a.Draw the following for a cubic unit cell. [$\bar{1}\,\bar{2}\,\bar{3}$] , [2 0 0], [$\bar{2}\,\bar{3}\,0$] . (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 : μ = 0.025 m²/Vs , R_H = 2.25 X 10⁻⁵ m³/c .

To find : Resistivity (ρ) .

Formula : $\rho = \dfrac{R_H}{\mu}$.

Solution : $\rho = \dfrac{2.25 X 10^{-5}}{0.025}$.

ρ = 9 X 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

$$E = hν .$$

It can also be represented as

$$E = mc^2 .$$

$$\therefore hν = mc^2 .$$

Now p= momentum associated with photon which travels in free space .

$$p= mc = \frac{mc^2}{c} = \frac{hν}{c} = \frac{h}{\lambda}$$

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

---

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.

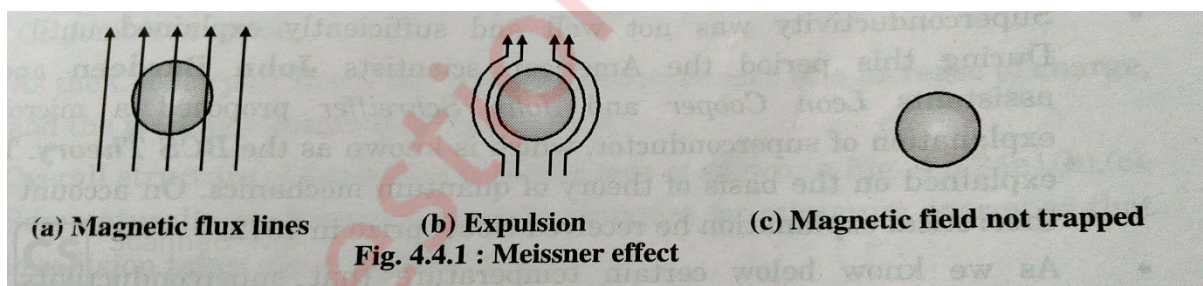**f. Explain Meissner Effect with the help of diagram .** (3M)

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.

(a) Magnetic flux lines   (b) Expulsion   (c) Magnetic field not trapped
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

$$\therefore \mu_0(H+M) = 0$$

Susceptibility = $\dfrac{M}{H}$ = -1 .

---

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 = $\dfrac{vt}{2}$ 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 $\overset{\circ}{}$ 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)**
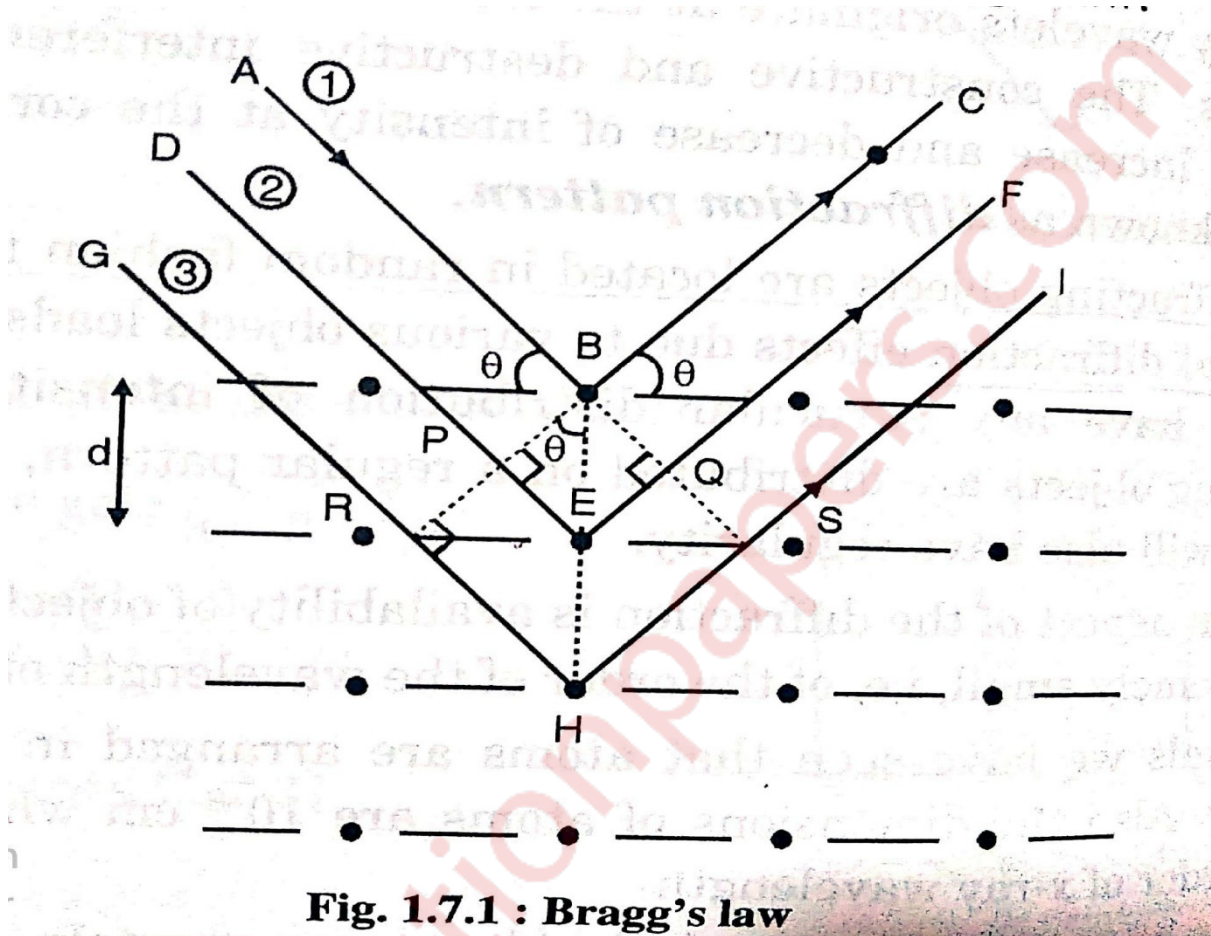
Ans : A monochromatic X-ray beam when made incident on them at an angle which is called as glancing angle, and showed that constructive interference takes place between the rays scattered by the atoms only when a condition called Bragg's Law is satisfied.

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

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

Δ = BE sinθ + BE sinθ = 2BE sinθ = 2d sinθ (BE = 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

$$\Delta' = 4d \sin\theta = 2(2d \sin\theta) = 2\Delta$$ i.e. integer multiple of Δ .

Numerical : (1 0 0) $\equiv$ (h k l) , a = 2.814 $\overset{\circ}{A}$, n = 1 , λ = 1.514 $\overset{\circ}{A}$

$$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}} = \frac{1.514}{\sqrt{1^2 + 0^2 + 0^2}} = 1.514 \, \overset{\circ}{A} .$$

nλ = 2dsinθ .

$$1 X 2.814 = 2 X 1.514 X \sin\theta$$.

$$\therefore \sin\theta = \frac{2.814}{2 X 1.514} = 0.0929 .$$

$$\therefore \theta = \sin^{-1}(0.929) = 6.833° .$$

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.
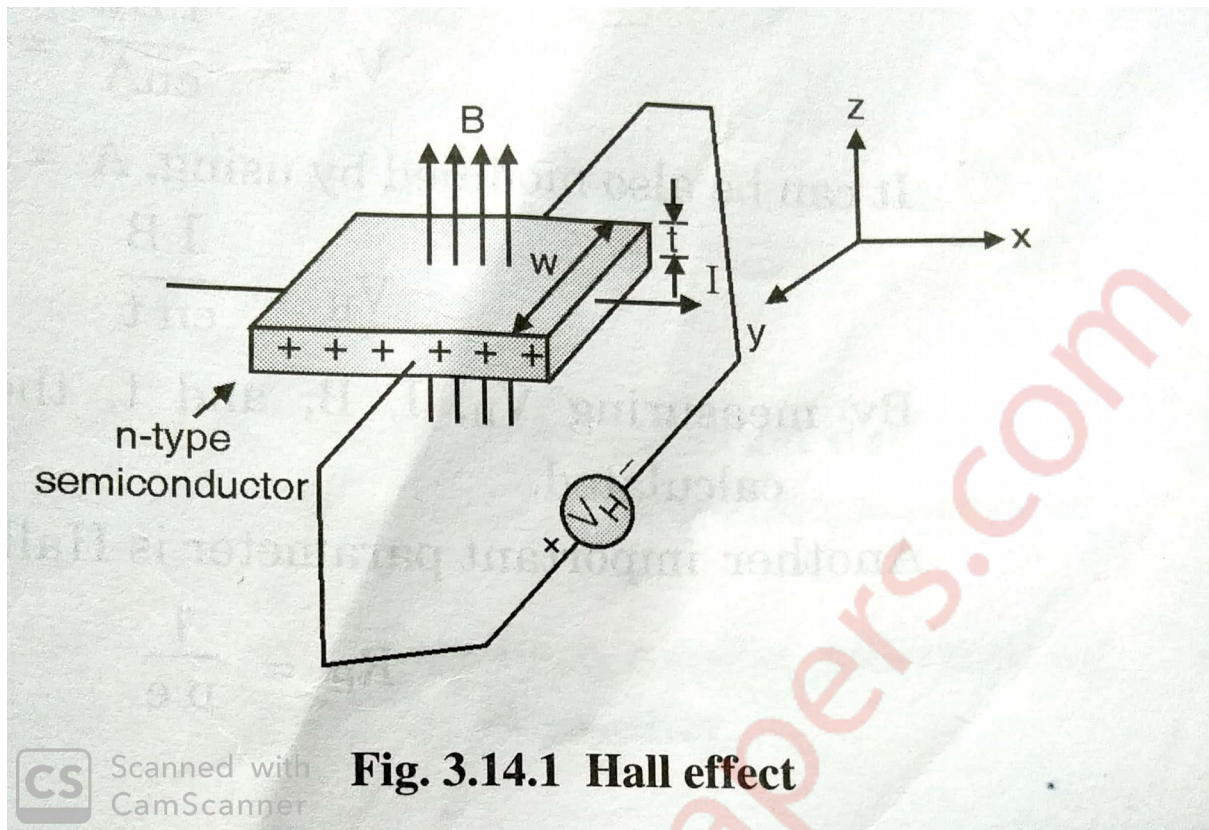
Fig. 3.14.1 Hall effect

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.

$$\therefore \text{Magnetic Force } F = e v B$$

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.

$$\therefore \quad E_H = \frac{V_H}{w}$$

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.

$$\therefore e E_H = evB$$

$$\text{Or } E_H = vB$$

$$\therefore V_H = Bvw$$

$$v = \frac{I}{enA} = \frac{J}{en} \qquad \qquad \text{where } J = \frac{I}{A}$$

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)

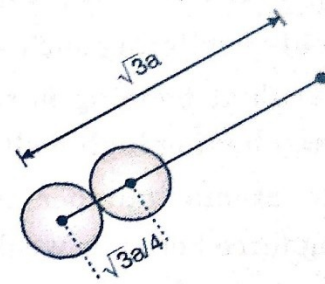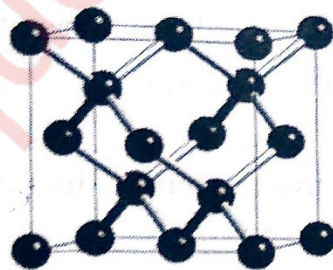$$R_H = \frac{1}{ne}$$ (for n-type semiconductor)

$$R_H = \frac{V_H t}{BI}.$$

As $\sigma = \mu n e$, $\mu = \sigma R_H$ 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 $\left(\dfrac{1}{4}, \dfrac{1}{4}, \dfrac{1}{4}\right)$.

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 $\dfrac{1}{4}$ 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 = $\dfrac{(Number\, of atoms\, per\, unit\, cell)\, X\, (Volume\, of\, one\, electron)}{Volume\, of\, unit\, cell}$.

$$= \frac{8X\dfrac{4}{3}\pi r^3}{a^3} = \frac{8X\dfrac{4}{3}\pi \left(\dfrac{\sqrt{3}a}{8}\right)^3}{a^3} = 0.34$$

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 : $\rho = 5.98\, \text{gm/cc}$, $M = 50\, \text{g}$.

We know that $\rho a^3 = \dfrac{nM}{N}$ where n is No. of atoms/unit lattice , N is Avogadro's Number .

$$\therefore a^3 = \frac{nM}{N\rho}$$

$$\therefore a^3 = \frac{2X50}{6.022X10^{23} X5.98}$$

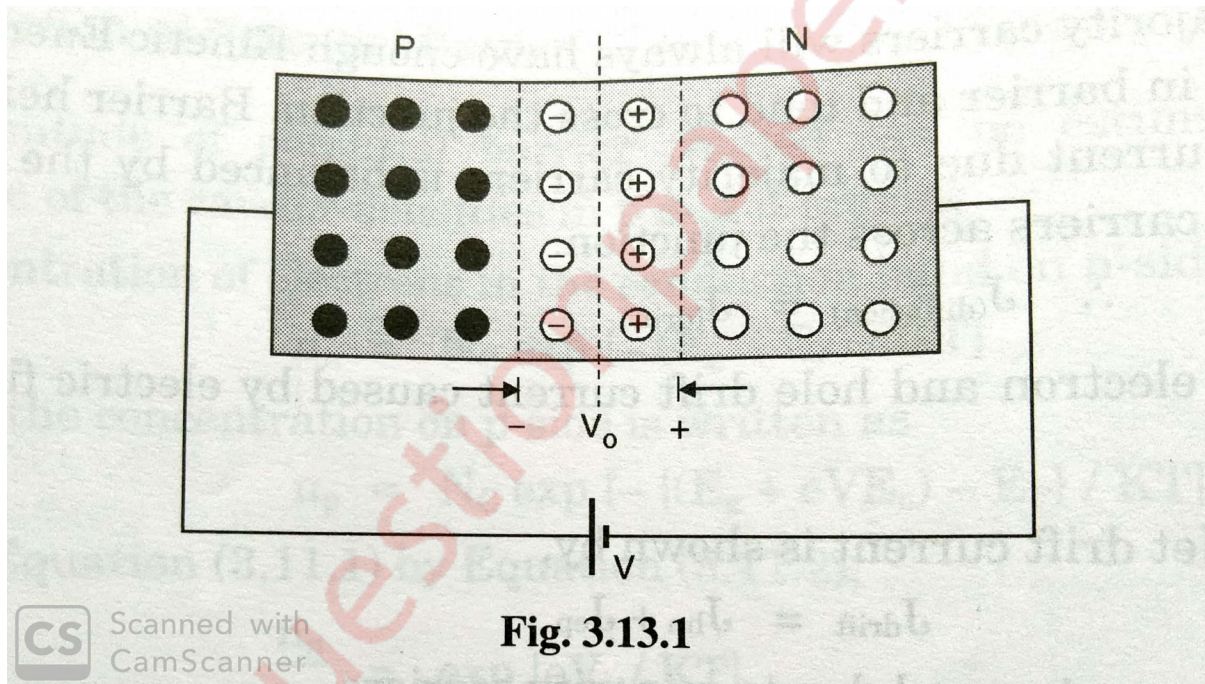$$\therefore a = 3.028 X 10^{-8} = 30.28 \quad A°$$

Since it is BCC lattice , $a = \dfrac{4r}{\sqrt{3}}$.

$$\therefore r = \dfrac{\sqrt{3}a}{4} = 1.311 \quad A°$$

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 .

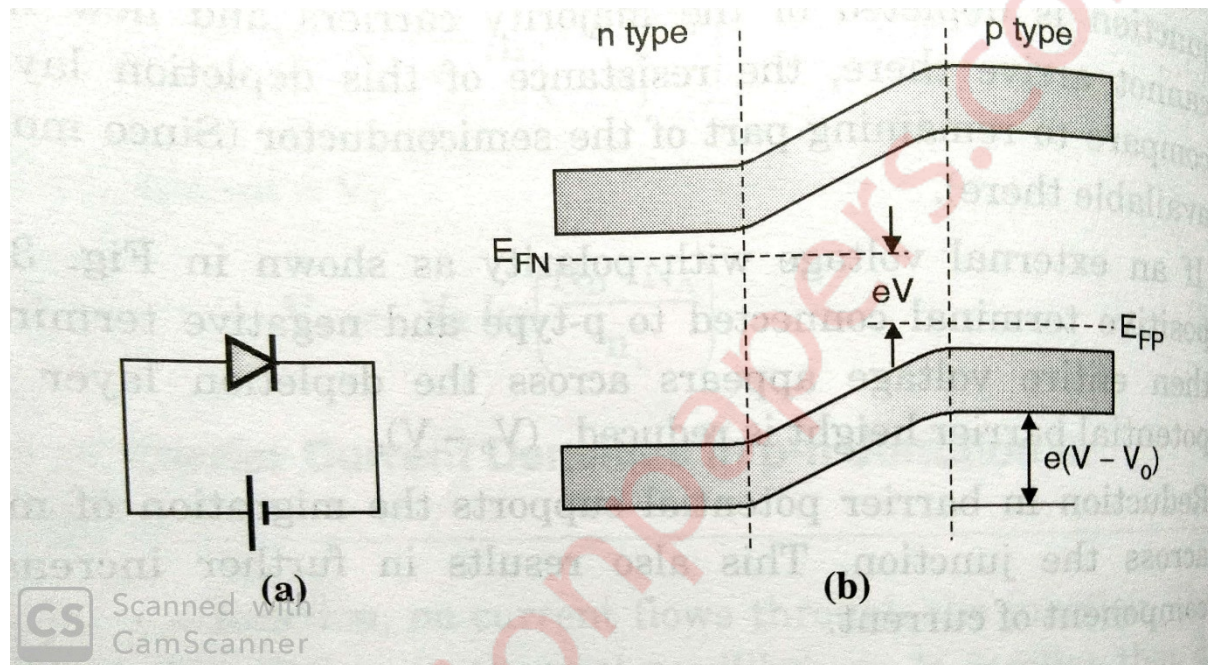Similarly ,

$$J_{(diffusion)} = J_{hp} + J_{en} \quad .$$

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).
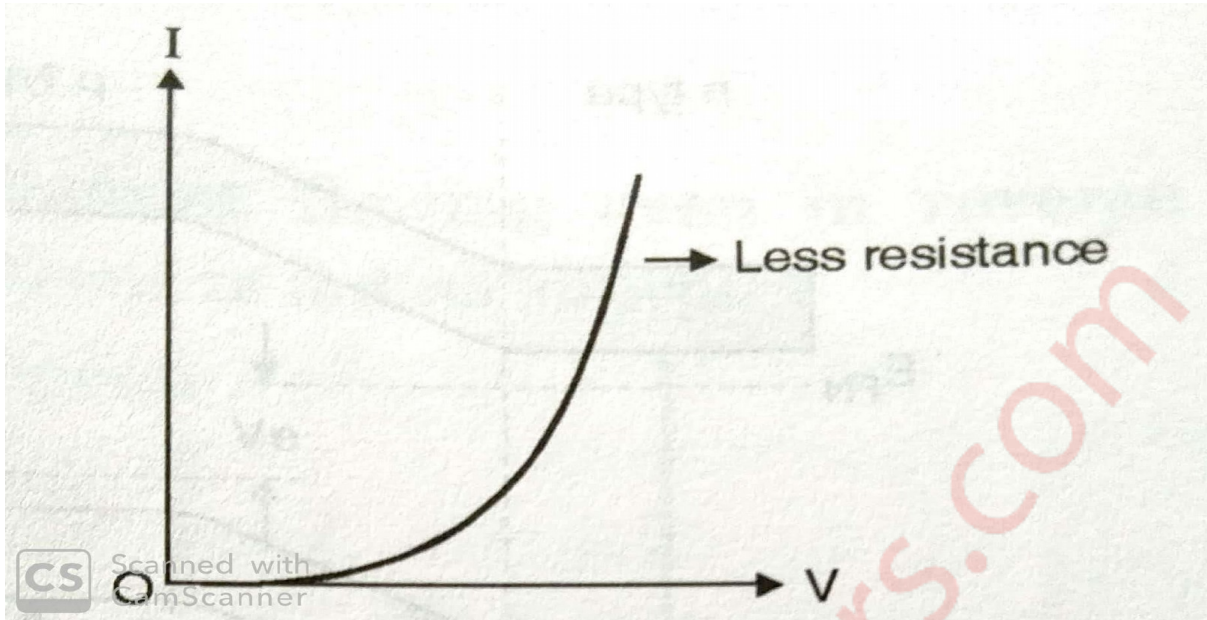
b. If an external voltage with polarity as positive terminal connected to p-type and negative terminal with n-type, then entire voltage appears across the depletion layer and hence the potential barrier height is reduced, $(V_0 - V)$.

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

$$\lambda = \dfrac{6.626 X 10^{-34}}{\sqrt{2 X 6.67 X 10^{-27} X 2 X 1.6 X 10^{-19} X 150}}$$ = 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 , $\dfrac{\Delta v}{v} = 0.01\% = \dfrac{0.01}{100} = 10^{-4}$.

To find : Δx .

Formula : $\Delta x.\Delta p \geq \dfrac{h}{2\pi}$.

Solution :   Momentum of electron = p = mv .

$\Delta p = m\Delta V = mv\dfrac{\Delta v}{v} = 9.11 X 10^{-31} X 350 X 10^{-4} = 3.189 X 10^{-32}$.

Using Heisenberg's Uncertainity Formula :

$$\Delta x.\Delta p \geq \dfrac{h}{2\pi}$$

$$\therefore \Delta x \geq \dfrac{h}{2\pi}.\dfrac{1}{\Delta p}$$

$$\therefore \Delta x \geq \dfrac{6.63 X 10^{-34}}{2\pi X 3.189 X 10^{-32}}$$

$$\therefore \Delta x \geq 3.309 X 10^{-3} \text{ m} .$$

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 10¹⁰ N/m² and ρ=2.650 gm/cc]. **(5M)**

Given :   t = 1 mm = 10⁻³ m , Y = 7.9 X 10¹⁰ N/m² , ρ = 2.650 gm/cc .

To find : η .

Formula : $\eta = \dfrac{k}{2t}\sqrt{\dfrac{Y}{\rho}}$.

Solution : For fundamental frequency, consider first harmonic i.e. k = 1 .

$$\eta = \dfrac{1}{2 X 10^{-3}}\sqrt{\dfrac{7.9 X 10^{10}}{2.65}}$$

$$\eta = 8.633 X 10^{7} Hz$$

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 :

$$\sigma_e = nX1.6X10^{-19}X0.14$$

$$4X10^4 = nX1.6X10^{-19}X0.14$$

$$n = 1.786X10^{24}/m^3$$

$$\sigma_p = pX1.6X10^{-19}X0.04$$

$$4X10^4 = pX1.6X10^{-19}X0.04$$

$$\therefore \quad p = \frac{4X10^4}{1.6X10^{-19}X0.04}$$
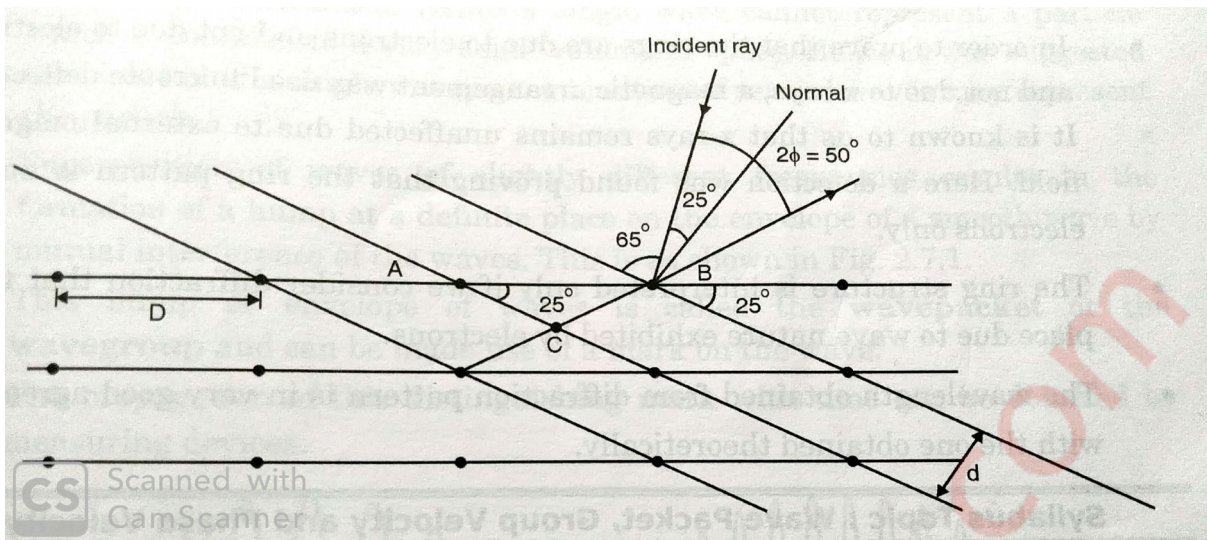
$$\therefore p = 6.25X10^{24}/m^3$$

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.
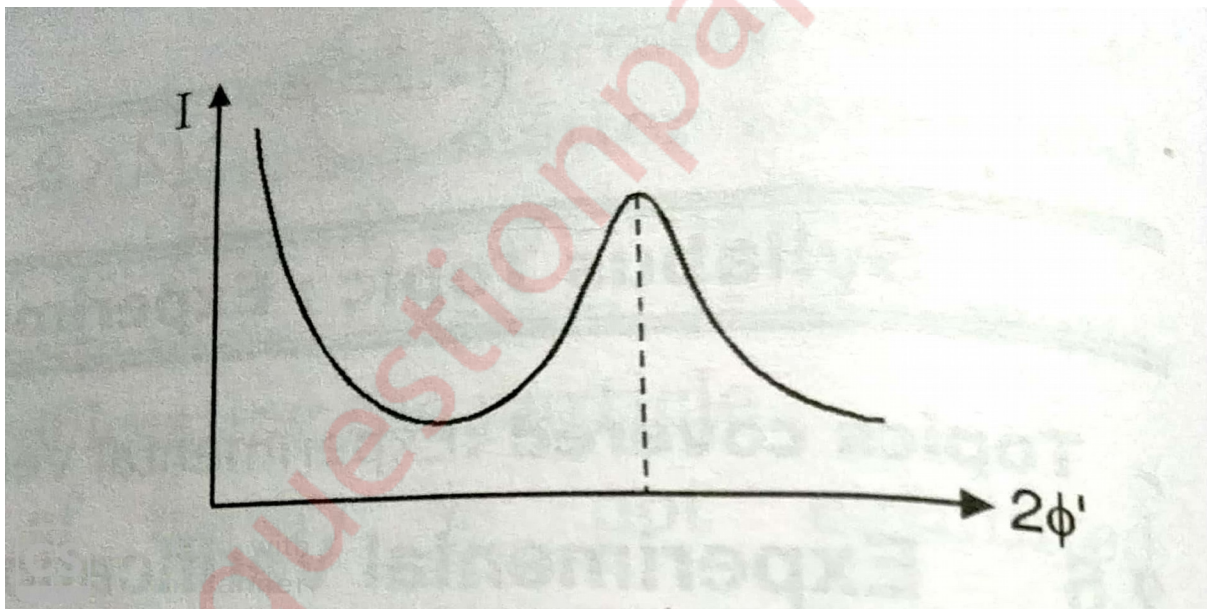
2. Since electrons are considered as beam and expected to experience diffraction, a detector is replaced for telescope. The detector can be rotated on a circular path around the crystal.

3. As expected, the electrons acting like a wave were diffracted in a particular direction which is in accordance with Bragg's Law.

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

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 - Φ' = 90° - 25° = 65°. The interplanar spacing is given by d = 0.909 °A.

7. In $\triangle ABC$, AB = D = 2.15 °A (Inter atomic spacing)

BC = d = Inter planar spacing

$$\therefore \sin 25° = \frac{d}{D}$$

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   .

$$\therefore \lambda = 1.65 A°$$

From theoretical value obtained from de Broglie 's law we have

$$\therefore \lambda = \frac{12.25}{\sqrt{V}} = 1.67 A°$$

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.

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   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.
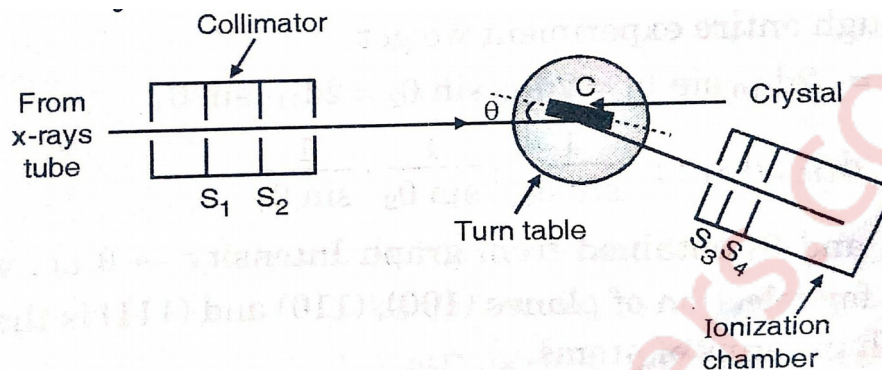

Fig. 1.8.1 : Schematic diagram of Bragg's spectrometer

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

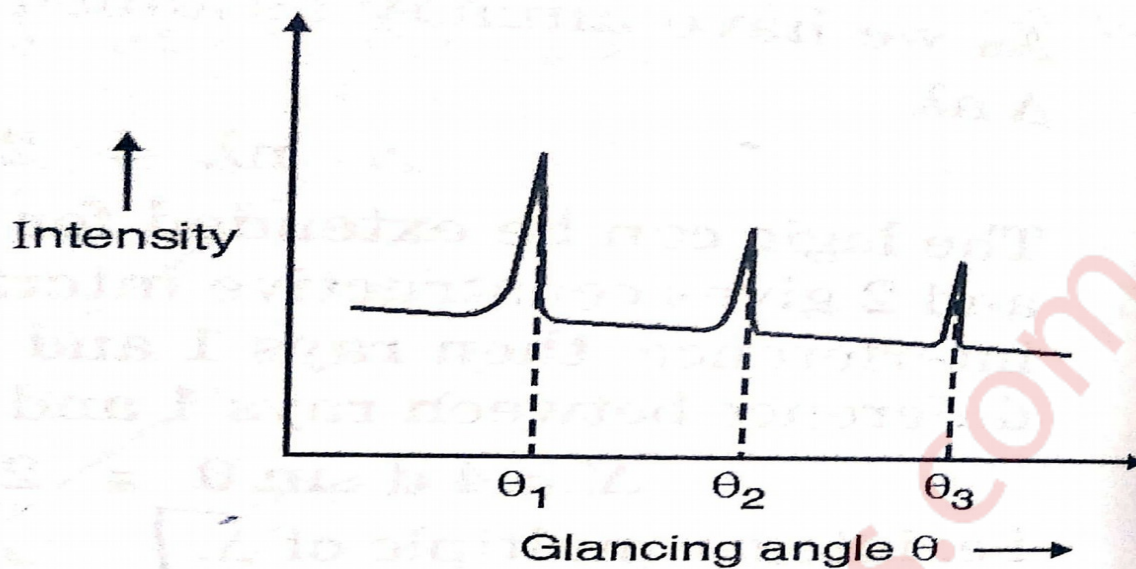As λ is same through entire experiment we get

Fig. 1.8.2 : Variation of ionisation current

$$\lambda = 2d_{100}\sin\theta_1 = 2d_{110}\sin\theta_2 = 2d_{111}\sin\theta_3 \quad .$$

$$\therefore d_{100} : d_{110} : d_{111} = \frac{1}{\sin\theta_1} : \frac{1}{\sin\theta_2} : \frac{1}{\sin\theta_3} \quad .$$

Where θ_1, θ_2 and θ_3 obtained from graph intensity $\to \theta$ 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 .

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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
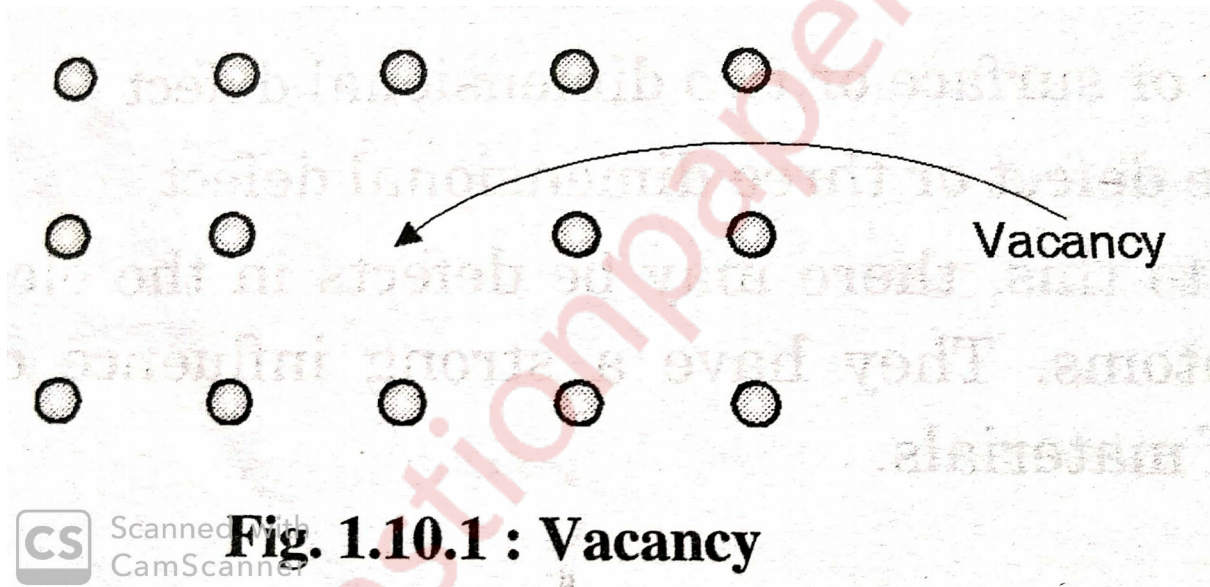
$$n = Ne^{\frac{-E_V}{KT}}$$

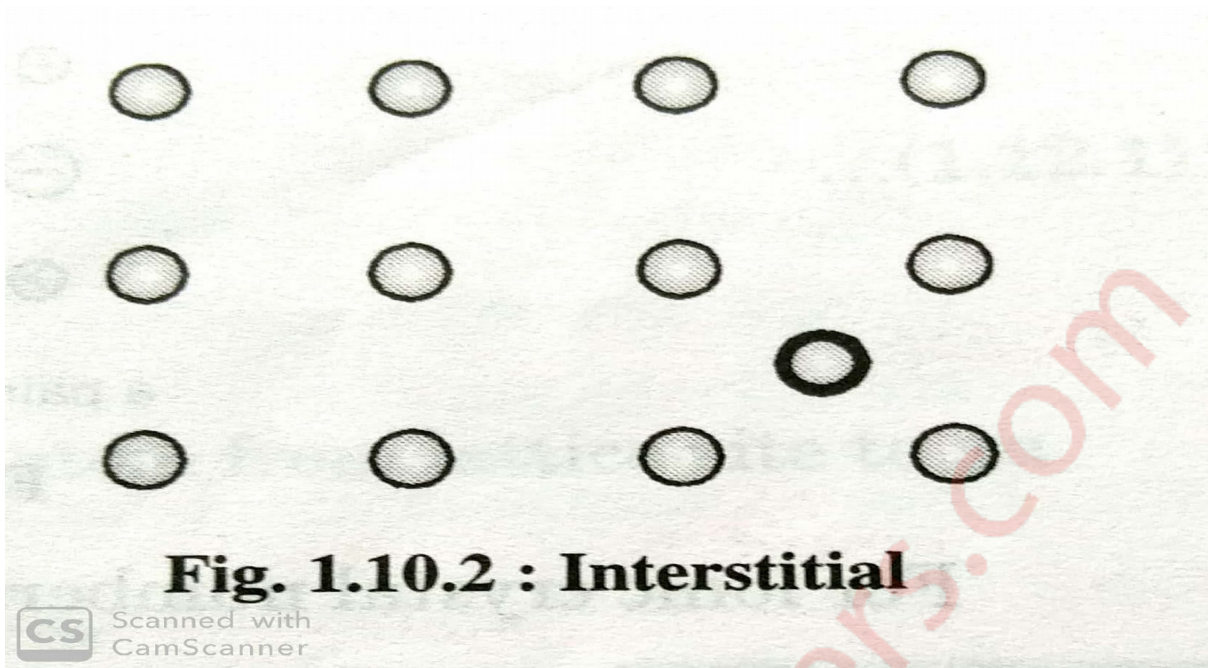Where n = Number of vacancies

N = Total number of atoms

T = Temperature in K .

E_V = Average energy required to create a vacancy .
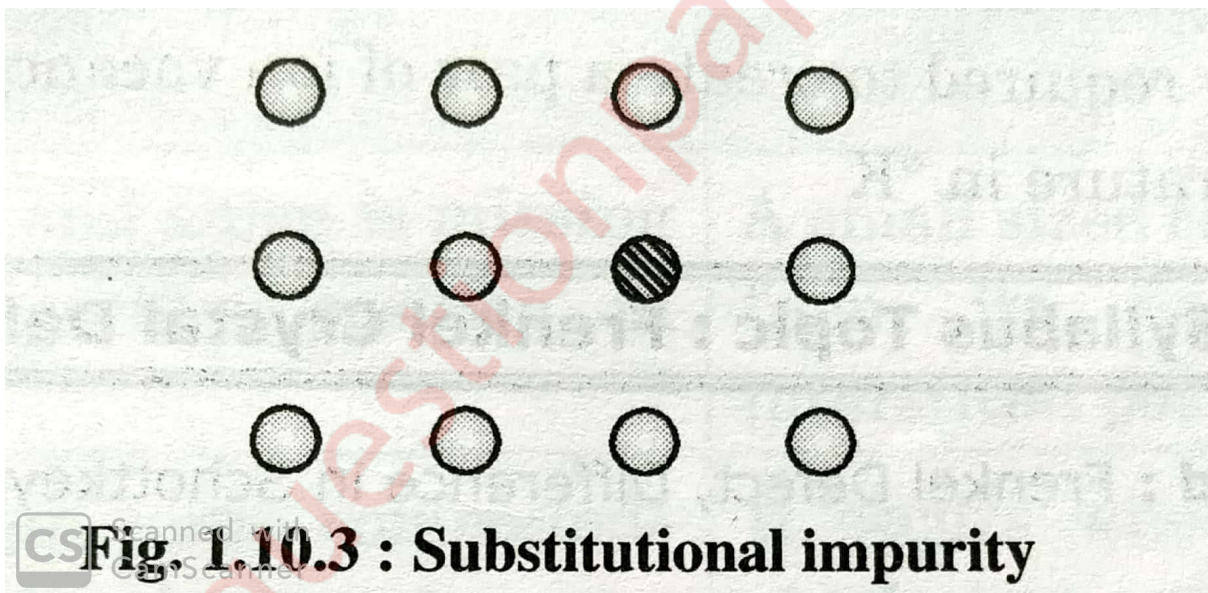

Fig. 1.10.1 : Vacancy

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

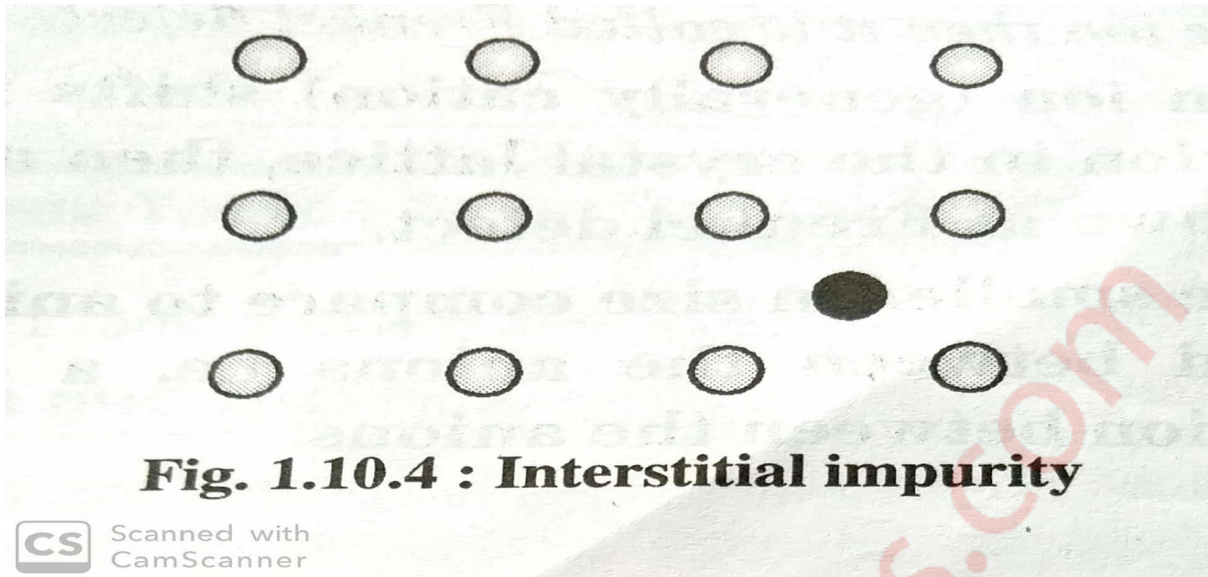d. Interstitial impurities :

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.
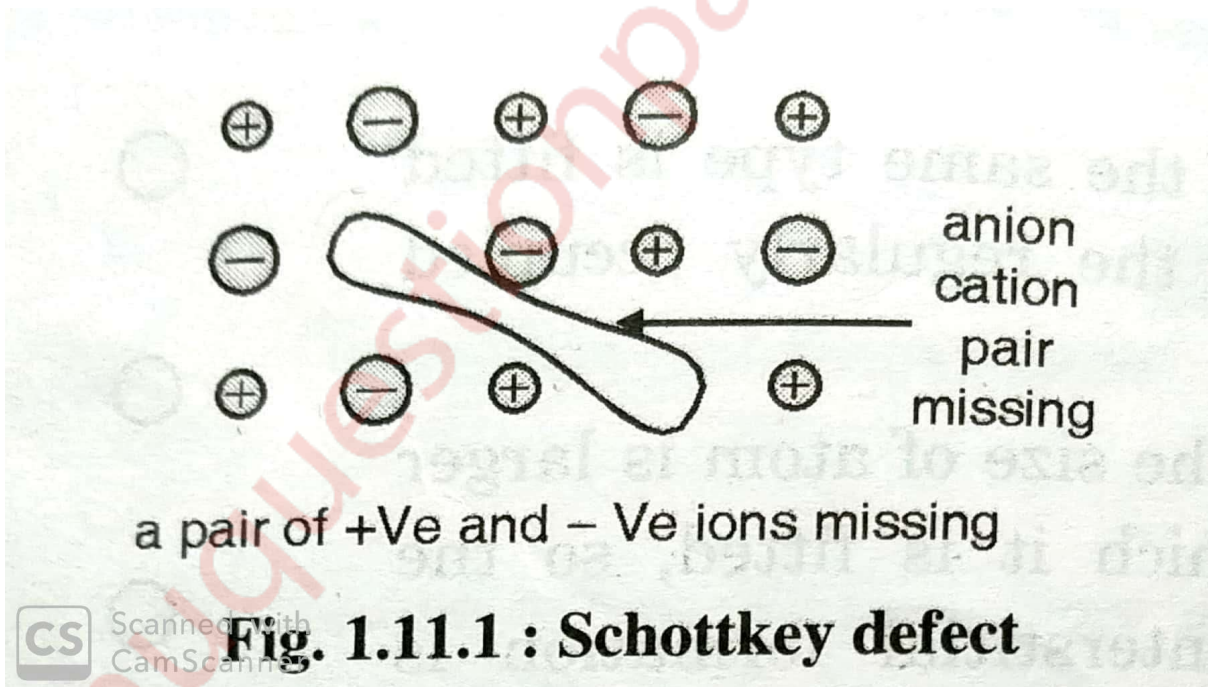

anion
cation
pair
missing

a pair of +Ve and – Ve ions missing

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 $N = (N_C N_A)^{\frac{1}{2}}$.
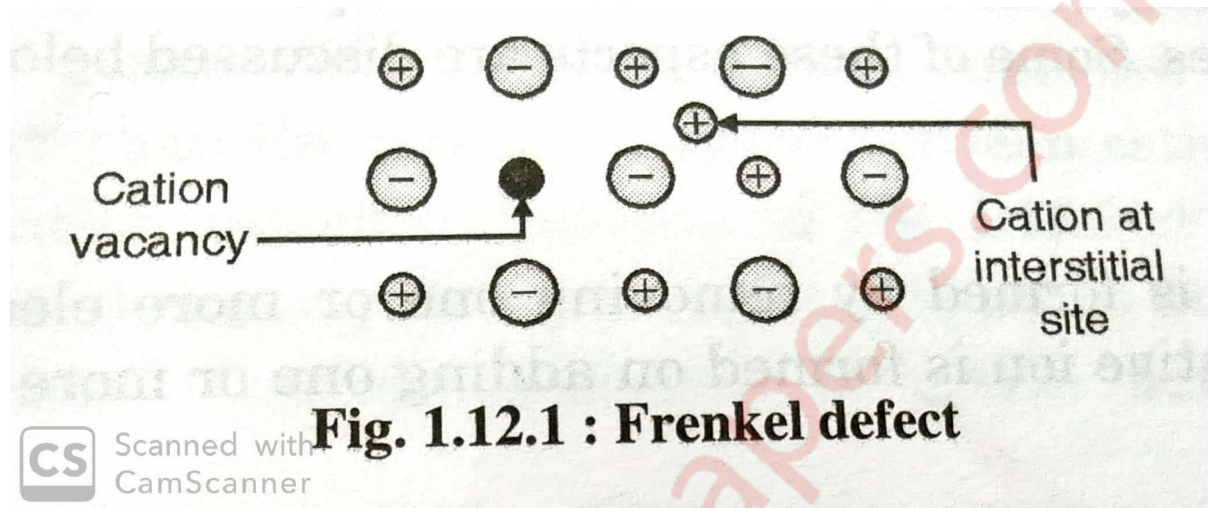
k = Boltzman constant

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 .