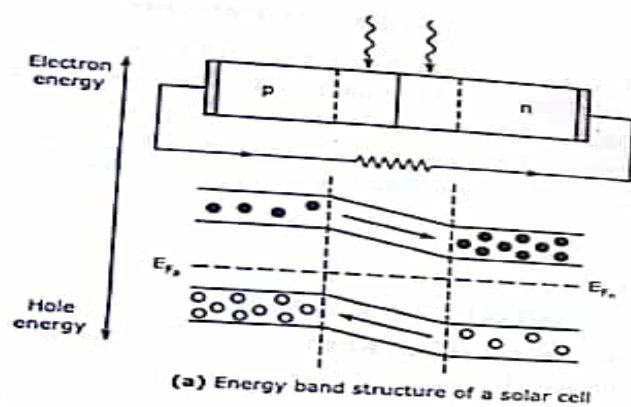
(b) Solar cell circuit

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

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