associated with wave in some condition & particles in other condition.
This is known as wave-particle duality.

If λ is wavelength of waves associated with matter particle, e is momentum of particle then,

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

i.e $$\lambda = \frac{h}{mv}$$

de - Broglie in terms of K.E

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

$$= \frac{1}{2m} m^2v^2$$ (Multiplying m both sides)

$$= \frac{m^2v^2}{2m}$$

$$E = p^2$$

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

$$\lambda = \frac{h}{\sqrt{2mE}} \quad \text{--- (1)}$$

de - Broglie in terms of accelerating potencial

If particle of charged e is accelerated through potential V, it's K.E becomes eV

$\therefore E = eV$ --- (2)

Substituting equation 2 in 1

$$\lambda = \frac{h}{\sqrt{2meV}} \quad \text{--- (3)}$$

Q. Calculate wavelength of de-Broglie wave associated with mass 1kg moving with speed 10^3 m/s.

$\Rightarrow m = 1\text{ kg} = 1 \times 100 = 100\text{g}$, $v = 10^3$ m/s

Formula :- $\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{100 \times 1000} = 6.63 \times 10^{-39}$

$\therefore$

Q. Find energy of neutron in units of electron volt whose de-Broglie's wavelength is mass of $n = 1.674 \times 10^{-27}$ kg

$\Rightarrow$ Formula: $\lambda = \frac{h}{\sqrt{2mE}}$

$\therefore E = \frac{h^2}{2m\lambda^2} = \frac{(6.63 \times 10^{-34})^2}{2 \times 1.674 \times 10^{-27} \times 10^{-10}} = 1.312 \times 10^{-20}$

Properties of Matter Wave.

1. Wavelength of matter wave is given by $\lambda = \frac{h}{mv}$ where m is mass & v is velocity of particle.
2. Properties of matter waves are $\lambda \propto \frac{1}{M}$, hence

Lighter the particle greater is wavelength associated with it.

3(i) λ is $\propto \frac{1}{v}$, hence greater the velocity of particle smaller is wavelength associated with it

4. Velocity of matter wave is not constant like electromagnetic wave but depends on velocity of particle generating them.
5. As $v \to \infty$, then $\lambda \to 0$. but wave becomes inderminant when $v \to 0$ then $\lambda \to \infty$.
6. This shows that matter waves are associated with particles in motion.
7. Waves do not depend on charge of particle & hence matter waves are not electromagnetic in nature.
8. The "wave & particle duality" of matter is not exhibited simultaneously.

9(i) The wave velocity of matter wave depends inversely on wavelength λ. This is basic difference b/w matter waves & light waves

Light waves have same velocity for all wavelength ?

Wave Packet, Phase velocity & Group velocity

Wave Packet :
A group consisting of no. of waves of slightly different superimposed upon each other is known as

Phase Velocity :
Velocity of each individual wave of wave packet is known as P.V. It is denoted by $V_P = \frac{\omega}{K}$
where $\omega = 2\pi\nu$ & $K = \frac{2\pi}{\lambda}$

Group Velocity :-
Velocity with which the envelope enclosing a wave group or a wave packet is transported is known as G.V.

OR

Velocity with which whole energy is transmitted in space is known as G.V.
It is denoted by $V_g = \frac{d\omega}{dK}$

Heisenberg's Uncertainity Principle. HUP.

According to HUP, quantum mechanics does not permit exact measurement of position and momentum of particle at same time with accuracy. If we try to measure both quantities simultaneously then product of uncertainities is of the order of planck's constant (h).

It is given mathematically as,
$$\Delta x \cdot \Delta p = \frac{\hbar}{2}$$
where $\hbar = \frac{h}{2\pi}$

in which Δx is in uncertainity in position
& Δp is in uncertainity in momentum

* **Absence of Electron inside nucleus.** OR
Application of HUP.

1. As we known size of nucleus is of order of 10^{-14} m
∴ If electron where to be in nucleus, maximum uncertainity Δx in the position of electron = diameter of nucleus.
2. $\Delta x = 2 \times 10^{-14}$ m
Now uncertainity in momentum of electron can be given by HUP.

$$\Delta P = \frac{\hbar}{2 \Delta x}$$
$$= \frac{h}{4\pi \Delta x}$$
$$\Delta P = \frac{6.63 \times 10^{-34}}{4\pi \times 2 \times 10^{-14} \text{ m}}$$
$$\Delta P = 2.63 \times 10^{-21} \text{ kg } \frac{m}{s}$$

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$= \frac{400 \times \cancel{400}}{\cancel{9.14 \times 10^{-17}}}$ 9.1×10

$\Delta P = 3.16 \times 10^{-28}$ 3.64×10^{-32}

$\Delta P = m \Delta v$

$3.64 \times 10^{-32} = 6.4 \times 10^{-12} \times \frac{0.01}{100}$

$\Delta P = 6.4 \times 10^{-12} \times 1$ 6.63×10^{-34}

$\Delta x = h / 4\pi \times 3.64 \times 10^{-32}$

$\Delta x = 1.447 \times 10^{-3}$

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8MKs

Schrodinger's Time Dependent equation.

1. The eq^n that describes wave nature of particle in mathematical form is known as Schrodinger's eq^n.
2. This mathematical theory place same role as Newton's law in classical mechanics.
3. For 1 dimensional case classical wave eq^n has following form:-

$$E \cdot \quad \frac{d^2y}{dx^2} = \frac{1}{v^2}\frac{d^2y}{dt^2} \quad \text{—— (1)}$$

where y is displacement & v is velocity.

4. Solution of eq^n can be written as,

$$y = Ae^{-i(\omega t - kx)}$$

5. By analoging we can write wave eq^n for motion of free particle as

$$\frac{d^2\psi}{dx^2} = \frac{1}{v^2}\frac{d^2\psi}{dt^2} \quad \text{—— (2)}$$

6. Now, let solution of equation 2 be

$$\psi = Ae^{-i(Et - px)} \quad \text{—— (3)}$$

differentiating ψ in eq (3) w. r. to . x

We have,

$$\frac{\partial \psi}{\partial x} = Ae^{\frac{-i}{\hbar}(Et-px)} \frac{ip}{\hbar}$$

$\psi = Ae^{-i(\omega t - kx)}$

$\psi(x, t)$

$\gamma(x) =$

$\omega = 2\pi v$

$= \frac{2\pi E}{h}$

$k = \frac{2\pi}{\lambda}$

$\psi = \frac{2\pi p}{h}$

8. Differentiating again w. r. to. x.

$$\frac{\partial^2 \psi}{\partial x^2} = A\left(\frac{ip}{\hbar}\right)^2 e^{\frac{i}{\hbar}(Et-px)}$$

$$\frac{\partial^2 \psi}{\partial x^2} = \psi\left(\frac{ip}{\hbar}\right)^2$$

$$\frac{\partial^2 \psi}{\partial x^2} = \psi - \frac{p^2}{\hbar^2}$$

$$p^2\psi = -\hbar^2 \frac{\partial^2 \psi}{\partial x^2} \quad \text{—— (4)}$$

9. Now differentiating eq^n (3) w. r. to t

$$\frac{\partial \psi}{\partial t} = Ae^{-\frac{i}{\hbar}(Et-px)} \cdot \left(\frac{-iE}{\hbar}\right)$$

$$\frac{\partial \psi}{\partial t} = -\psi\left(\frac{iE}{\hbar}\right)$$

$$E\psi = \frac{-\hbar}{i}\frac{\partial \psi}{\partial t}$$

$$E\psi = i\hbar \frac{\partial \psi}{\partial t} \quad \left\langle \because \frac{1}{i} = -i \right\rangle \text{—— (5)}$$

10. E is total energy of particle. Let m be mass of particle.

$\therefore$ E = Potencial energy + Kinetic energy

$$E = \frac{p^2}{2m} + V \quad \text{—— (6)}$$

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5M

Schrodinger's Time independent Equation.

1. When conservative force acts on particle its P.E is time independent. Eg of such forces are electrostatic force, magnetic force etc.
2. Schrodinger's time dependent equation is given by

$$i\hbar \frac{\partial \psi}{\partial t} = \frac{-\hbar^2}{2m} \frac{\partial^2 \psi}{\partial x^2} + V\psi \quad \text{—— (1)}$$

3. This is a partial differential equation, 1 of method to solve such equation is by separation of variables
4. Let us assume that solution of equation 1 is

$$\Psi(x,t) = \psi(x)\,\phi(t) \quad \text{where —— (2)}$$

$\psi(x)$ is function of x
$\phi(t)$ is function of t
Substitute equation (2) in eq^n (1).

$$i\hbar \frac{\partial \psi(x)\phi(t)}{\partial t} = \frac{-\hbar^2}{2m} \frac{\partial^2 \psi(x)\phi(t)}{\partial x^2} + V\psi$$

$$i\hbar\, \psi(x) \frac{\partial \phi t}{\partial t} = \frac{-\hbar}{2m}\, \phi t\, \frac{\partial^2 \psi(x)}{\partial x^2} + V\psi(x)\phi(t)$$

—— eq (3).

Dividing equation (3) by equation (2),

here each side must be constant, let this constant be energy. E.

$$E = i\hbar \frac{1}{\phi(t)} \frac{\partial \phi(t)}{\partial t}$$

$$E = \frac{-\hbar^2}{2m} \frac{1}{\psi(x)} \frac{\partial^2 \psi(x)}{\partial x^2} + V$$

$$\frac{-\hbar^2}{2m} \cdot \frac{\partial^2 \psi(x)}{\partial x^2} + V\psi(x) = E\psi(x)$$

This equation is known as Schrodinger's time independent equation.

Derivation:-

Particle trapped in 1 dimensional infinite potential well

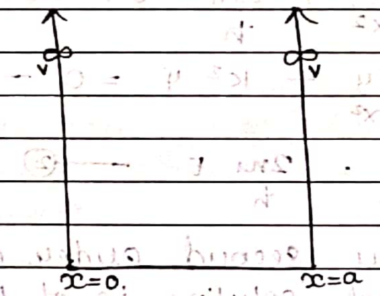
OR

• Particle in 1 dimensional rigid box.

Show that of a particle in box is directly proportional to square of natural no.

⇒

1. Consider a particle of mass m moving inside 1 dimensional box of infinite height and width as a



2. The particle is assumed to move freely inside the box motion of particle is restricted by walls of the box.
The particle is bouncing back and forth b/w the walls of box at $x=0$ & $x=a$.

3. The position particle at any instant is given by $0 < x < a$
The potencial energy of particle is infinite on both sides of box.

4. Due to infinite potential well particle cannot escape from box $x > a$, $x < 0$

5. Since the particle cannot exist outside box, wave function ψ is also 0, outside the box.

6. Our aim to find the value of ψ within box. Now, we know Schrodinger

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{2m}{\hbar^2}(E-V)\psi = 0$$

where $V = 0$ ∴

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{2m}{\hbar} E\psi = 0$$

$$\frac{\partial^2 \psi}{\partial x^2} + k^2 \psi = 0 \quad \text{—— (1)}$$

where $k^2 = \frac{2m E}{\hbar}$ —— (2)

7. Eqn (1) is an second order differential eqn. and its general solution is of the form

$$\psi = A \sin kx + B \cos kx \quad \text{—— (3)}$$

where A and B are constant.

8. The boundary condition are:

$\psi = 0$ for $x = 0$, $x = a$

Now using boundary condition $\psi = 0$ for $x = 0$ in equation (3)

$$A \sin k(0) + B \cos k(0) = 0$$

$$0 + B = 0$$

$$B = 0$$

Now using $\psi = 0$ $x = a$

$$A \sin ka + B \cos ka = 0$$

$$A \sin ka = 0$$

$$\sin ka = 0$$

$$ka = n\pi$$

$$k = \frac{n\pi}{a}$$

9. ∵ k is constant and it cannot be 0

So $\sin ka = 0$

$$k^2 = \frac{n^2\pi^2}{a^2} \quad \text{—— (4)}$$

10. Now comparing eqn (2) & (4) we have

$$\frac{2mE}{\hbar^2} = \frac{n^2\pi^2}{a^2}$$

$$E = \frac{n^2\pi^2\hbar^2}{a^2\, 2m}$$

$$E = \frac{n^2h^2}{8ma^2}$$

$$E = \boxed{\frac{h^2}{8ma^2}}\, n^2$$

$$E \propto n^2$$

Thus energy of electron in box is directly proportional to square of natural no

Q. Find out lowest energy of an electron in 1 dimensional box width of 4A°.

→ E for lowest energy $n = 1$

$a = 4A$

$$E = \frac{n^2 h^2}{8ma^2}$$

$$E = (1)\frac{(6.63 \times 10^{-34})^2}{8 \times \cancel{9\times 1}\ 9.1\times10^{-35}) \times 4^2}$$

$$E = \frac{(6.63 \times 10^{-34})^2}{16 \times 8 \times 9.1 \times 10^{-35}}$$

$$E = 3.773 \times 10^{-35}$$

Q. An electron is found in 1 dimensional potential of well width 2A° find its energy value in ground state and first & second excited state. 1, 2, 3

⇒ Ground state $n = 1$

$$E = \frac{n^2 h^2}{8ma^2}$$

$$= \frac{1\ h^2}{8m(2\times10^{-4})^2}$$

$$= \frac{(6.63\times10^{-34})^2}{8\times9.1\times10^{-35}(2\times10^{-4})^2}$$

$$E = \frac{1.509 \times 10^{-58}}{2m\ \ 1.6\times10^{-19}} J$$

$$E = 9.43 \times 10^{-78}\ eV$$

For 1 excited state, $n = 2$

$$E = \frac{n^2 h^2}{8ma^2}$$

$$= \frac{4 \times (6.63\times10^{-34})^2}{8\times(9.1\times10^{-35})(2\times10^{-4})^2}.$$

$$= 6.038 \times 10^{-26}\ J.$$

$$= \frac{6.038\times10^{-26}}{1.6\times10^{-19}}\ eV$$

$$= 3.77\times10^{-45}\ eV.$$

For 2 excited state $n = 3$.

$$E = \frac{n^2 h^2}{8ma^2}$$

$$= \frac{3^2 (6.63\times10^{-34})^2}{8\times(9.1\times10^{-35})(2\times10^{-4})^2}$$

$$= 1.131 \times 10^{-44}$$

5M

1) Find the energy of the neutron in units of electron volt whose de-Broglie wave length is $2A^\circ$. 1.674×10^{-27} kg.

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

$$\lambda^2 = \frac{6.63\times10^{-34}}{\sqrt{2\times 9.1\times10^{-35}\times E}}$$

$$E = \frac{6.63\times10^{-34}}{4\, m^2 \lambda^2}$$

$$E = \frac{6.63\times10^{-34}}{4\times(1.674\times10^{-27})^2(10^{-10})^2}$$

$$E = \frac{(6.63\times10^{-34})^2}{2\times(1.674\times10^{-27})(10^{-10})^2}$$

$$= 0.08\ eV$$

2) Calculate de-Broglie wavelength of proton with velocity $= \frac{1}{20}^{th}$ speed of light.

$\frac{1}{20} \times 3\times10^8$

$\Rightarrow$ Formula. $\lambda = \frac{h}{mv}$

$$= \frac{6.63\times10^{-34}\times20}{1.67\times10^{-27}\times 3\times10^8}$$

$$\lambda = 2.64\times10^{-14}\ m$$

$$\lambda \quad 2.64\times10^{-4}\ A^\circ$$

5M

3) What is the wavelength of beam of neutron having 1) an energy of 0.025 eV.
2) an electron and proton each $\lambda = 2A^\circ$, what are their momentum & energy.

$E = 4\times10^{-2}$

$\Rightarrow$ mass of neutron $= 1.676\times10^{-27}$ kg.

For neutron

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

$$\cancel{2A = \frac{6.63\times10^{-34}}{}}$$

$$\cancel{\lambda^2 = \frac{h^2}{2mE}}$$

$$\cancel{(10^{-10})^2 = \frac{(6.63\times10^{-34})^2}{2\times \ \ 0.025}}$$

λ $\quad 1.6\times10^{-19}$.

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

$$= \frac{6.63\times10^{-34}}{2\times1.6\times10^{-27}\times0.025\ eV} \times 1.6\times10^{-19}$$

$eV \rightarrow J = 4\times10^{-21}$.

$$= 1.85\times10^{-10}$$

For electron, momentum.

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

$$p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{2\times10^{-10}}$$

$$= 3.31\times10^{-24}.\ \ kgm/s$$

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Photon Momentum,

$$P = \frac{E}{c}$$

$$= \frac{9.94 \times 10^{-16}}{3 \times 10^{8}}$$

$$P = 3.313 \times 10^{-24} \ kg\,m/s.$$

Numers :-

1) Find de-Broglie wavelength of electron accelerated through potencial 182 V and 11ag object moving with speed of 1m/s. Comparing result explain why is the wave nature of matter not apparent in daily life.

⇒ Solu :-

∵ the dimension is very small we cannot see wave in daily nature.

For electron,

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

$$\cancel{\frac{\lambda^2}{h^2}} = \cancel{\frac{1}{2meV}}$$

$$\cancel{\lambda} \quad \cancel{\frac{h^2}{\lambda^2}}$$

$$\lambda = \cancel{h} \ \frac{12.26}{\sqrt{eV}}$$

$$\lambda = \frac{12.26}{\sqrt{V}}$$

$$\lambda = 0.908 \text{Å}$$

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3. Calculate the energies in eV of electron & proton whose de-Broglie $\lambda = 1A°$.

For electron,

$$\lambda = 1A°$$

$$\lambda = 10^{-10} m.$$

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

$$(\lambda)^2 = \frac{(6.63\times10^{-34})^2}{2\times9.1\times10^{-31}\times E}$$

$$E = \frac{(6.63\times10^{-34})^2}{2\times9.1\times10^{-31}\times(10^{-10})^2}$$

$$E = 150.9 \text{ eV}$$

For proton,

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

$$E = \frac{h^2}{2m\lambda^2}$$

$$= \frac{(3.63\times10^{-34})^2}{2\times1.6\times10^{-27}\times(10^{-10})^2}$$

$$= 1.373\times10^{-20} A°.$$

$$= \frac{1.373\times10^{-20}}{1.6\times10^{-19}}$$

$$= 0.08 \text{ eV}.$$

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5. An electron is bound in 1 dimensional potential well of width 3A°. Find its energy in ground state & first 2 excited states. 3×10^{-10} m.

⟹ Ground state.

$$E = \frac{n^2 h^2}{8ma^2}$$

$$= \frac{(1)^2 (6.63 \times 10^{-34})^2}{8 \times 9.1 \times 10^{-35} \times (3 \times 10^{-10})^2}$$

$$E = 6.70 \times 10^{-15} \text{ J.}$$

$$\frac{6.70 \times 10^{-15}}{1.6 \times 10^{-19}}$$

$$= 41875 \text{ eV.}$$

1st excited state, $n = 2$

$$E = \frac{n^2 h^2}{8ma^2}$$

$$= \frac{4 \times (6.63 \times 10^{-34})^2}{8 \times (9.1 \times 10^{-35})(3 \times 10^{-10})^2}$$

$$= 2.68 \times 10^{-14} \text{ J}$$

$$= \frac{26.83 \times 10^{-19}}{1.6 \times 10^{-19}}$$

$$E = 16.76 \text{ eV}$$

For $n = 3$

$$E_2 = \frac{n^2 h^2}{8ma^2} = \frac{(3)^2 (6.63 \times 10^{-34})^2}{8 \times 9.1 \times 10^{-35} \times (3 \times 10^{-10})^2}$$

$$= 60.3 \text{ J}$$

$$= 37.73 \text{ eV}$$

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An electron is confined in box of 10^{-8} m
Calculate mini. uncertainity in velocity.

⇒ Solution.

$$\Delta x \ \Delta P = \frac{\hbar}{2}$$

$$= \frac{h}{4\pi}$$

$$\Delta P = \frac{6.63 \times 10^{-34}}{4\pi \ \Delta x}$$

$$\Delta P = 5.27 \times 10^{-27}$$

$$\Delta P = m \Delta V$$

$$5.27 \times 10^{-27} = 9.1 \times 10^{-31} \times \Delta V$$

$$\frac{5.27 \times 10^{-27}}{9.1 \times 10^{-31}} = \Delta V$$

$$5791.20 \ \frac{m}{s} = \Delta V.$$

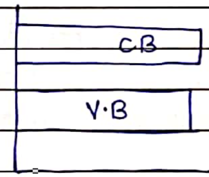
$$\Delta V = 5791.20 \ m/s.$$

2.) SEMICONDUCTOR

* Materials are classified in 3 types based on their conductors.
  - Conductors
  - Insultors
  - Semiconductors

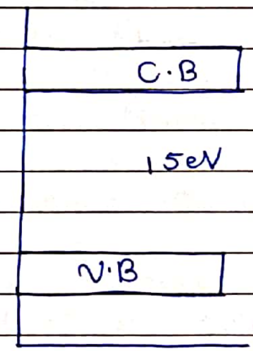
Materials are also classified into 3 types on basis of energy band diagram.

1. Conductor

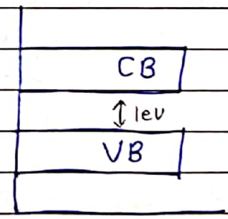


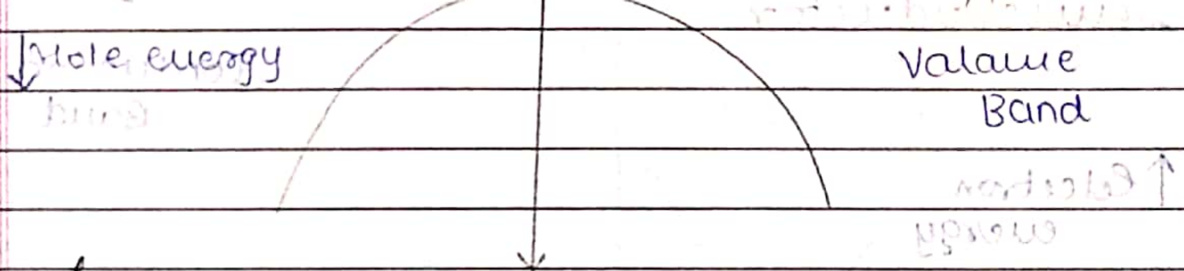
Very less forbid Energy Band gap.

2. Insultors.



3. Semiconductor





In above fig. upper parabola in conduction band represents free electron and lower parabola in valence band represents the holes.

Gap b/w 2 parabolas is known as bandgap

On basis of transition, from Valence band to conduction, when energy is supplied & it gains momentum, Semiconductors are classified 2 categories.

i.) Direct Band Gap Semiconductor.

ii.) Indirect Band Gap Semiconductor.

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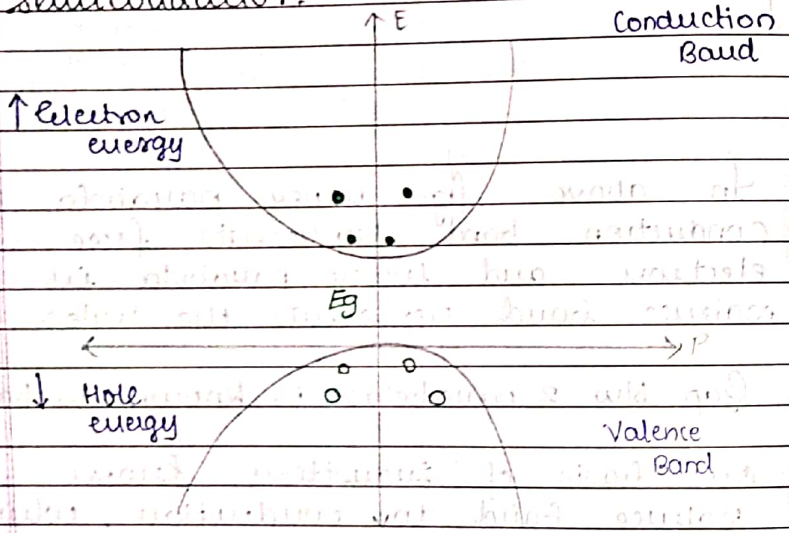
1. DIRECT BAND GAP SEMICONDUCTOR

When an electron makes transition from maximum of valence band to minimum of conduction band at same momentum, it is categorised as direct band gap semiconductor.



Examples of such semiconductor are Ga As (Gallium Arsenide).

During electron - hole recombination optical energy is released, which has wide applications in LEDs & lasers as efficient generation of photons takes place in direct band gap semiconductors.

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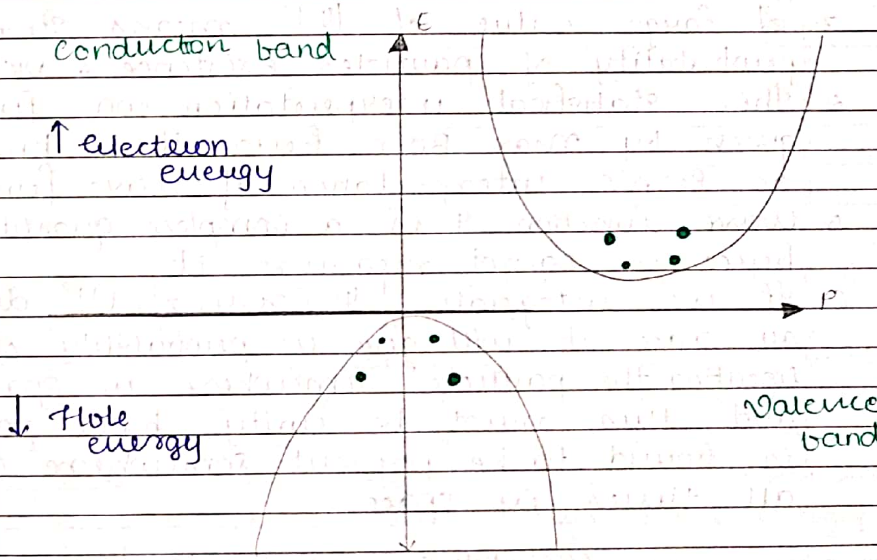
2. INDIRECT BAND GAP SEMICONDUCTOR.

When an electron makes transition from maximum of valence band to minimum of conduction band at same diff. momentum it is categorised as direct band gap semiconductor.

Exampes of such semiconductor are Silicon and Germanium.



* Wave function & Physical Interpretation of Wave function.

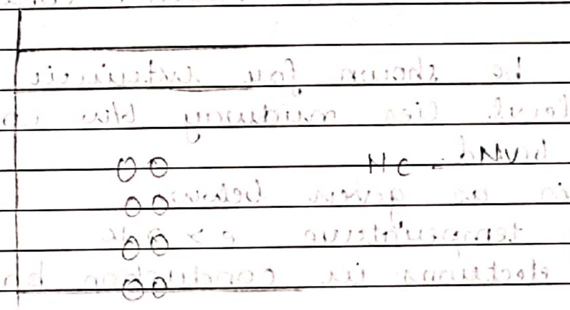
1. A variable quantity that represents or characterisis de-Broglie wave is known as wave function and denoted by (Ψ) psi.
2. If we consider wave function Ψ associate with a system of particle or electron than $|\Psi|^2 \, dv$ is probability density of particle in volume dv.
3. A large value of $|\Psi|^2$ means strong probability of particles existence & viceversa.
4. This statisfical interpretation was first given by Max Born, hence it is known as Born's interpretation of wave function.
5. Wave function Ψ is a complex quantity & hence we cannot measure it.
6. If we integrate $|\Psi(x, y, z, t)|^2 \, dv$ over all space it will give us probability of locating the particle somewhere in space and this must be unity b'coz particle is bound to be present somewhere at all times in space.

$$\therefore \int_{\text{all space}} |\Psi(x, y, z, t)|^2 \, dv = 1$$

This eq^n is known as normalization condition.

7. When a wavefunction Ψ satisfies the wave equation it is said to be normalised.

1. When filling of electrons is undertaken, the universal rule is that the lowest energy level gets filled first.
2. However their will be many more allowed energy levels left vacant as shown in fig.



3. Energy of highest occupied level at 0°C absolute is called fermi energy & level is referred as fermi level. (E_F).
4. All energy levels above fermi level at $t = 0\,K$ are empty & those lying below are completely filled. It provides a reference with which other energy levels can be compared.

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$$\cancel{N_e} = \cancel{N_c}\, \cancel{e}^{\left(-\frac{E_C - E_F}{KT}\right)}$$

$$n_e = n_h$$

$$N_c \cdot e^{-\left(\frac{E_C - E_F}{KT}\right)} = N_V \cdot e^{-\left(\frac{E_F - E_V}{KT}\right)}$$

$$\frac{N_C}{N_V} = \frac{e^{-\frac{E_F - E_V}{KT}}}{e^{-\frac{E_C - E_F}{KT}}}$$

$$1 = e^{\left(\frac{-2E_F + E_V + E_C}{KT}\right)}$$

$$\log 1 = \log e^{\left[\frac{-2E_F + E_V + E_C}{KT}\right]}$$

$$0 = \left(-2E_F + E_V + E_C\right) \log e \quad \left\{\begin{matrix}\log 1 = 0 \\ \log e = 1\end{matrix}\right\}$$

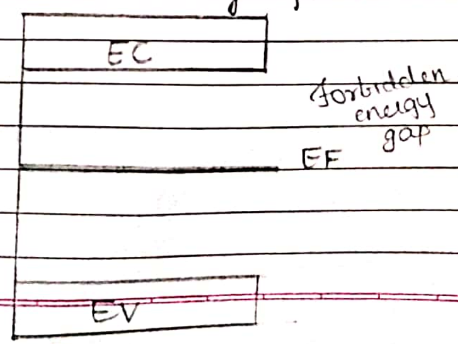
$$0 = -2E_F + E_V + E_C$$

$$0 = E_V + E_C$$

$$2E_F = E_V + E_C$$

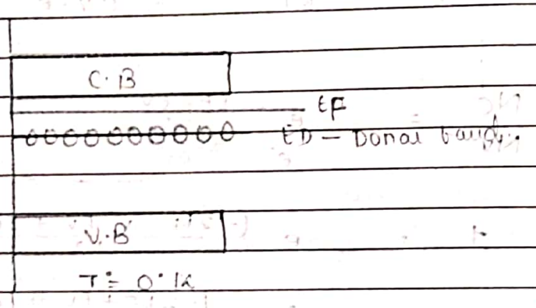
$$E_F = \frac{E_V + E_C}{2}$$

8. Thus, the fermi level in intrinsic semiconductor lies at centre of forbidden energy gap.

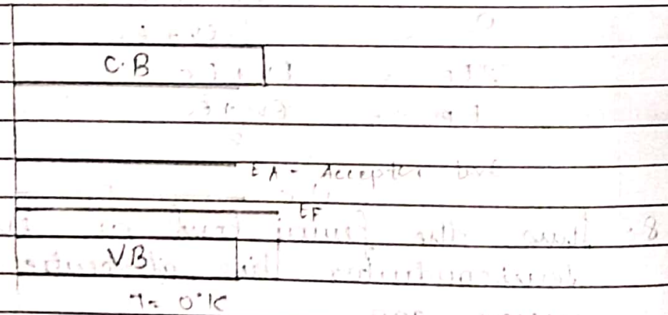


Fermi level in extrinsic semiconductor.

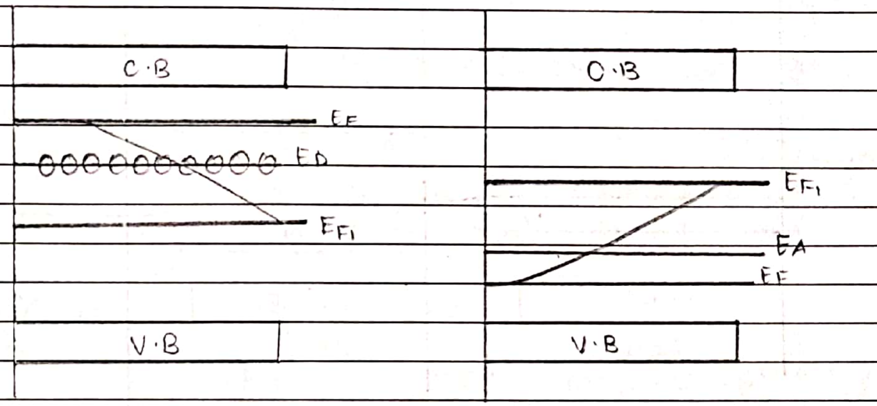
Fermi level in n-type semiconductor.



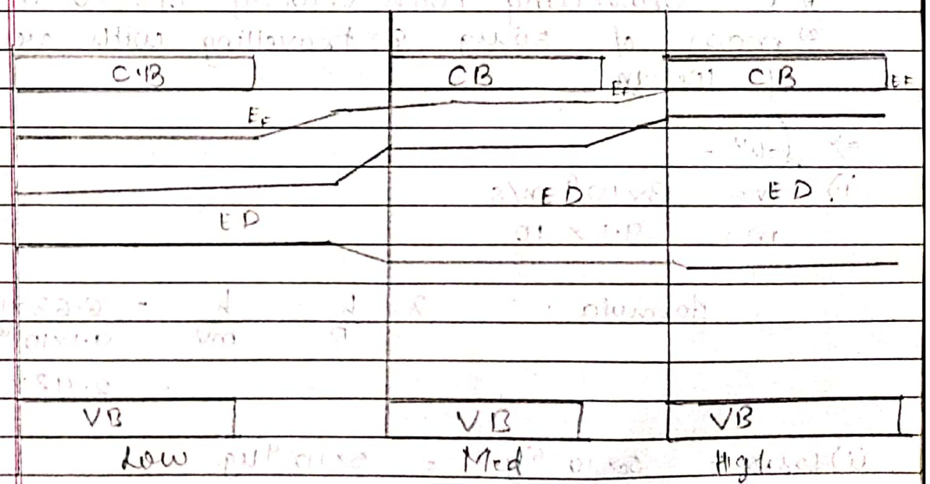
Fermi level in p type semiconductor.

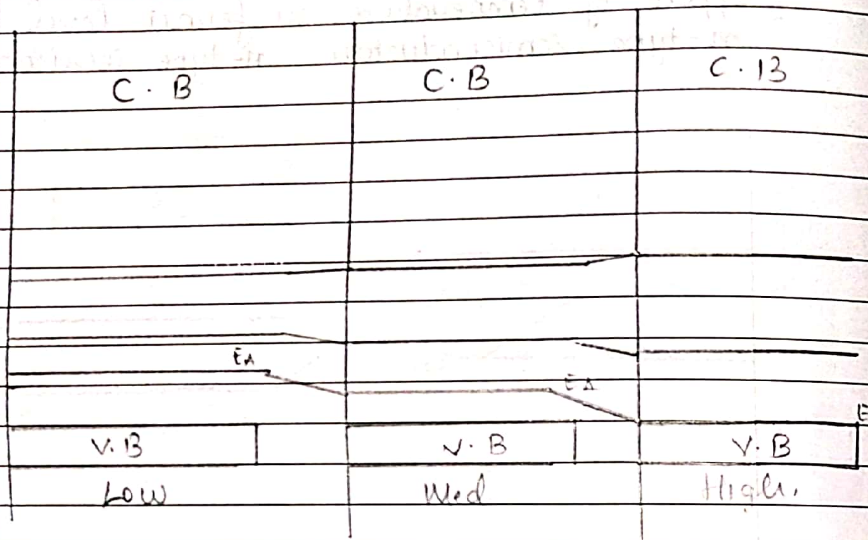


Effect of temperature on fermi level in n-type semiconductor p-type semiconductor.



Effect of impurity concentration in n-type semiconductor.





Numericals:-

Q. Calculate de-Broglie wavelength associated with foll. particle.

1) e^- travelling with velocity of 3×10^6 m/s

2) mass of 50 ug & travelling with velocity of 100 cm/s

⇒ Soln:-

i) $v = 3 \times 10^6$ m/s

$m = 9.1 \times 10$

formula : $\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 3 \times 10^6}$

$= 2.42 \times 10^{-10}$ A°.

ii.) 50ug $= 50 \times 10^{-6}$ g $= 5 \times 10^{-9}$ ug.

$v = 100 \frac{cm}{s} = 1$ m/s.

$\lambda = \lambda_p = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{50 \times 10^{-9} \times 1}$

$\lambda = 1.326 \times 10^{-26}$ AΩ.

$\lambda = 1.326 \times 10^{-26+10}$

$\lambda = 1.3261 \times 10^{-16}$ A°.

Q. Calculate velocity & de-Broglie wavelength of a particle of energy 1k eV mass of α-particle $= 6.68 \times 10^{-27}$ kg

⇒ $m = 6.68 \times 10^{-27}$ kg

$E = 1$ keV $= 1 \times 1000 = 1000$ eV ⇒convert J.

$= 1.6 \times 10^{-16}$ J.

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

$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 6.68 \times 10^{-27} \times 1.6 \times 10^{-16} J}}$

$= 4.53 \times 10^{-13}$ m

$\lambda = 4.53 \times 10^{-3}$ A°.

$\lambda = \frac{h}{mv}$

$v = \frac{h}{m\lambda}$

$= \frac{6.63 \times 10^{-34}}{\cancel{9.1 \times 10^{-31}} \times 4.53 \times 10^{-13} \times 6.68 \times 10^{-27}}$

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

$$= \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 6.68 \times 10^{-27} \times (2 \times 1.6 \times 10^{-19}) \times 30 \times 10^{3}}}$$

$$= 5.85 \times 10^{-14}\ m$$

$$= 5.85 \times 10^{-4}\ Å.$$

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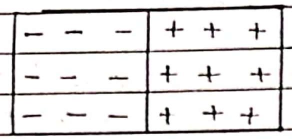
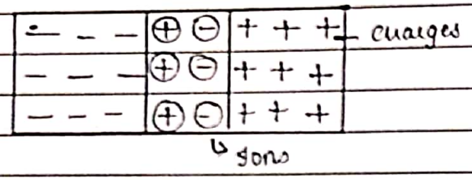
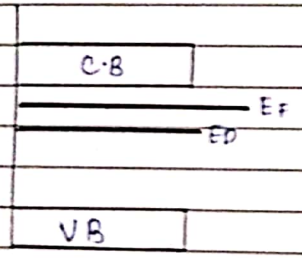
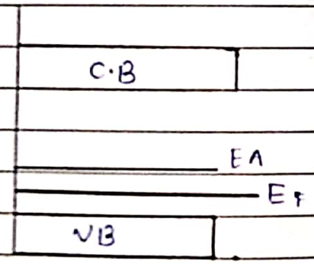
P-n function.







Fermi level in n-type



Fermi level in P-type.

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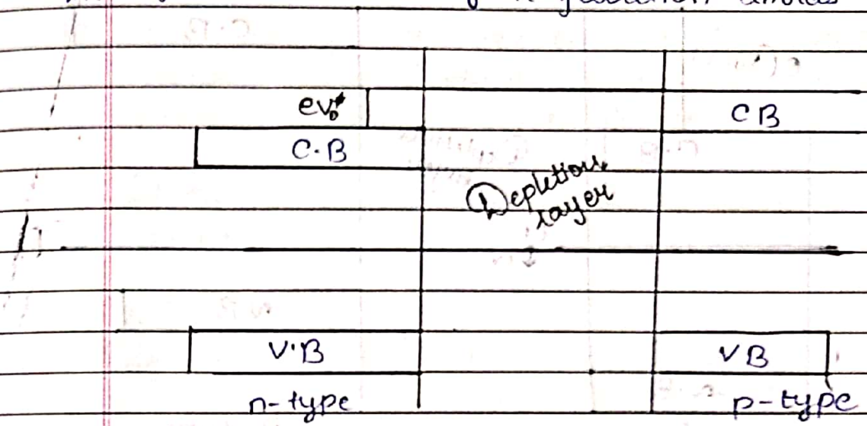
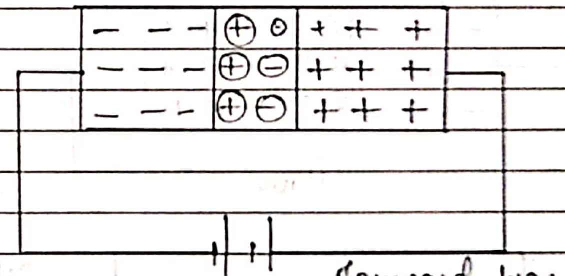
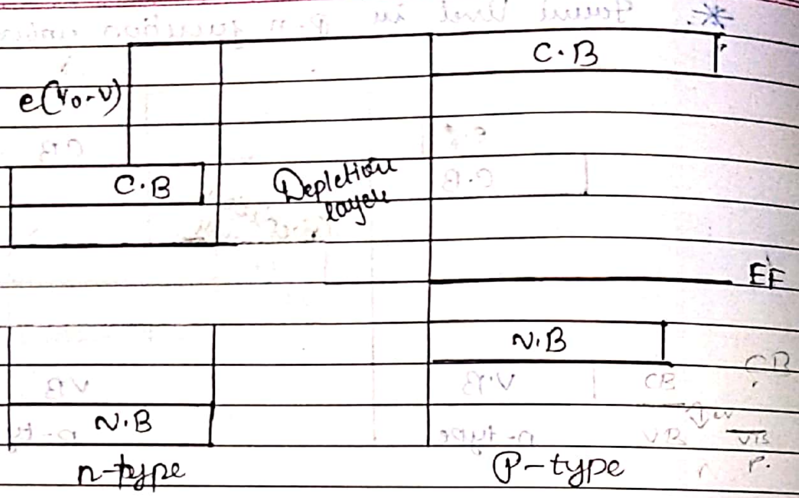
*. Fermi level in P-n junction unbias

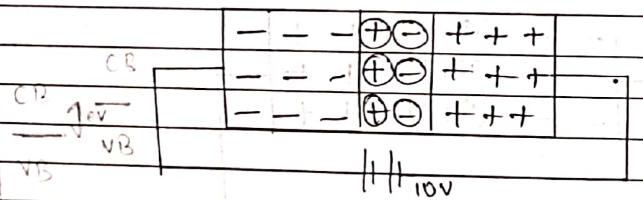


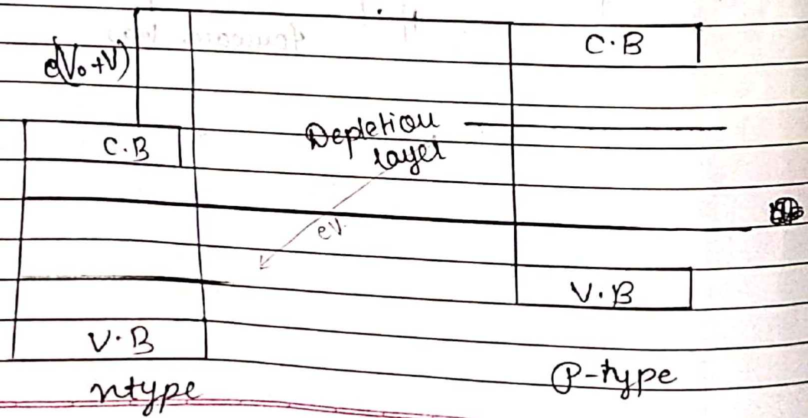
*. Fermi level in forward bias p-n function





* Fermi level in p-n junction (Reverse bias)





* Resistivity of copper is $1.72 \times 10^{-8}\ \Omega m$. Calculate the mobility of electrons in copper. (no. of electrons per unit vol. $= 10.41 \times 10^{28}\ m^{-3}$)

Solution :-

Formula:- $\mu = \dfrac{\sigma}{ne}$

$\sigma = \dfrac{1}{\rho}$

Given :- $\rho = 1.72 \times 10^{-8}\ \Omega m.$

$n = 10.41 \times 10^{8}\ m^{-3}$

$$\mu = \frac{\sigma_e}{ne} = \frac{1}{\rho \times ne}$$

$$= \frac{1}{1.72 \times 10^{8} \times 10.41 \times 10^{28} \times 1.6 \times 10^{-19}}$$

$= 3.49 \times 10^{-8}\ m^2\ V^{-1}\ sec^{-1}.$

Formulas :-

$R = \dfrac{\rho L}{A}$

$\rho = \dfrac{AR}{L}$

$\mu = \dfrac{v}{E} = \dfrac{m/s}{V/m} = \dfrac{m^2}{Vs}$

conductivity $\sigma = \dfrac{1}{\rho}$ ρ – Resistivity

$\sigma_e = ne\mu_e$ = $ne\mu_h$

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2) Calculate electron & hole conc in intrinsic silicon at room temp if its electrical conductivity is $4 \times 10^{-4} \Omega^{-1} m^{-1}$

{ Mobility of electron is $0.14 \frac{m^2}{Vol \cdot sec}$ }

{ Mobility of holes $= 0.04 \frac{m^2}{Vol \cdot sec}$ }

Solution:-

Given :- $\sigma = 4 \times 10^{-4} \ \Omega^{-1} m^{-1}$

$\mu_e = 0.14 \ m^2 V^{-1} sec^{-1}$

$\mu_h = 0.04 \ m^2 V^{-1} sec^{-1}$

To find :-

Formula :- for intrinsic semiconductor $n_e = n_h = n_i$

$$\sigma = ne(\mu_e + \mu_h)$$

$$n = \frac{\sigma}{e(\mu_e + \mu_h)}$$

$$= \frac{4 \times 10^{-4}}{1.6 \times 10^{-19}(0.14 + 0.04)}$$

$$= 1.38 \times 10^{16} \ m^{-3}$$

3) Resistivity of intrinsic semiconductor at room temperature is $2 \times 10^{-4} \ \Omega \ cm$. If mobility of electron is $6 \ m^2 V^{-1} sec^{-1}$ & mobility of holes is $0.2 \ m^2 V^{-1} sec^{-1}$, Calculate its Intrinsic carrier density :-

Given :- Intrinsic semiconductor

$\rho = 2 \times 10^{-4} \ \Omega \ cm.$

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$\mu_e = 6 \ m^2 V^{-1} sec^{-1}$ $\quad \sigma_e = n e \mu_e$

$\mu_h = 0.2 \ m^2 V^{-1} sec^{-1}$ $\quad \sigma_h = n e \mu_h$

Formula :-

$$n_{in} = \frac{\sigma_{in}}{e(\mu_e + \mu_h)}$$

$$n = \frac{1}{\rho e(\mu_e + \mu_h)}$$

$$= \frac{1}{2 \times 10^{-6} \times 1.6 \times (6 + 0.2) \times 10^{-19}}$$

$$= 5.04 \times 10^{23} \ m^{-3}$$

4) Calculate a current produced in germanium sample of cross section $1\ cm^2$ & thickness of 0.01 m when potential diff. of 2V is applied accross a. The conc. of free electron in germanium $2\times10^{19}\ m$ & $\mu_e = 0.36\ m^2 V^{-1} sec^{-1}$ & $\mu_h = 0.17\ m^2 V^{-1} sec^{-1}$

⇒ Given :- $PD = 2V$

$\mu_e = 0.36$

$\mu_h = 0.17$

$\sigma = ne(\mu_e + \mu_h)$

$= 2\times10^{-19} \times 1.6\times10^{-19}(0.36+0.17)$

$= 1.696\ \Omega^{-1} m^{-1}$

$\rho = \frac{1}{\sigma}$

$R = \frac{\rho L}{A}$

$R = \frac{0.01}{10^{-4} \times 1.696}$

$= 58.96\ \Omega$

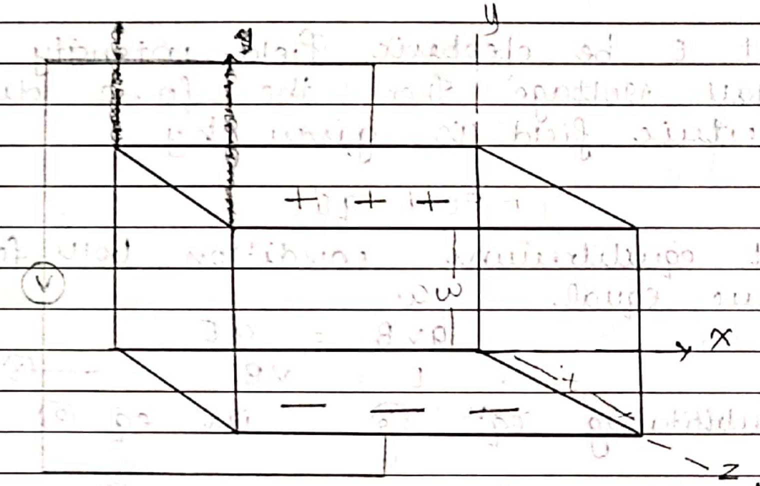
$I = \frac{V}{R}$

$= \frac{2}{58.96}$

$I = 0.033 A.$

Hall Effect.

If a metal of semiconductor carrying current I is placed in a transverse magnetic field V. A potential diff is produced in dir^n normal to both current & dir^n of magnetic field. This phenomena is called hall effect.



Consider a rectangular plate of n-type semiconductor carrying current I which flows along x-dir^n. If it is subjected to external magnetic field which is along positive z-dir^n. According to fleming's right hand rule the majority charge carriers to get accomulated at bottom surface. Thus Potential Diff. will develop accross the 2 surface. Voltage thus develop is known Voltage Hall.

$R = l \times b$

$$A = w \times t$$

$$V_H = \frac{IB}{net} \quad \text{(6)}$$

Another important parameter is Hall coefficient is,

$$R_H = \frac{1}{ne} \quad \text{(n-type semic)}$$

$$R_H = \frac{1}{pe} \quad \text{(p-type semic)}$$

$\therefore$ equation (6) becomes,

$$V_H = \frac{R_H I B}{t}$$

$$R_H = \frac{V_H t}{IB}$$

Thus measuring V_H, V, I, t all coefficients can be determined.

Importance of Hall effect,

- Determine the sign of charge carriers & type of semiconductor.
- Determine the charge carrier conc.
- Determine the mobility of charge carrier if conductivity of material is known.

$\sigma = neu$ $\qquad R = \frac{\rho L}{A}$

$\sigma_n = neu_n$

$\sigma_H = neu_H$ $\qquad \sigma = \frac{1}{\rho}$

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Numericals :-

1) A copper strip 2 cm wide and 1mm thick
5M. is placed in a magnetic field $B = 1.5 \frac{wb}{m^2}$. If a current of 200A is set up in a stream. Calculate all voltage that appears across strip. $[R_H = 6\times10^{-7}\ m^3/c]$

Given :- $R_H = 6\times10^{-7}\ m^2/c$

$I = 200A.$

$B = 1.5\ wb/m^2$

$t = 1mm = 1\times10^{-3} m.$

To find :- V_H - ?

Solution :

$$V_H = \frac{R_H\ IB}{t}$$

$$= \frac{6\times10^{-7}\ 200\times1.5}{1\times10^{-3}}$$

$$V_H = 0.18\ V$$

2) In a hall exp. A potential diff of $4.5\mu V$
5M is developed across a foil of zinc of thickness 0.02 mm. When a current of 1.5A is in dir^n $\perp^{r}$ to applied magnetic field of $2\ wb/m^2$.
Calculate i) Hall coefficient of zinc
ii) Conc. of electron.

Given :- Potencial diff $= 4.5\mu V = 4.5\times10^{-6} V$

$t = 0.02mm = 0.02\times10^{-3} m = 2\times10^{-5}$

$I = 1.5A$

$B = 2\ wb/m^2$

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Solution :- $V_H = \frac{R_H\ IB}{t}$

$$R_H = \frac{V_H t}{IB}$$

$$R_H = \frac{4.5\times0.02\times10^{-3}}{0.5\times2}$$

$$R_H = \frac{4.5\times10^{-6}\times2\times10^{-5}}{1.5\times2}$$

$$R_H = 3\times10^{-11}$$

b) $R_H = \frac{1}{ne}$

$$n = \frac{1}{R_H e} = 2.083\times10^{29}\ m^{-3}$$

Q.3) Mobility of holes is $0.025\ m^2/Vs$. What would be resistivity of p-type silicon if hole coeficient of sample is $2.25\times10^{-5}\ m^3/c$

Given :- $\mu = 0.025\ m^2/Vs$

$R_H = 2.25\times10^{-5}\ m^3/c$

To find: $\rho = ?$

Solution :- $R_H = \frac{1}{\rho e}$ $\qquad \sigma = ne\mu$

$\rho = \frac{1}{R_H e}$ $\qquad \mu = \frac{\sigma}{ne}$

$\mu = R_H \sigma$

$\sigma = \frac{\mu}{R_H}$

$$p = \frac{1}{2.25\times10^{-5}\times1.6\times10^{-19}}$$

$\rho = \frac{R_H}{\mu}$

$$= 2.78\times10^{23}\ m^{-3}$$

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$R_H = \frac{1}{Pe}$

$P = \frac{1}{R_H e}$

$P = \frac{1}{2.25\times10^{-5} \times 1.6\times10^{-19}}$

$P = 2.78 \times 10^{23}$ m

$\sigma = ne\mu_h$

$= 2.78\times10^{23} \times 1.6\times10^{-19} \times 0.025$

$112\ \Omega^{-1} m^{-1}$

$\rho = \frac{1}{\sigma_h}$

$= 8.99 \times 10^{-4}\ \Omega m$

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

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4) Hall coefficient of specimen is 3.66×10^{-4} m^3/c. It's resistivity σ is $8.93\times10^{-3}\ \Omega m$. Find μ & ~~n~~. mobility & conc. of electron.

Given :- 3.66×10^{-4} m^3/c
$\sigma = 8.93\times10^{-3}\ \Omega m$.

$R_H = \frac{1}{ne}$

$n = \frac{1}{R_H e}$

$n = \frac{1}{3.66\times10^{-4} \times 1.6\times10^{-19}}$

$n = 1.70 \times 10^{22}\ m^{-3}$

$\sigma = ne\mu$

~~$= 1.70\times10^{22} \times k$~~

~~$\alpha \times \frac{\sigma}{1.70\times10^{22}\times1.9\times10^{-19}}$~~

$\rho = \frac{R_H}{\mu}$

$= 3.66\times10^{-4}$

$\mu = \frac{R_H}{\rho}$

$\mu = 0.091\ m^2 V^{-1} s^{-1}$

5) Resistivity of copper is $1.72 \times 10^{-8}\ \Omega m$. Calculate the mobility of electrons in copper no. of electron per unit vol. = 10.41×10^{28}

Given:- $\sigma = 1.72 \times 10^{-8}\ \Omega m$
$n = 10.41 \times 10^{28}$

$$\mu = \frac{R_H}{\rho}$$

$$\mu = \frac{1}{ne\rho}$$

$$\mu = \frac{1}{10.41 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.72 \times 10^{-8}}$$

$$\mu = 3.49 \times 10^{-3}\ m^3\ V/s$$

6) Find resistivity ρ of intrinsic germanium at $300^\circ K$ [σ of carriers = $2.5 \times 10^{19}\ m^{-3}$]. Mobility of electrons $\mu_e = 0.39$ $R_H = 0.19$ μ_e & μ_h
Given:- σ of carriers = $2.5 \times 10^{19}\ m^{-3}$.

Solution:-

$$n_e = n_h = n_i$$

$$\sigma = ne(\mu_e + \mu_h)$$

$$\sigma \frac{1}{\rho} = 2.5 \times 10^{19} \times (0.39 + 0.19) \times 1.6 \times 10^{-19}$$

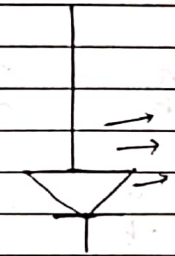
$$\frac{1}{\rho} = \cancel{1.7 \times 10^{37}}$$

$$\therefore \rho = 0.43\ \Omega m$$

LED.

Light Emitting Diode

Symbolic Representation



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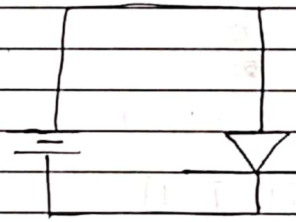
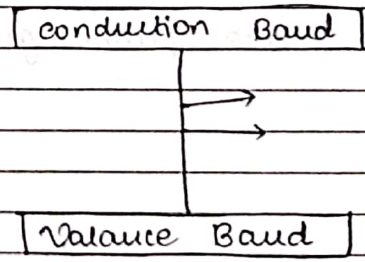
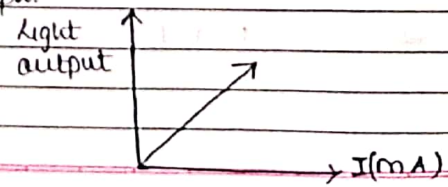




Graph:-



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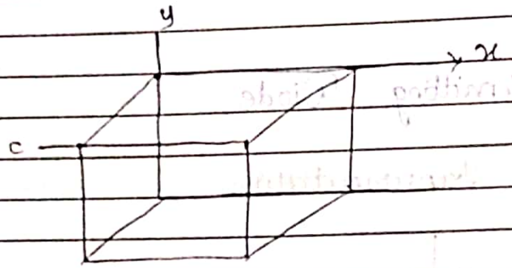
3. Crystalline Structure.



Intercept $\frac{m}{a} = \frac{n}{b} = \frac{p}{c}$

$m = a$

$n = -b$

$p = c$

$\frac{a}{2a} \quad \frac{-b}{2b} \quad \frac{c}{2c}$

Reciprocal reduction $\frac{1}{2}$ $\quad 1 \quad -1 \quad 1$

Miller Indices $(1 \; \bar{1} \; 1)$

Draw the planes from given miller indices

1. $(1 \; 1 \; 1)$

Reciprocal $\Rightarrow$ 1 1 1

Intercepts $\Rightarrow$ 1 1 1

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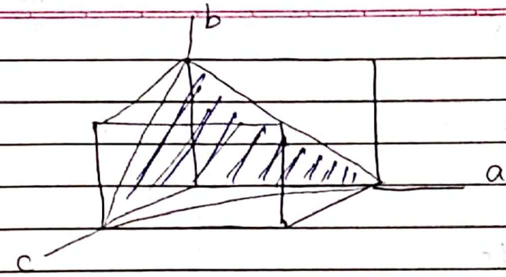
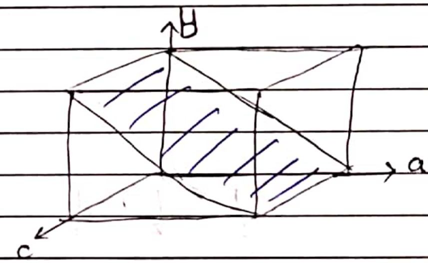


2) $(1 \; 1 \; 0)$

Reciprocal 1 1 0

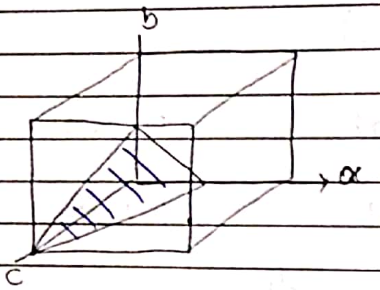
Intercept 1 1 ∞



3. $(2\ 3\ 1)$

Repurocal $\frac{1}{2}\ \ \frac{1}{3}\ \ \frac{1}{1}$

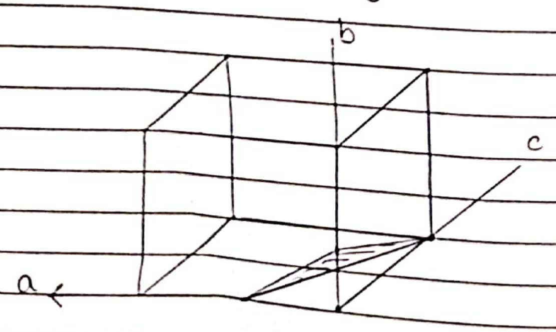
Intercepts



4) $(\bar{2}\ \bar{3}\ \bar{1})$

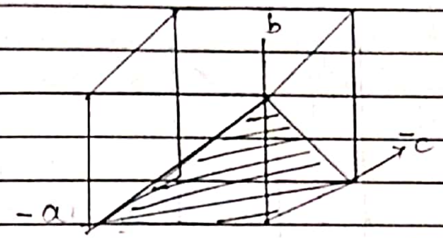
Reciprocal $\frac{-1}{2}\ \ \frac{1}{3}\ \ \frac{-1}{1}$

Intercepts $\frac{-1}{2}\ \ \frac{1}{3}\ \ -1$



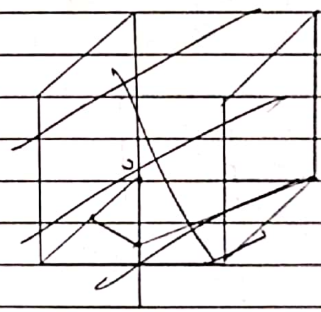
5) $(\bar{1}\ 1\ \bar{1})$

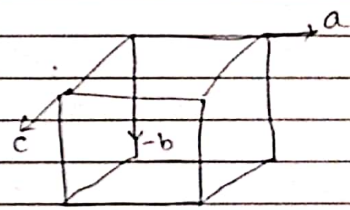
$-1\ \ \ 1\ \ \ -1$



6) $(1\ \bar{2}\ 3)$

R $\frac{1}{1}\ \ \frac{-1}{2}\ \ \frac{1}{3}$

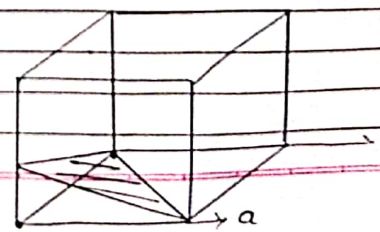




7) $(1\ 2\ \bar{1})$

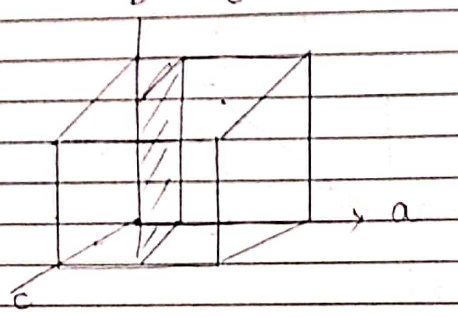
$1\ \ 2\ \ -1$

$1\ \ \frac{1}{2}\ \ -1$



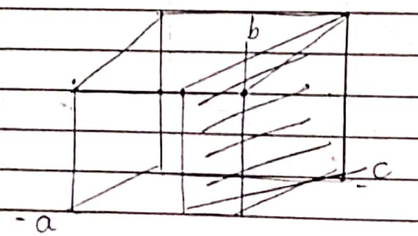
8. $(3\ 0\ 0)$

$\frac{1}{3}$ ∞ ∞



9) $(\bar{2}\ 0\ \bar{1})$

$-\frac{1}{2}$ ∞ -1



X-ray Diffraction

Diffraction is defined as the bending of a ray of light when it encounters an object whose dimensions are of order of wavelength.

In crystal, we have seen that atoms are arranged in perfectly ordered manner. Also dimensions of atoms are 10^{-8} cm which is nearly of the same order of x-ray wavelength.

Hence when x-rays are made incident upon crystals, we get an ordered, regular diffraction pattern or one can say that a crystal act as 3D reflecting grating with x-rays

When a monochromatic x-ray beam is made incident on them at angle θ, which is called as glancing angle, it is shown that constructive interference takes place b/w the rays scattered by atoms only when condition called 'Bragg's Law' is satisfied.

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

where d, is interplanar spacing

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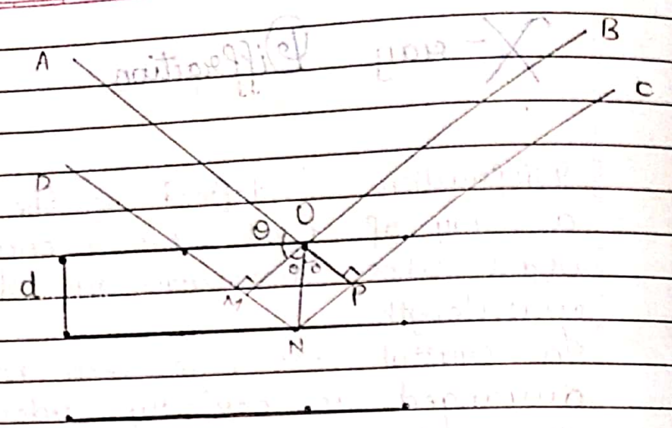

An ordered arrangements of atoms has been shown. Let interspacing be d. An parallel and monochromatic beam of x-ray is made incident on planes.

Ray AO will scattered at Point O in 1st plane. Ray DN will also experienced scattering at point N.

Among these scattered rays select rays OB and NC which are parallel to each other.

It is assume that they produce constructive interference & hence they have path difference

$$\Delta = n\lambda \quad \text{--- (1)}$$

Draw ⊥ers OM & OP to rays DN and NC respectively.

∴ Path difference b/w rays 1 and 2 is

$$\Delta = MN + NP$$

Consider $\triangle OMN$

$$\sin\theta = \frac{MN}{ON}$$

$$MN = ON\sin\theta \quad \text{--- (2)}$$

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Consider $\triangle OPN$.

$$\sin\theta = \frac{NP}{ON}$$

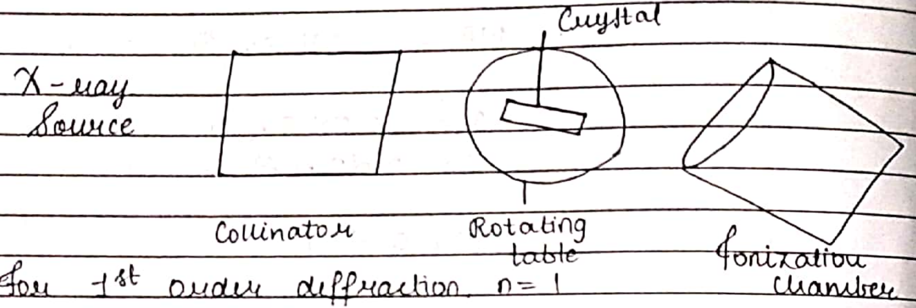
$$NP = ON\sin\theta \quad \text{--- (2)}$$

$$\Delta = 2ON\sin\theta$$

$$\Delta = 2d\sin\theta$$

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

Bragg's Differatometer.



For 1st order diffraction $n=1$

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

$\lambda = 2d_{100} \sin\theta_1$

$\lambda = 2d_{110} \sin\theta_2$

$\lambda = 2d_{111} \sin\theta_3$

$d_1 : d_2 : d_3 :: \frac{1}{\sin\theta_1} : \frac{1}{\sin\theta_2} : \frac{1}{\sin\theta_3}$

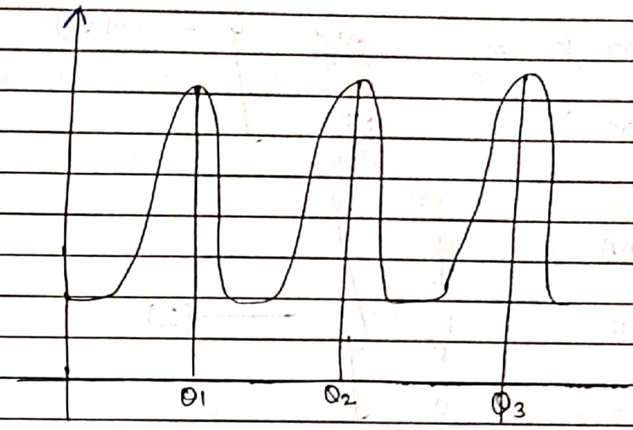
If reading turns out to be

SC – $1 : \frac{1}{\sqrt{2}} : \frac{1}{\sqrt{3}}$

BCC – $1 : \frac{2}{\sqrt{2}} : \frac{1}{\sqrt{3}}$

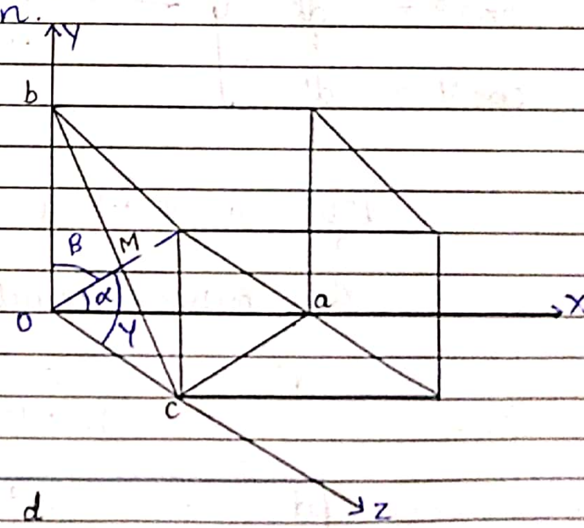
FCC – $1 : \frac{1}{\sqrt{2}} : \frac{2}{\sqrt{3}}$

Graph of Ionization Chamber.



Interplanar Spacing

Derivation.



OM = d

$$\left.\begin{aligned}\cos\alpha &= \frac{OM}{OA}\\ \cos\beta &= \frac{OM}{OB}\\ \cos\gamma &= \frac{OM}{OC}\end{aligned}\right\} \quad (1)$$

$$\left.\begin{aligned}OA &= \frac{a}{h}\\ OB &= \frac{b}{k}\\ OC &= \frac{c}{l}\end{aligned}\right\} \quad (2)$$

$$\left.\begin{aligned}\cos\alpha &= \frac{dh}{a}\\ \cos\beta &= \frac{dk}{b}\\ \cos\gamma &= \frac{dl}{c}\end{aligned}\right\} \quad (3)$$

$\because \cos^2\alpha + \cos^2\beta + \cos^2\gamma = 1$

$$\frac{d^2h^2}{a^2} + \frac{d^2k^2}{b^2} + \frac{d^2l^2}{c^2} = 1$$

In cubic structure $a = b = c$

$$d^2 = \frac{a^2}{h^2+k^2+l^2}$$

$$\boxed{d = \frac{a^2}{\sqrt{h^2+k^2+l^2}}}$$

Q.1. Find interplanar spacing b/w family of planes (1, 1, 1) in crystal of lattice constant $3A°$.

Miller indices $(h\ k\ l) \approx (1, 1, 1)$

$$d = \frac{3}{\sqrt{1+1+1}}$$

$$= \frac{3}{\sqrt{3}}$$

$$d = \sqrt{3}A$$

Q.2. Calculate the glancing angle at plane (100) for crystal of rock salt. $A = 2.125A°$ Consider case of 2^{nd} order max. and $\lambda = 0.592\,A°$.

$\Rightarrow \lambda = 0.592\,A°$

$a = 2.125A°$

$n = 2$

$$d = \frac{2.125}{\sqrt{1}}$$

$$d = 2.125\,A°$$

Bragg's Law $2d \sin\theta = n\lambda$

$$2(2.125)\sin\theta = 2(0.592)$$

$$\theta = 16.6°$$

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* In hall effect exp. a p.d. of 4.5 V is developed across a foil of zinc of $t = 0.02$ mm when current of 5A is passed in dirn $\perp^{er}$ to applied magnetic field of 2π. Calculate.

i) Hall coff. of zinc

ii) conc. of electron.

$\Rightarrow$ Soln :-

P. diff $= 4.5V = 4.5 \times 10^{-6}$

$t = 0.02\,mm \quad 2 \times 10^{-3}$

$I = 5A$

$B = 2\pi$

$$R_H = \frac{Vt}{IB}$$

$$R_H = 3 \times 10^{-11}$$

$$R_H = \frac{1}{ne}$$

$$3 \times 10^{-11} = \frac{1}{n \cdot 1.6 \times 10^{-19}}$$

$$n = \frac{1}{3 \times 10^{-11} \times 1.6 \times 10^{-19}}$$

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* Resistivity of copper is $1.72 \times 10^{-8}\ \Omega m$. Calculate mobility of e^- in copper. (no. of e^- per unit vol. $10.41 \times 10^{-28}\ m^{-3}$).

⇒ $\sigma = ne\mu$

$\frac{1}{\rho} = ne\mu$

$\frac{1}{1.72 \times 10^{-8}} = 10.41 \times 10^{-28} \times 1.6 \times 10^{-19} \times \mu.$

$3.49 \times 10^{-3}\ \frac{m^2}{VS} = \mu.$

* Calculate e^- and Hall conc. in intrinsic silicon at room temp. if electrical conduct. 4×10^{-4} (Mobility of e^- = $0.14\ \frac{m^2}{VS}$ mobility of whole = $0.04\ \frac{m^2}{VS}$).

$\sigma = ne(\mu_e + \mu_h)$

$\cancel{\sigma} = e\mu_e + \mu$

$\frac{\sigma}{e(\mu_e + \mu_h)} = n$

$1.38 \times 10^{16} = n.$

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* An electron is acc. through 1200V, & is reflected from a crystal. The 2nd order reflection occurs when glancing angle 60°. Calculate interplanar spacing of crystal.

⇒ $V = 1200V.$

$\lambda = \frac{12.26}{\sqrt{V}}$

$= \frac{12.26}{\sqrt{1200}}$

$\lambda = 0.35\ A°.$

$\lambda = 0.35 \times 10^{-10}\ m.$

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

$2d \sin 60 = 2 \times 0.35.$

$d = 4.04 \times 10^{-11}\ m.$

* X-ray of unknown wavelength gives 1st order Bragg's reflection at glancing $\angle\theta = 20°$ with (212) plane of copper structure. find wavelength of X-rays if lattice for copper is 3.615 A°.

⇒ $\lambda = 3.615 A°.$

$= 3.615 \times 10^{-10}\ m.$

$\cancel{2d}\ \ \cancel{\frac{12.26}{a}}$

$d = \frac{a}{\sqrt{h^2 + k^2 + l^2}}$

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$$d = \frac{3.615}{\sqrt{2^2+1^2+2^2}}$$

$$d = 1.205$$

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

$$2 \times 1.205 \sin 20 = \lambda$$

$$0.824\ \mathring{A} = \lambda$$

* Find the energy of neutron in units of ~~elect~~ eV whose de-Broglie's wavelength is $1\mathring{A}$ (Mass of neutron = 1.674×10^{-27} kg).

$\Rightarrow \lambda = 1A$

$= 1 \times 10^{-10}$ m.

$m = 1.674 \times 10^{-27}$

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

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

$$E = \frac{h^2}{2m^2\lambda^2}$$

$$= 1.312 \times 10^{-20} J \,/\, (1.6 \times 10^{-19})$$

$$E = 0.082 \text{ eV}.$$

α = helium nuclei. Ano. 2

β = electron

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* Calculate de-Broglie wavelength associated with α-particle accl. ~~to~~ by p.diff of 200V (mass of α-particle = 6.68×10^{-27} kg).

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

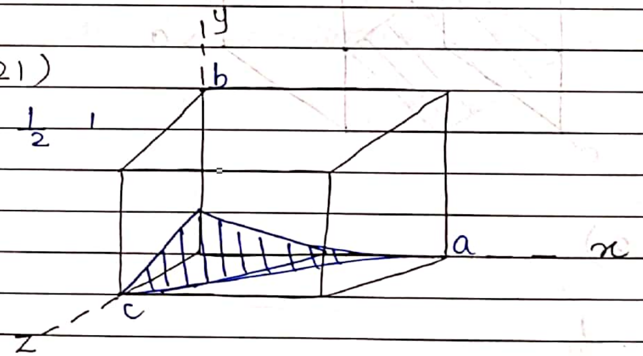
$$= \frac{6.64 \times 10^{-34}}{\sqrt{2 \times 6.68 \times 10^{-27} \times 2 \times 1.6 \times 10^{-19} \times 200}}$$

$$\lambda = 7.180 \times 10^{-13} \text{ m}.$$

* Draw the following (121), (110), (r, 11) planes

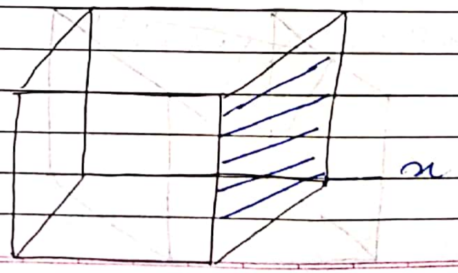
1.) (121)

1 $\frac{1}{2}$ 1

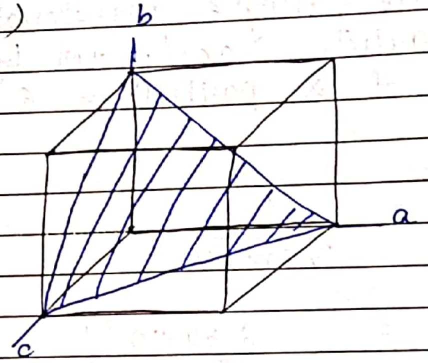


2. (1 0 0)

1 ∞ ∞

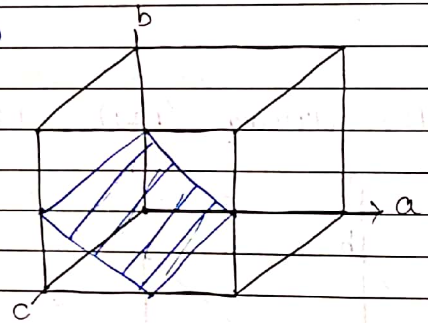


3) $(1\,1\,1)$



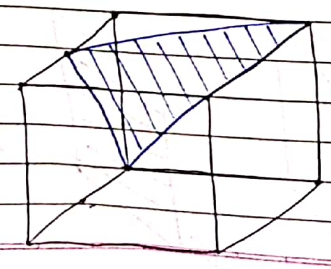
4) $(2\,2\,0)$ $(1\,\bar{1}\,2)$

$\frac{1}{2}$ $\frac{1}{2}$ ∞



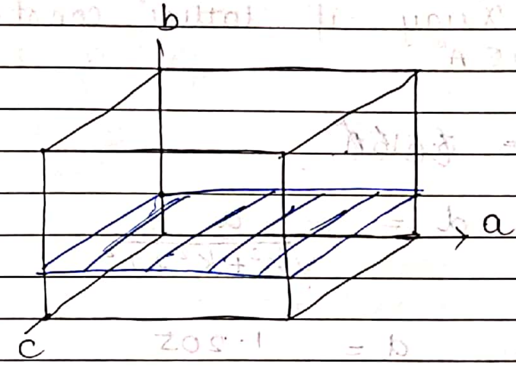
5) $(1\,\bar{1}\,2)$

1 -1 $\frac{1}{2}$



6. $(0\ 4\ 0)$

$(\infty, \frac{1}{4}, \infty)$



Q.1 An electron is accelerated through 1200V. and is reflected from a crystal. The 2nd order reflection occurs when glancing 160°. Calcute interplanar spacing of crystal.

→ $\lambda = \frac{12.26}{\sqrt{V}}$

$= \frac{12.26}{\sqrt{1200}}$

$\lambda = 0.35.$

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

$2d \sin 60 = 2 \times 0.35.$

$d = 0.40 A^\circ.$

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Q. Calculate De-broglie wavelength of proton having a velocity equal to $\frac{1}{120}$ th velocity of light. $(1.6 \times 10^{-27}$ kg) $\frac{1}{120}$ mass of mp.

$= m_p = 1.6 \times 10^{-27}$ kg.

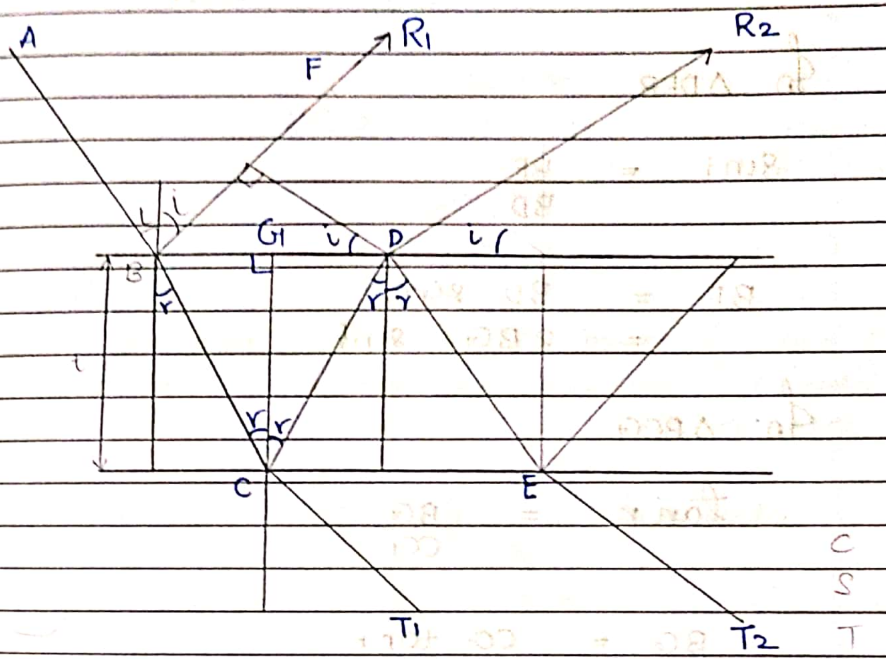
$v = \frac{3 \times 10^8}{120}$

$\lambda = \frac{h}{mv}$

$= 2.76 \times 10^{-14}$ m

$= 2.76 \times 10^{-4}$ Å.

there is integral multiple of λ or an odd multiple of $\frac{\lambda}{2}$



Geometrical Path Difference (GPD).

$$GPD = BC + CD - BF$$

$$\Delta = \mu (BC + CD) - BF \quad \text{———} (1)$$

In Δ BCG

$$\cos r = \frac{CG}{BC}$$

$$BC = \frac{CG}{\cos r} = \frac{t}{\cos r} \quad \text{———} (2)$$

$$\Delta = \frac{2\mu t}{\cos r}(1-\sin^2 r)$$

$$\Delta = \frac{2\mu t}{\cos r}\cos^2 r$$

$$\Delta = 2\mu t \cos r$$

$$\Delta = 2\mu t \cos r + \frac{\lambda}{2}$$

Since the medium is top surface of thin film is backed up by denser medium, additional path difference of $\frac{\lambda}{2}$ is introduced.

∴ Total path difference becomes

$$\Delta = n\lambda$$

$$2\mu t \cos r + \frac{\lambda}{2} = n\lambda$$

$$2\mu t \cos r = n\lambda - \frac{\lambda}{2}$$

$$2\mu t \cos r = (2n-1)\frac{\lambda}{2}$$

For destructive interference

$$\Delta = (2n+1)\frac{\lambda}{2}$$

$$2\mu t \cos r + \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$$

$$2\mu t \cos r = n\lambda.$$

SEMICONDUCTORS.

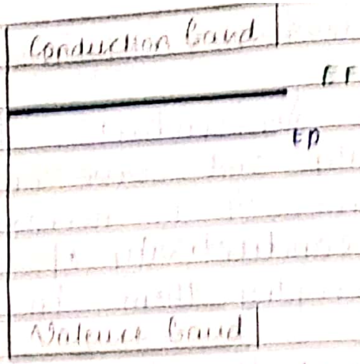
Fermi level in Extrinsic Semiconductor.

Intrinsic Semiconductor have low conductivity and serve only in limited applications. It is necessary to modify & control conductivity of intrinsic semiconductor to employ them in Manufacturing devices.
The conductivity of intrinsic semiconductor can be increased by adding impurities. The process of adding impurities is known as doping.
The impurity is called dopant. The doped semiconductor is called extrinsic Semiconductor.

Fermi Level in n-type.

If pentavalent impurity is added to pure semiconductor it becomes n-type extrinsic semiconductor. Impurity is called donor impurity.

The addition of impurity adds an allowed energy level E_D at a very small distance below conduction band as shown.
This energy level lies in forbidden energy gap

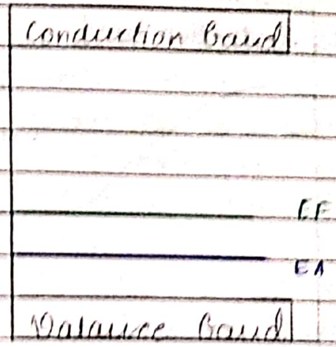


In n-type semiconductor as there are many free electrons in conduction band fermi level gets shifted towards conduction band.
At 0°K it is b/w bottom of conduction band & level ED.

Fermi level in P-type

If trivalent impurity is added to a pure semiconductor it becomes p-type extrinsic semiconductor.
It is called as acceptor impurity.

The addition of impurity adds an allowed level EA at a very small distance above the top of valence band as shown.

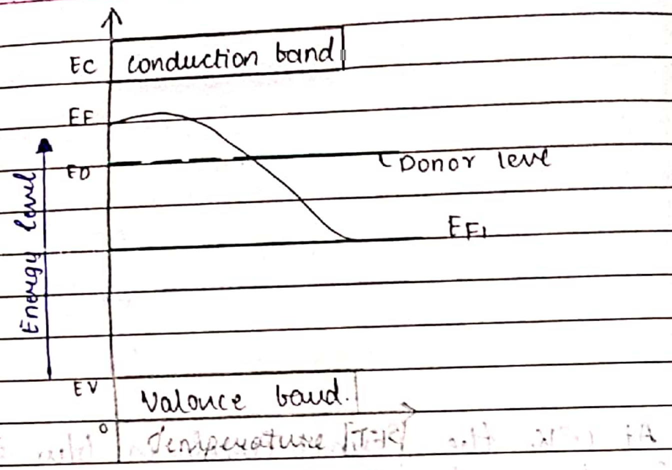


At 0°K the fermi level is b/w top of valence band and level EA.

Effect of Temperature on n-type Material

At low temperature :
When the temperature in semiconductor is low only few donor atoms get ionized & electrons move from donor level to C.B. Hence, fermi level for n-type semiconductor at low temp. lies midway b/w bottom of conduction band and donor level.

At Moderate Temperature :
At moderate temp. all donor atoms are ionized. So conc. of electrons in C.B is equal to be conc. of donor atoms.



At higher temperature :-
At high temp. conc. of transfer of electrons from valence band to C.B is more as compared to conc. of electrons from donor atoms & fermi level is shifted to middle of the forbidden gap.

The variation of fermi level with temperature for n-type of material.

Effect of Temperature on p-type material.

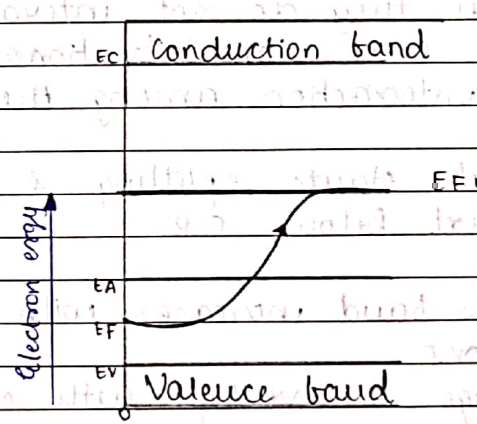
At low temperature :-
At low temp only few acceptor levels are occupied & simultaneously holes are produced in valence band.

So, fermi level is in middle of top of V.B and acceptor level.

At moderate temperature :
At moderate temp. all acceptor levels are fill. So at moderate temp. fermi level gradually moves up. i.e moves towards the middle of the forbidden gap.

At higher temperature :-
At very high temperature, contribution of conduction band for formation of holes in valence band is more compared to acceptor impurity.

Hence at very high temperature :



Fermi level approaches middle of energy gap i.e the position of EFi for intrinsic semiconductor. The variation of EF with temperature in p-type material is shown above.

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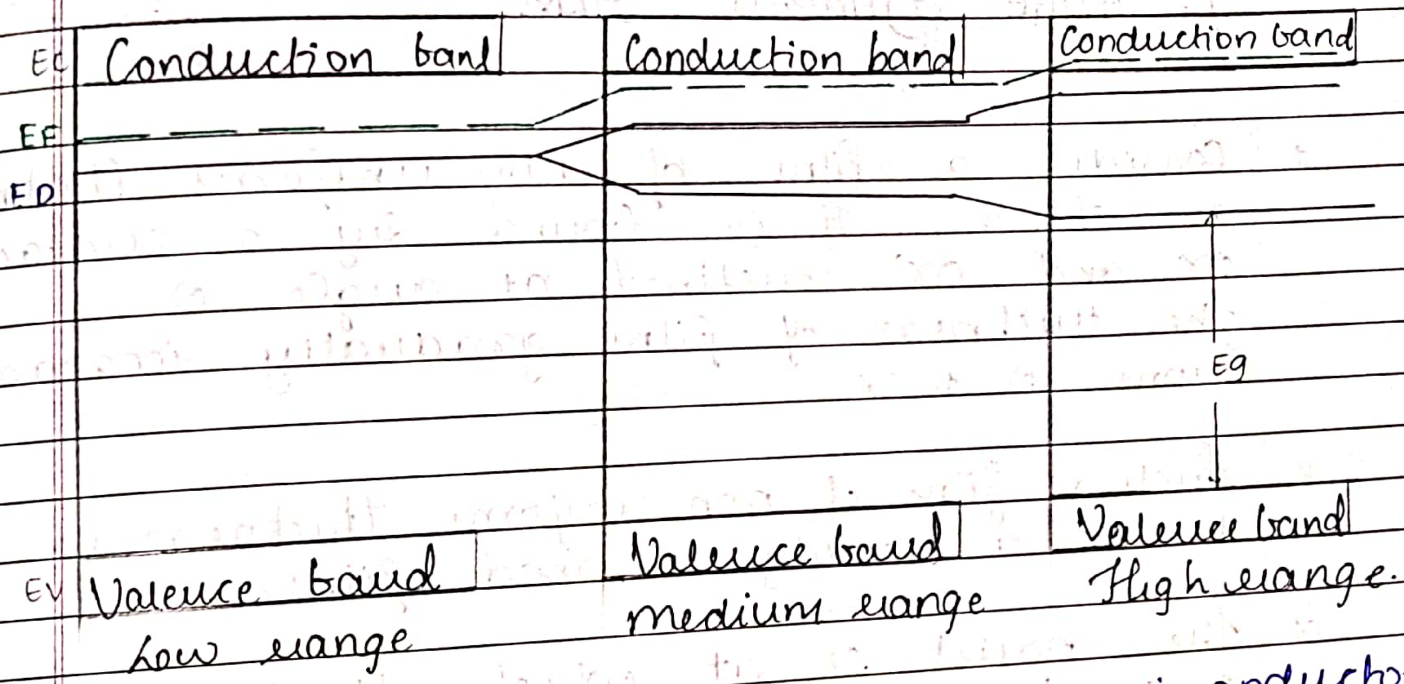


In same way, for p-type semiconductor increase in impurity conc. makes fermi level shifts into valence band

* The total path difference b/w rays R_1 & R_2 is given by

$$\Delta = 2\mu t \cos(r+\theta) + \frac{\lambda}{2}$$

For constructive interference.

$$\Delta = n\lambda$$

$$2\mu t \cos(r+\theta) + \frac{\lambda}{2} = n\lambda$$

$$2\mu t \cos(r+\theta) = (2n-1)\frac{\lambda}{2} \quad \text{—— (1)}$$

This is the condition for conductive interference in wedge shaped film.

6. Total path difference is given by.

$$\Delta = 2\mu t \cos(r+\theta) + \frac{\lambda}{2}$$

7. For air film $\mu = 1$
If angle of incidence is normal, $r = 0$.

$$\therefore \Delta = 2t \cos(r+\theta) + \frac{\lambda}{2}$$

For very small angle of wedge, $\theta = 0$.
$\cos\theta = 1$.

$$\therefore \Delta = 2t + \frac{\lambda}{2}$$

8. For constructive interference.

$$\Delta = n\lambda$$

$$2t + \frac{\lambda}{2} = n\lambda$$

$$t = \frac{n\lambda}{2}$$

For $n = 1$ $t = \frac{\lambda}{4}$

For $n = 2$ $t = \frac{3\lambda}{4}$

For $n = 3$ $t = \frac{5\lambda}{4}$

i.e, every next bright fringe will occur for thickness interval of $\frac{\lambda}{2}$ each.

9. For destructive interference.

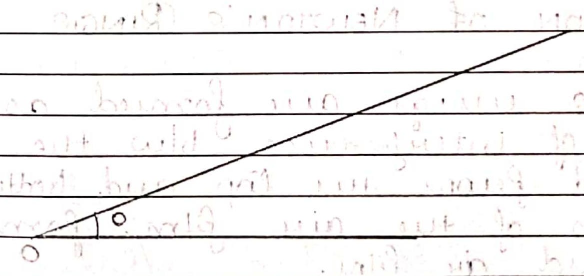
$$\Delta = (2n+1)\frac{\lambda}{2}$$

$$2t + \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$$

$$t = (2n+1)\frac{\lambda}{2}$$

$$t = n\lambda/2$$

i.e, every next dark fringe will occur for thickness interval of $\frac{\lambda}{2}$ each.

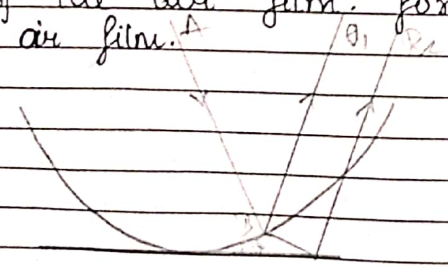


NEWTON RINGS

When a plano convex lens of large radius of curvature is placed on a plane glass plate and an air film is formed b/w lower surface of lens and upper surface of plane.
The thickness of the film gradually inc from point of contact to outwards.
If monochromatic is allowed to fall normally on this film, a system of alternate bright and dark concentric rings, with their centre dark is formed in the air film.
These rings were first studied by Newton and hence known as Newton's rings.

FORMATION OF NEWTON'S RINGS.

Newton's rings are formed as a result of interference b/w the waves reflected from the top and bottom surfaces of the air film. formed b/w lens and air film.



As show let AB be beam of monochromatic light of wavelength λ

As a resultant of reflection at reflection at top and bottom phases Ray R_1 & R_2 are coherent rays which interfere in reflected system.
Total path difference is given by.

$$2\mu t\cos(r+\theta)+\frac{\lambda}{2}$$

For conductive interference

$$\Delta = n\lambda$$

$$2\mu t\cos(r+\theta)+\frac{\lambda}{2} = n\lambda$$

$$2\mu t\cos(r+\theta) = (2n-1)\frac{\lambda}{2}$$

For destructive interference

$$\Delta = (2n+1)\frac{\lambda}{2}$$

$$2\mu t\cos(r+\theta)+\frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$$

$$2\mu t\cos(r+\theta) = n\lambda$$

Q. Why does the centre of Newton ring always appear dark.

⇒ Path difference is given by

$$\Delta = 2\mu t \cos(r+\theta) + \frac{\lambda}{2}$$

For air film $\mu = 1$

For normal incidence $r = 0$

$$\Delta = 2t + \lambda/2$$

Now, $t = 0$

$$\Delta = \frac{\lambda}{2}$$

$\frac{\lambda}{2}$ is condition for destructive inference

So centre of Newton ring always appears dark.

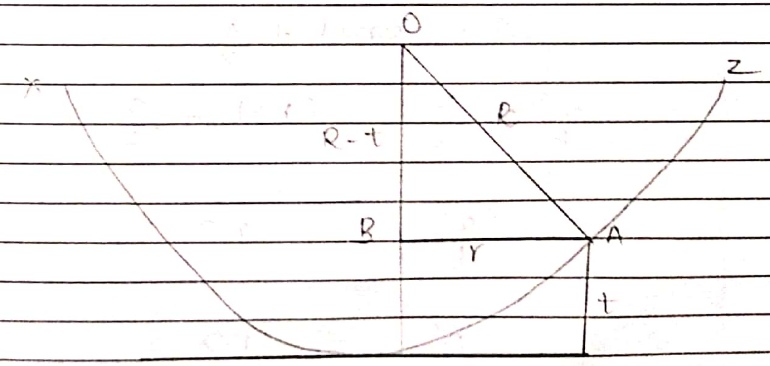
Q. Show that diameter of n^{th} dark circle is proportional to square root of natural no.

⇒ Let x, y, z be plano convex len placed on a plane glass plate.
Let R be radius of curvature of length surface in contact with the plate.
Let r_s be radius of newton's ring correspond to ~~thin~~ constant film of 't'.
The path difference b/w two interfering rays in the reflected system is given by,

$$\Delta = 2\mu t \cos(r+\theta) + \frac{\lambda}{2}$$

For air film $\mu = 1$
For normal incidence $r = 0$

$\theta = 0$ for radius of curvature



$$\Delta = 2t + \frac{\lambda}{2} \quad \text{---(1)}$$

In ΔOAB,
By pythagoras theorem,

$$OA^2 = OB^2 + (BA)^2$$
$$R^2 = (R-t)^2 + r^2$$
$$R^2 = R^2 - 2Rt + t^2 + r^2$$

$$2Rt = r^2 + t^2$$
$$2Rt = r^2 + \cancel{t^2}$$
$$2t = \frac{r^2}{R}$$

$$\Delta = \frac{r^2}{R} + \frac{\lambda}{2}$$

For dark circle,

$$\Delta = 2n+1 + \frac{\lambda}{2}$$

$$\frac{r^2}{R} + \frac{\lambda}{2} = 2n+1 + \frac{\lambda}{2}$$

$$\frac{r^2}{R} = n\lambda$$

$$\frac{D^2}{4R} = n\lambda$$

$$D_n^2 = 4Rn\lambda$$

$$\therefore D_n \propto \sqrt{n}$$

$\therefore$ Diameter of n^{th} circle is $\propto$ to $\sqrt{n}$.

For bright circle

$$\Delta = n\lambda$$

$$\frac{r^2 n}{R} + \frac{\lambda}{2} = n\lambda$$

$$\frac{r^2 n}{R} = (2n-1)\frac{\lambda}{2}$$

$$\frac{D_n^2}{4R} = (2n-1)\cdot\frac{\lambda}{2}$$

$$D^2 n = 4(2n-1)R\frac{\lambda}{2}$$

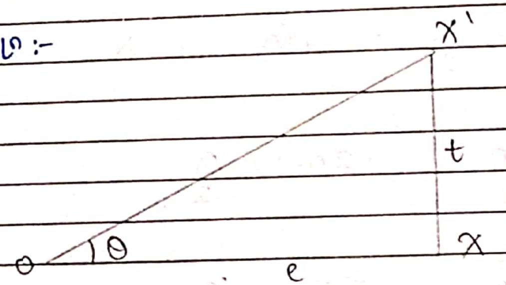
$$D^2 n = 4R(2n-1)\frac{\lambda}{2}$$

$$\boxed{D_n \propto \sqrt{(2n-1)}}$$

Q. Applications :-

1.) How will you determine the thickness of very thin particle using wedge shaped film.

⇒ Soln :-



In $\Delta OXX'$,

$$\tan\theta = \frac{t}{l} = \theta \quad \text{—— (1)}$$

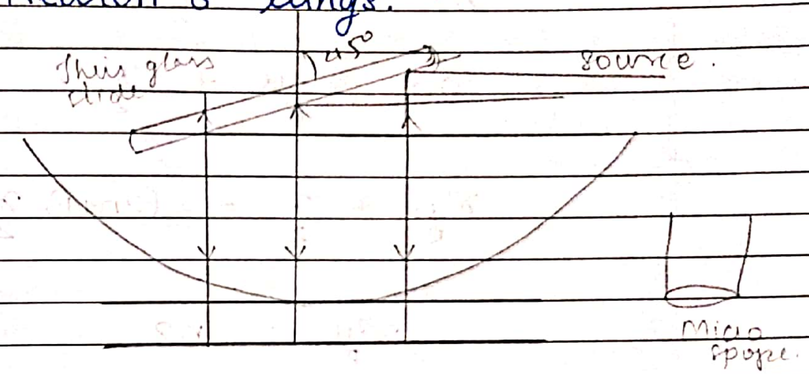
$$\beta = \frac{\lambda}{2\theta}$$

$$\theta = \frac{\lambda}{2\beta}$$

$$\frac{t}{l} = \frac{\lambda}{2\beta}$$

$$t = \frac{\lambda l}{2\beta}$$

2.) How will you determine radius of curvature or wavelength of light using Newton's rings.



For n^{th} dark circle.

$$D_n^2 = 4nR\lambda$$

$$D_{n+p}^2 = 4(n+p)R\lambda$$

$$D_{n+p}^2 - D_n^2 = 4PR\lambda$$

$$R = \frac{D_{n+p}^2 - D_n^2}{4P\lambda}$$

Q.3] How will you refractive index of liquid using Newton's Ring experiment.

⇒

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$$= 4 \times 10 \times 100 \times \lambda$$

$$\lambda = 5.881 \times 10^{-5} \text{ cm}$$

Q.2) In a newton's ring exp. d of 10^{th} dark circle changes from 1.4cm to 1.27cm when a liq is introduced b/w len and plane. Calculate refractive index of liq.

⇒ Solution :-

Diameter sqaare is

$$D_n^2(a) = 4nR\lambda$$

$$D_n^2(l) = \frac{4nR\lambda}{\mu}$$

Dividing

$$\mu = \frac{D_n^2(\text{air})}{D_n^2(\text{liq})}$$

$$\mu =$$

$$\mu = 1.21$$

Q.3] Newton's rings are formed using light of wavelength 5896 Å in reflected light with liq placed b/w plane & curved surface. Diameter of 7th dark fringe is 0.4 cm & radius of curvature is 1m. Find refractive index of liq.

⇒ Solution :-

$$D_n^2 = \frac{4nR\lambda}{\mu}$$

$$(0.4)^2 = D_n^2 = \frac{4 \times 7 \times 1 \times 5.896 \times 10^{-8}}{\mu}$$

$$= 1.0318 \times 10^{-}$$

Q.4] In Newton's ring exp. diameter of 5th ring was 0.336 cm and diameter 15th ring 0.59 cm. Find radius of curvature plano convex lens if wavelength of light 5890 Å.

Solution :-

$$R = \frac{D_{n+p}^2 - D_n^2}{4p\lambda}$$

$$0.59^2 - 0.336^2 = 4 \times 10 \times R \times 5890 \times 10^{-8}$$

$$R = 99.83\,cm.$$

Q.5] Fringes of equal thickness are observed in thin glass wedge of refractive index 1.52. The fringe spacing is 1mm and λ of light is 5893 Å. Calculate ∠ of wedge in sec of arc.

$r = 0° = \text{sec}. \quad cm \Rightarrow r.$

⇒ Solution :-

$$\beta = \frac{\lambda}{2\mu\theta}$$

$$0.1 = \frac{5893 \times 10^{-8}}{2 \times 1.52\,\theta}$$

$$\theta = 1.938 \times 10^{-4} \text{ radr}$$

$$\theta = 1.11 \times 10^{-} \text{ Secn}$$

$$\theta = 39.96 \text{ sec}$$

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Q.6] A wedge shape air film having 1/40 sec is eliminated by monochromatic light & fringes are observed vertically through a microscope. Distance measured b/w consecutive bright fringes is 0.12 cm. Calculate the wavelength of light in sec.

→ Solution :-

$$\beta = \frac{\lambda}{2\alpha\theta}$$

$$\lambda = 2\alpha\theta\beta$$

$$\lambda = 2 \times 0.12 \times 1.93 \times 10^{-5}$$

$$\lambda = 4.632 \times 10^{-5} \text{ Å}$$

Monday

Chapter. 5

Chap-
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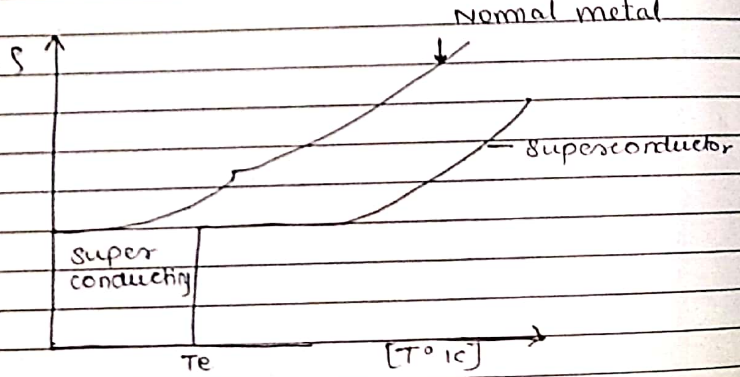
SUPERCONDUCTORS &

SUPERCAPACITORS.

K. onnes observed that for few of metals. electrical resistance drops to zero below a certain temp. This material are called superconductors. Drop of electrical resistance is shown in the figure.



Resistance of a superconductor in the non-super conducting state decreases with decrease in temp. This is similar to a normal metal at a particular temperature Tc. The resistance abruptly drops to zero & then onwards metal passes into superconducting states.

The temperature at which a normal material turns into superconducting state is called Critical Temperature Tc.

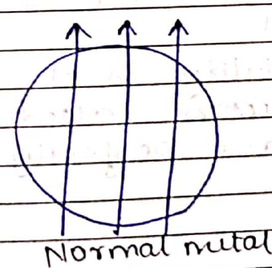
MEISSNER'S Effect:

1. A superconducting material kept in magnetic field expells magnetic flux out of its body when cooled below Tc and exhibits perfect diamagnetic. This effect is called Meissner's effect.

2. Ref fig. A where a specimen is subjected to magnetic field. The speciman is in normal state we find that magnetic field penetrates the speciman.

3. Ref. fig. B Now the speciman is cooled below its critical temp, Superconductor expells filled lines from its body. This is meissner's effect

4. As



Normal metal

Fig A

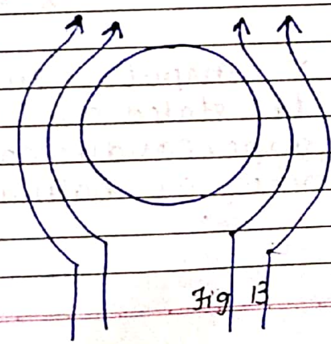


Fig B

5. As specimen expells magnetic flux, it is exhibition of perfect diamagnetism. Susceptibility is found out to be -1.

6. Let c in mathematically. For normal metal magnetic induction inside specimen is given by

$$B = \mu_0 (H+M)$$

where μ_0 → absolute permeability
H → external applied field.
M → Magnetization produced within specimen

At $T < T_c$

$$B = \mu_0 (H+M)$$

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

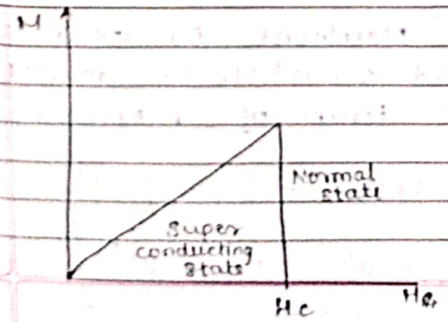
$$H+M) = 0$$

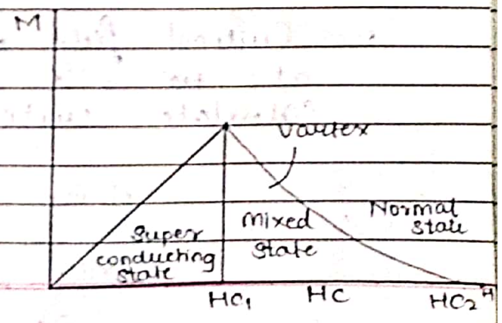
$$H = -M$$

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

∴ magnetic susceptibility is -1, it can be stated as conductors called as superconductors are perfectly diamagnetic in nature.

Type - 1	Type - 2.
1. Commerically these superconductors are called as soft superc.	Comerically these superconductors are hard superconductors.
2. These superconductor exhibit only one critical field (H_c).	These superconductor exhibit only 2 critical field namely H_{c_1}, H_{c_2} Lower Critical field Higher Critical field.
3. Critical magnetic field value is low	Critical magnetic value is high.
4. This superconductors exhibit perfect and complete miessner effect	These superconductor do not exhibit perfect & complete miessner's eff.
5. These materials have limited technical application b'coz of very low fill straight line.	These have high technical application





Eg:- Pb and Hg are some examples of Type-1 superconductors

Eg: Nb_3Ge, Nb_3Si are some examples of Type 2 superconductors

Q. Numeri

1. A superconductor has T_c 3.7°C at 0 magnetic field. (H_c). At 0°C the critical magnetic field is 0.0306 Tesla. What is critical magnetic field at T = 2°K.

⇒ T_c = 3.7°C

H_{c_0} = 0.0306

T = 2°K

$$H_c(T) = H(0)\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

$$= 0.0306\left[1 - \left(\frac{2}{3.7}\right)^2\right]$$

$$= 0.0216\ T$$

2. Critical field of Neobium is 1×10^5 Tesla at ~~10~~ 8°K and 2×10^5 Tesla at 0°C Calculate critical temp of element.

$$H_c(T) = H(0)\left[1 - \left(\frac{T}{T_c}\right)^2\right]$$

$$1\times10^5 = 2\times10^5\left[1 - \left(\frac{8}{T_c}\right)^2\right]$$

$$T_c = 11.313$$

Chapter. 6)

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6 Engineering Materials & Applications

Liquid Crystal

There are 3 types of liq crystalls.

1) In some substances, tendency towards an ordered arrangement of molecule is so great that crystalline solids does not melt directly into liquid state but passes first through an intermediate change called liq. crystal. Before changing into a liquid state on futher application of heat

$$\boxed{\text{Solid}} \xrightarrow{\text{Heat}} \boxed{\text{liq Crystal}} \xrightarrow{\text{Heat}} \boxed{\text{liq.}}$$

2) Liquid Crystalls shows some of the properties of solid state and some of porperties of liquid state

3) Properties related to solid state are

a) It exhibit double refraction of light and interference pattern in polarized light

b) Ordered arrangement of atoms or molecules is still found.

c) Properties related to liquids are

i) Exhibits, surface tension, flow and Viscosity

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Ordered arrangement of atoms or molecule is of short order.

There are 3 types of liq. Crystal.

i) Smectic or Soap like liq. Crystal.

ii) Nematic or Thread like liq. Crystal

iii) ~~cht~~ Cholestoeric liq. Crystal.

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1) Find the energy of neutron in units of eV whose de - Broglie's wavelength is 1 A (m of n 1.674×10^{-27} kg.).

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

$$1 \times 10^{-10} = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 1.674 \times 10^{-27} \times E}}$$

$$E = 1.31 \times 10^{-20} \div 1.6 \times 10^{-19}.$$

$$E = 0.08 \text{ eV}$$

2) An electron is accelerated through 1000V & it is reflected from a crystal. 1st order reflection occurs when glancing ∠70°. Calculate d.

⇒

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

$$2d \sin 70 = 1\lambda$$

$$\lambda = \frac{12.26}{\sqrt{V}}$$

$$\lambda = 0.39$$

$$d = 0.207 \text{ cm}$$

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3) Calculate de-Broglie wavelength associated with α-particle accle. by a potencial diff of 200 V. (mass α-particle → 6.68×10^{-27} kg)

⇒ V = 200 V.

$$\lambda = \frac{h}{\sqrt{2 m_e V}}$$

$$\lambda = 7.17 \times 10^{-13} \text{ m.}$$

$$\lambda = 7.17 \times 10^{-3} \text{ A.}$$

4) An electron has a speed of 400 m/s. with uncertainity of 0.01%. Find accuracy in its position.

⇒

$$\Delta x \cdot \Delta p = \frac{\hbar}{2\pi}$$

$$= \frac{\hbar}{4\pi}$$

$$= 5.27 \times 10^{-35}$$

$P = mv$

$\Delta P = m \Delta v$

$= m \times \frac{0.01}{100} \times 400$

9.1×10^{-31}

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$$\Delta P = 3.64 \times 10^{-32}.$$

$$\frac{h}{4\pi \times \Delta P} \quad \Delta x = 1.44 \times 10^{-3}.$$

5) Calculate Bragg's angle if (200) plane of BCC crystal with lattice parameter 2.814 A° gives second order reflection with x-rays of λ = 0.071 A°.

⇒

$$d = \frac{a}{h^2 + k^2 + l}$$

$d = \cancel{1.40 \ldots}$

$d = 1.407$

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

$$\theta = 30.30^\circ.$$

Semiconductors

$$f(E) = \frac{1}{1 + e^{\left(\frac{E_C - E_F}{KT}\right)}}$$

temp. constant

Probability of

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VVImp

★★ 1.) What is probability of electron being thermally excited to C.B in Silicon at 27°C ? Band gap energy is 1.12 eV & K = 1.38×10^{-23} J/Kelvin.

$$EC - EF = \frac{Eg}{2} = 0.56 \times 1.6 \times 10^{-19} = 8.96 \times 10^{-20}$$

$$f(E) = \frac{1}{1 + e^{\left(\frac{EC - EF}{KT}\right)}}$$

$$= \frac{1}{1 + e^{\frac{0.56}{300 \times 1.38 \times 10^{-23}}}}$$

$$= \frac{1}{1 + e^{\frac{8.96 \times 10^{-20}}{300 \times 1.38 \times 10^{-23}}}}$$

$$= 3.98 \times 10^{-10}$$

2.) What is probability of electron being thermally excited to C.B in silicon at 20°C ? Band gap energy is 1.12 eV

273
20
93

$$f(E) = \frac{1}{1 + e^{\left(\frac{EC - EF}{KT}\right)}}$$

$$E = 2.37 \times 10^{-10}$$