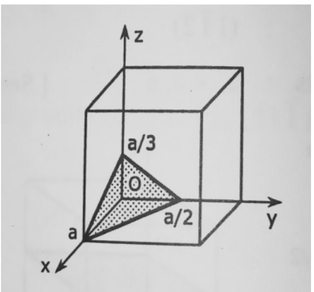
APLLIED PHYSICS 1

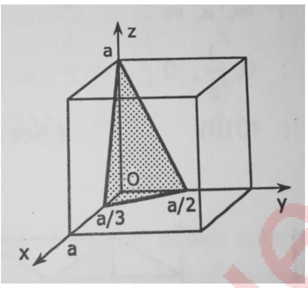
(CBCGS DEC 2018)

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

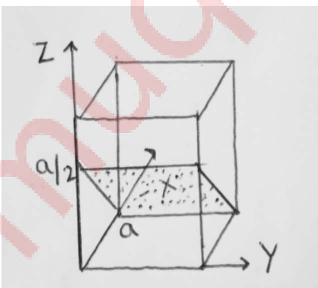
Ans) *(123)*



(321)



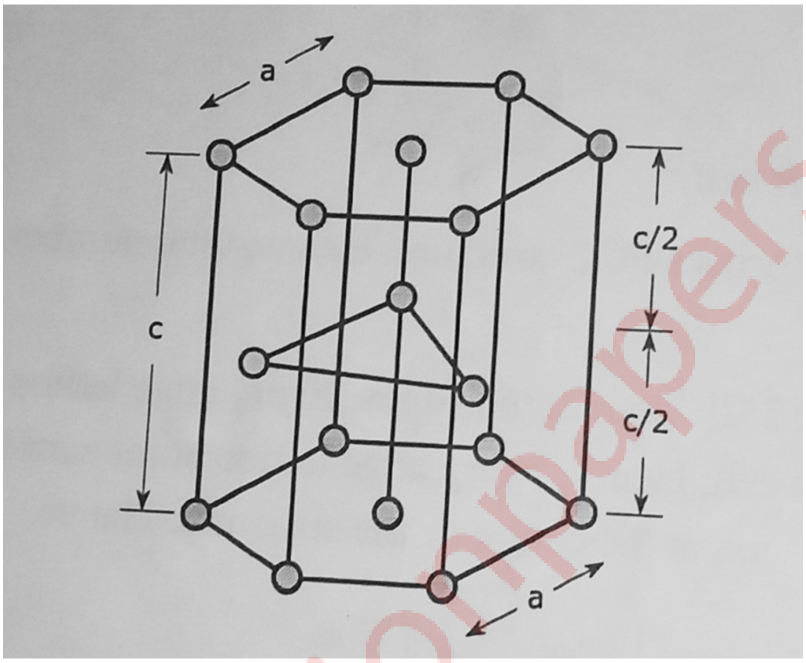
$(\bar{1}02)$



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

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

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



Every unit cell is structured as follows

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

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

---

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

Ans)

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

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

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

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

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

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

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

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

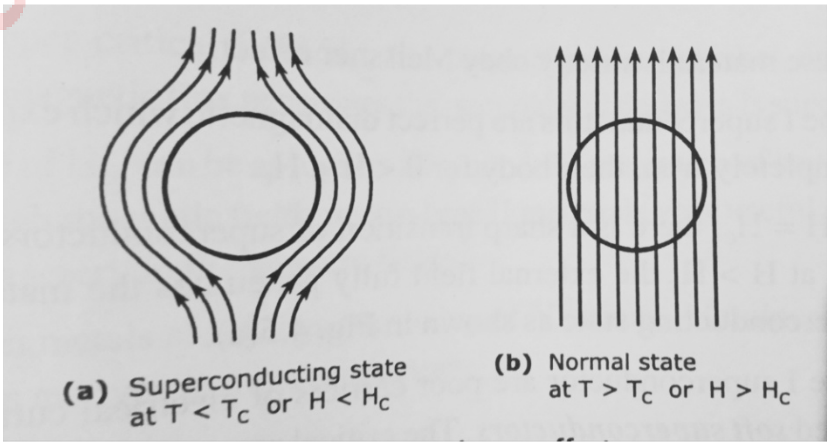
Answer: Carrier concentration=$1.388\times 10^{16}/m^3$

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

Ans:-

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

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



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

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

(3)

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

Formula:*T=0.161×V/a*

Calculations: *T= 0.161×V/a*

T=(0.161×2000)/100

=3.22 sec

Answers:*Reverberation time = 3.22 sec.*

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

Ans) *Non destructive testing:*

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

Emulsification:

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

Medical applications:

Ultrasonic waves are used in

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

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

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

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

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

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

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

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

From the limiting condition of Heisenberg's uncertainty principle,

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

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

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

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

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

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

Therefore, the electron behaves as a relativistic particle.

The relativistic energy of the electron is

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

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

$E=pc$

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

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

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

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

Numerical Solution :

Data: *v=350 m/sec, Δv/v=0.01%*

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

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

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

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

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

Answer:*Minimum uncertainty in position is* 3.314×10^{-3} m

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

Ans)

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

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

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

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

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

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

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

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

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

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

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

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

as (E_V-E_F) is negative.

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

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

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

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

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

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

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

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

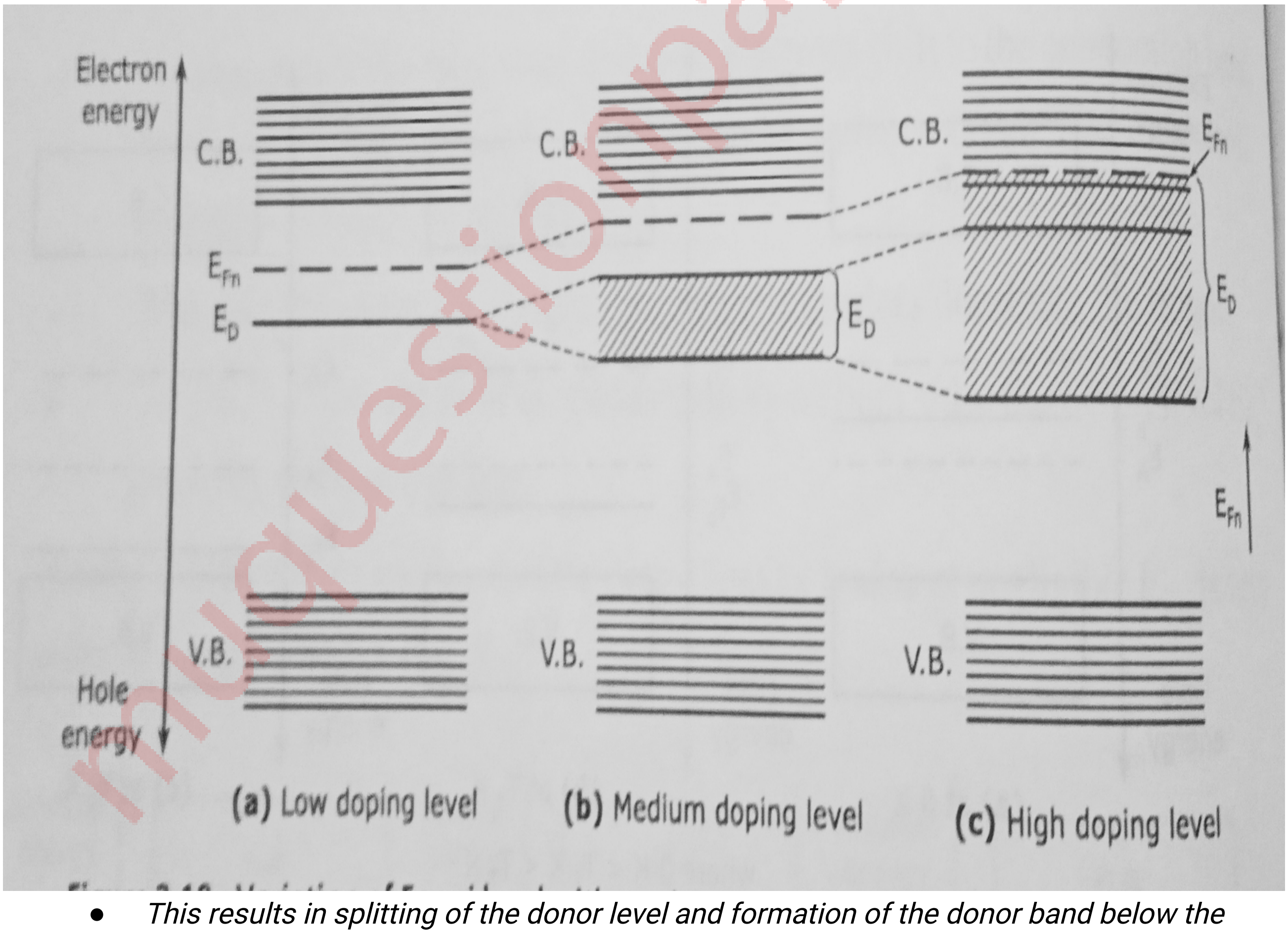
$E_C + E_V = 2E_F$

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

Thus the Fermi energy level lies in the middle of the forbidden energy gap in an intrinsic semiconductor.

***Variation of Fermi Level with impurity concentration**:*

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

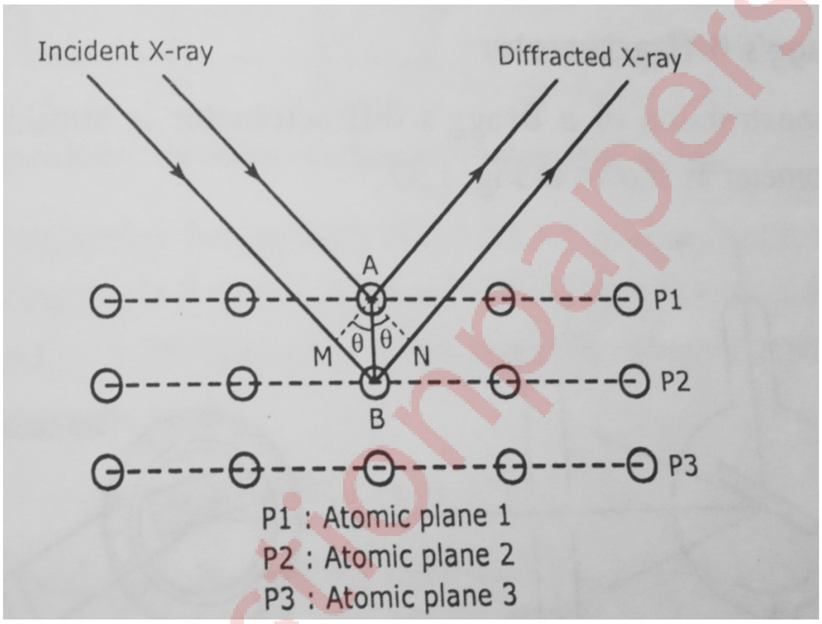


- *This results in splitting of the donor level and formation of the donor band below the conduction band. With the increase in impurity concentration the width of the band increases. At one stage it overlaps with the conduction band. As the donor band* *widens the forbidden gap decreases.In the process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

Q3](a) Derive Bragg's condition for X-ray diffraction. Monochromatic X rays are incident on a crystal. If the first order rejection is observed at an angle of 3.4°, at what angle would second order reflection expected.
(8)

Ans)

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



When a beam of X-rays is incident on a crystal it is scattered by individual atoms of the rich atomic planes.Thus,each atom become a source of scattered radiation.The atomic planes responsible for the X-ray diffraction are called BRAGG'S PLANES. Therefore,the sets of Braggs planes constitute the crystal grating. Bragg's scattering or Bragg's diffraction is also referred as Braggs reflection. Bragg derived a law called Bragg's law to explain the X-ray diffraction effect. Here a beam of X-ray is incident on a set of parallel planes of a crystal.The rays makes glancing angle θ and are practically reflected from different successive planes.The phase relationship of the scattered rays can be determined from their path differences.Here two parallel X-rays are reflected from two consecutive planes P_1 and P .The path differences between them as shown

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

Here AB = d,the interplanar spacing of the crystal

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

The two diffracted rays reinforce each other when they interfere constructively when their path

difference δ is equal to nλ

Hence, $2d\sin\theta = n\lambda$ *is called as Bragg's Law*

***Numerical solution**:*

Data: $\theta_1 = 3.4°$

***Formula**:* $2d\sin\theta = n\lambda$

***Solution**: From equation,* $\sin\theta \propto n$

Hence, $\sin\theta_1/\sin\theta_2 = n_1/n_2$

$\sin(3.4)/\sin\theta_2 = 1/2$

$\sin\theta_2 = 0.1186$

$\theta_2 = 6.8113°$

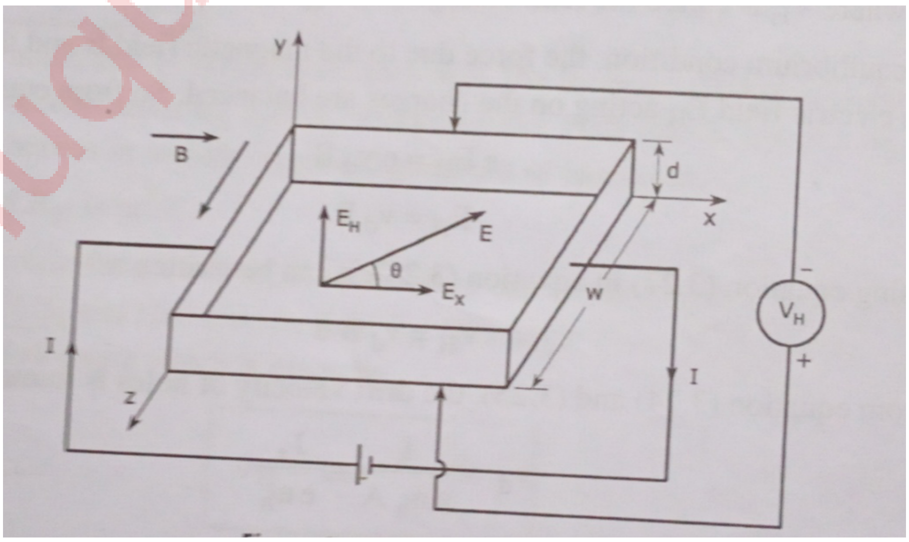
***Answer**: Hence, second order reflection is expected at 6.8113°*

Q3](b) Derive an expression for Hall voltage and Hall coefficient with neat labelled diagram. (7)

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

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

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



$I = n_h Aevd$……………………………(1)

where n_h=density of holes

$A = w \times d$ = cross sectional area of the specimen

v_d = drift velocity of the holes.

The current density is

$J = I/A = n_h ev_d$…………………….(2)

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

$F_m = ev_d B$ ……………………………(3)

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

Due to this a corresponding equivalent negative charge is left on the top surface.The separation of charge set up a transverse electric field across the specimen given by

$E_H = V_H/d$ …………………………..(4)

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

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

$eE_H = ev_d B$

$E_H = v_d B$……………………………….(5)

Using equation (4) in the equation (5)

$V_H = v_d Bd$ ……………………….(6)

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

$v_d = I/en_h A = J_x/en_h$ …………………….(7)

Hence,hall voltage can be written as

$$\boxed{\begin{aligned} VH &= IB_d/en_h A \\ &= J_x Bd/en_h \end{aligned}}$$

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

$$\boxed{R_h = V_H A/IB}$$

Q4](a) Differentiate between Type-I & Type - II Superconductors.
(5)

Ans)

Sr.No.	***Type I superconducters***	***Type II superconductors***
1.	*They exhibit complete Meissner effect.*	*They exhibit partial Meissner effect.*
2.	*There are perfect diamagnetics.*	*They are not perfect diamagnetics.*
3.	*These are known as soft superconductors.*	*They are known as hard superconductors.*
4.	*They have only one critical magnetic field.*	*They have two critical magnetic fields.*
5.	*These material undergo a sharp transition from the superconducting state to the normal state at the critical magnetic field.*	*These materials undergo a gradual transition from the superconducting state to the normal state between the two critical magnetic fields.*
6.	*The highest value of critical magnetic field is 0.1 WB/*m^2	*The upper critical magnetic filed can be of the order of 50 Wb/*m^2
7.	*Application are very limited.*	*They are used to generate very high magnetic fields.*
8.	*Examples: Lead, Tin, Mercury, etc*	*Examples: Alloys like Nb-Sn, Nb-Ti, etc.*

Q4](b) Discuss in details any three factors affecting acoustics of a hall with their remedies.
(5)

Ans) *(1)**Defect*-**Echo**

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

Design*:A splayed (fan shaped) floor plan and the covering of interior surfaces with suitable absorbent material minimize the defect and distribute the sound energy uniformly throughout the hall.*

(2) ***Defect*** ~~-~~**Echelon Effect**

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

Design *: The steps inside the hall should be covered with absorber like carpets.*

(3) ***Defects*** *:* **Reverberation**

The persistence of sound in a room due to multiple reflection from the walls,thefloor and the ceiling for some time,is called reverberation.

Design*:Though excessive reverberation distorts the original sound a small amount of reverberation is desirable in a concert hall since it improves the quality of music. The reverberation is optimized by placing and fixing sound absorbing material in the hall. This way the reverberation time is controlled to a desired value.*

Q4](c) A quartz crystal of thickness 1 mm is vibrating at resonance. Calculate its fundamental frequency. (Assume that for quartz, Y= 7.9× 10^{10} N/m^2 and ρ = 2.650 gm/cc. (5)

Ans) ***Data****:* t_1 = 1 mm= 10^{-3} m, Y = 7.8 × 10^{10} N/m^2,

ρ = 2.650 gm/cc = 2650 kg/m^3

Formula*:* f= 1/2t •√Y/ρ

Calculations*:* f = 1/2× 10^{-3} √ 7.9× 10^{10}/2650 = 2.73 MHz

Answer*:Frequency = 2.73 MHz*

Q5](a) Define Ligancy. Find the value of critical radius ratio for Ligancy 3. (5)

Ans*)In an ionic solid, the actions are positioned at alternate lattice points. Generally,cations are smaller than anyone in size. in a crystal,thr number of anions surrounding a cation is called as Ligancy.*

Ligancy 3*:Triangular configuration*

The arrangement is triangular since a triangle is formed if the centres of the neighbouring anions are joined.In critical condition all the neighbouring anions and the central cation are in contact with each other,as shown in figure,

Here, BC=r_A and OC=r_A+r_C and ∠ BCO=30^0

In the Δ OBC,we get

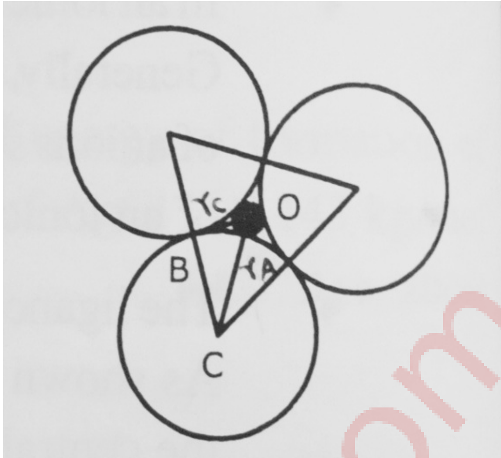
$BC/CO = \cos 30^0$

or $\quad r_A/r_C + r_A = \sqrt{3}/2$

or $\quad r_C + r_A/r_A = 2/\sqrt{3}$

The critical radius ratio is thus

$r_C/r_A = 0.155$



Q5](b) For an electron passing through potential difference 'V', show that its wavelength is; (5)

λ=12.26/√V A°.

Ans) *The wavelength of an electron with kinetic energy E is given by*

$\lambda = h/\sqrt{2mE}$ .... (1)

On the other hand, the kinetic energy of an electron passing through potential difference'V' is,

$1/2\, mv^2 = eV$

Hence, $\quad E = eV$ *Thus, replacing E with eV in equation (1), we get,*

$\lambda = h/\sqrt{2meV}$ .... (2)

Substituting values of,

$h = 6.63 \times 10^{-34}$ kg-m/s

$m = 9.1 \times 10^{-31}$ kg

$e = 1.6 \times 10^{-19}$ coulomb

in equation (2), we get,

$\lambda = 1.226 \times 10^{-19} / \sqrt{V}$ metre

$\lambda = 12.26 / \sqrt{V}$ A°

Q5](c) What is the probability of an electron being thermally excited to conduction band in Si at 27°C.The band gap energy is 1.12 eV. (5)

Ans) ***Data***: $\quad T = 27°C = 300\ K, \quad E_g = 1.12\ eV$

$K = 1.38 \times 10^{-23}$ J/K $= 86.25 \times 10^{-26}$ eV/K

Formula: $f(E_C) = 1/1+e^{(Ec-Ef)/kT}$

Calculations: *Since an intrinsic semiconductor. Hence,*

$E_C - E_F = E_G/2 = 0.56$ eV

$f(E_C) = 1/1+ \exp[0.56/86.25\times 10^{-6}\times 300] = 3.9 \times 10^{-10}$

Answer:*Probability* $= 3.9 \times 10^{-10}$

Q6](a) Explain Point defects in crystals. (5)

Ans) *In any crystal, at all temperatures above absolute zero, there are always some free atoms present which lodge themselves anywhere other them their scheduled lattice sites. This give rise to point defects.*

Point defects can be classified into the following categories:

Vacancy defects: *This is a defect in which an atom is missing from a regular lattice site, l. Such vacancies arise in close packed structures, i.e., metallic structures.*

Interstitial defects: *An interstitial defect is an imperfection in which an atom that has moved from its*

regular lattice dates lodges itself in the interstices i. e., the void space.

Substitutional impurity: *When a regular atom leaves behind a vacancy and goes to the interstices the vacant lattice site can be occupied by a foreign atom.*

Interstitial impurity: *This is the kind of imperfection when a foreign atom lodges itself in the interstices. Thus can oxide only when the foreign atomism substantially smaller than the host atom.*

Schottky defect: *In an ionic crystal, a pair of vacancies arise which leas to missing of one Casio and one anion from the regular lattice sites. This is known as Schottky defect in which the charge neutrality is maintained.*

Frankel defect: *The cations are v smaller than anions. In ionic crystals if a cation leaves its regular lattice site and lodges itself in the interstices it is called Frenkel defect. It is a combination of a cation vacancy and one intersticial defect.*

Q6](b)Show that group velocity of matter waves associated with a particle is equal to the particle velocity($V_{group}=V_{particle}$) (5)

Ans)

Consider a particle of rest mass m, moving with a vclocity,v,which is very large and comparable to c with v <c.Its mass is given by the relativistic formula,

$$m = mo / \sqrt{1-(v^2/c^2)} \text{ ....(1)}$$

Let ω be the angular frequency and k be the wave number of the de Broglie wave associated with the particle.Here v is the frequency and λ is the wavelength of the matter wave. Hence,it can be written that

$$\omega = 2\pi v = 2\pi(mc^2/h)$$

$$\omega = 2\pi/h \cdot m_o c^2/\sqrt{1-(v^2/c^2)} \text{............(2)}$$

And $k = 2\pi/\lambda = 2\pi p/h = 2\pi mv/h$

$$k = 2\pi/h \cdot m_o v/\sqrt{1-v^2/c^2}$$

- *The wave velocity is the the phase velocity given by*

  $$v_p = \omega/k = c^2/v \text{.................(3)}$$

- *Since the wave packet is composed of waves of slightly different wavelength and velocities, the group velocity is written as*

  $$v_g = d\omega/dk$$

- *This can be calculated using equation (1) and (2) as*

$$v_g = \frac{dw/dv}{dk/dv}$$

$$= [d/dv(c^2/\sqrt{1-(v^2/c^2)})]\cdot[d/dv(v/\sqrt{1-(v^2/c^2)})]^{-1}$$

$$v_g = v$$

This shows that a matter particle in motion is equivalent to a wave packet moving with group velocity v_g whereas the component waves move with phase velocity, v_p.

Q.6](c) Explain the principle, construction and working of Light Emitting Diode. (5)

Ans) ***Principle***: *The recombination process:*

- *In a forward biased p-n junction through electrons and holes diffuse through the junction in opposite directions. In this process they recombine with each other in the depletion region and release some energy called the recombination energy.*
- *According to energy band structure, during the recombination process the electron*

come back to the valence band and fulfil the gap called a hole. This is accompanied by the release of some energy equal to the band gap energy E_g.

- *For ordinary semiconductors like Ge and Si the bandgap energies are 1.12 eV and 0.63 eV respectively. In these solids the recombination energy is heat energy.*
- *However, if E_g ranges from 1.7eV to 3.0 eV, according to $E = h\nu = hc/\lambda$, the emission takes place within the visible region. This is possible if the direct band AGP ionic crystals like Gallium Arsenide (GaAs), Gallium Arsenide Phosphide (GaAsP) and Gallium Phosphide (GaP) are used as the diode material. In this case the recombination energy is emitted as optical energy.*
- *The wavelength of the emitted light is given by*

  $\lambda = hc/E_g = 1.24/ E_g(eV) \;\; \mu m$

- *The colours of the emitted light are as follows:*

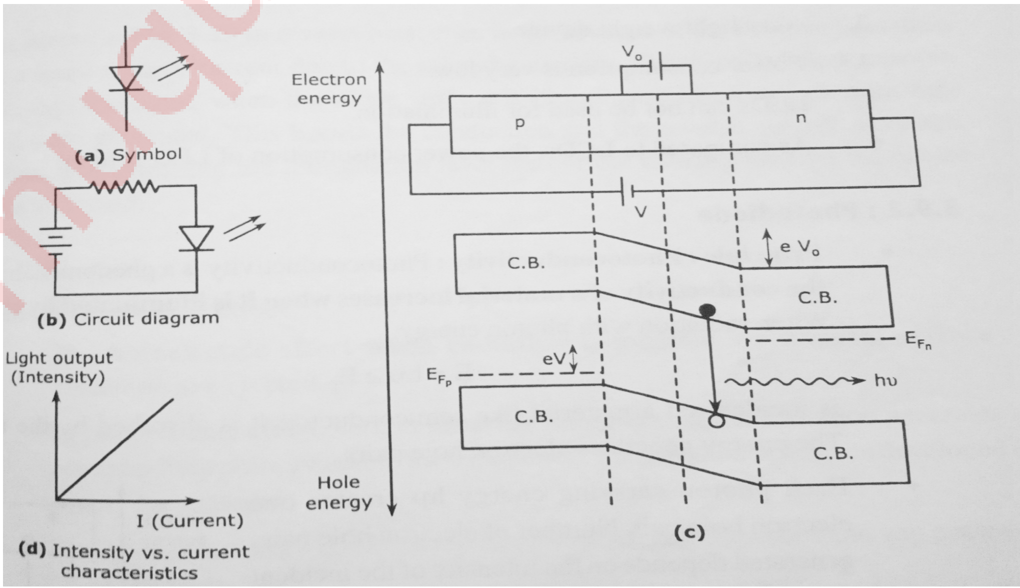
  (1) GaAs, GaP, GaAsP for red, orange, yellow and green light.

  (2) ZnS and SiC for blue,

  (3) GaN for violet.

Construction and working:

- *A light emittingdiode is always forward biased and the forward voltage across a LED is Typical forward LED voltage ranges from 1.2 V to 3.2 V depending on the device.*
- *The symbol of LED and a typical LED circuit are shown in Fig.(a)and (b)respectively.The energy band diagram showing the recombination process is shown in Fig.(c).The intensity of the light output of an LED is directly proportional to the forward current which is shown in Fig.(d).*
- *The materials used for LED operate at low voltages and current typically at 1.5 V and 10 mA. Hence, LEDs are low price device which cannot be used for illumination*



purposes.

- *The LEDs have very low reverse break down voltage, typically, 3V.Therefore, LEDs should never be reverse biased which will cause damage to it.*
