

18/08/18

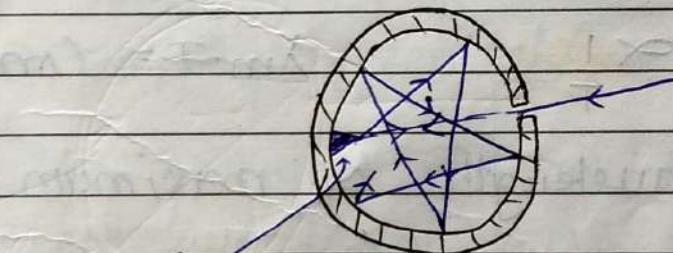
* Black Body:

A Body which absorb all incident radiation irrespective of frequency and wave length completely.

A Lamp black surface is near black but not perfectly black because it absorb visible light, infrared radiations but not far infrared radiations.

A Black body is perfectly absorver as well as emitter.

* Realization of a black body in practice:
Ferry:



Cannonical

Projection.

- Small opening and hole on the surface on the hollows on surface sphere act as a Black Body.
- When the Black Body is heated the emitted all the possible radiations.

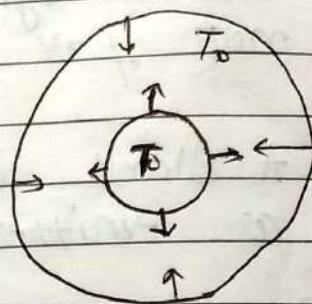
* Stefan's Law:

$$E \propto T^4$$

$$E = \sigma T^4$$

According to Stefan's Law Amount of radiate energy emitted per unit time per unit area is directly proportional to fourth power of its absolute temp.

then $E = \sigma (T^4 - T_0^4)$



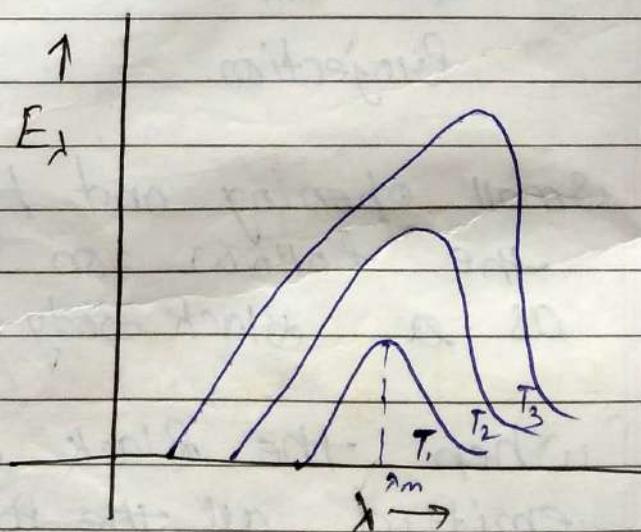
* Wein's Displacement Law:

$$\lambda_m \propto \frac{1}{T}$$

$$\lambda_m \cdot T = \text{Constant}$$

λ_m \Rightarrow wavelength of maximum radiation.

$$T_3 > T_2 > T_1$$

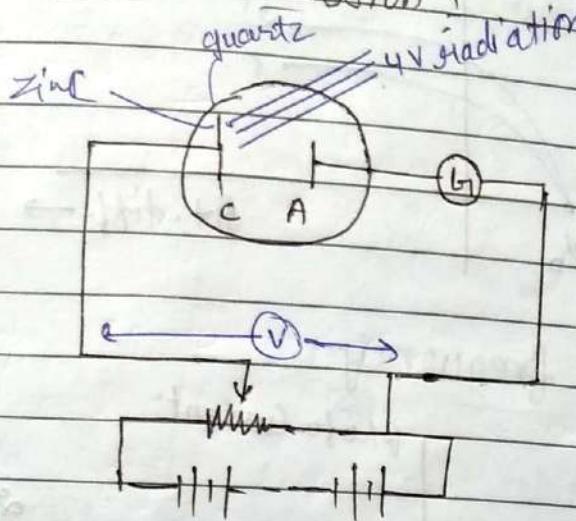


21/08/18.

DATE: / 20
PAGE NO:

~~* Photo electric emission :~~

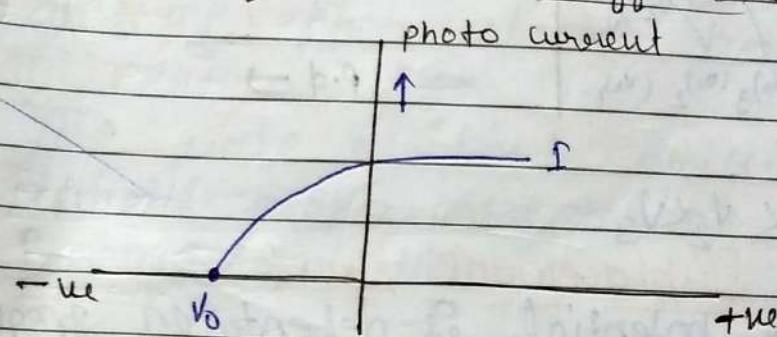
Duh



Su's

Subscribe

(i) Effect of potential difference :



$V_0 \rightarrow$ Stopping potential.

- Retarding potential for which photo electric current just become zero called stopping Potential.

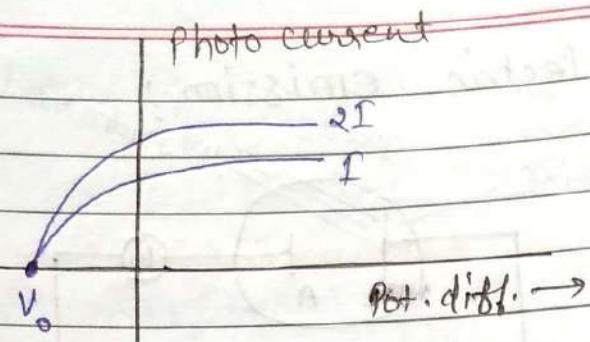
K.E of emitting = eV_0

$$\frac{1}{2}mv^2 = eV_0$$

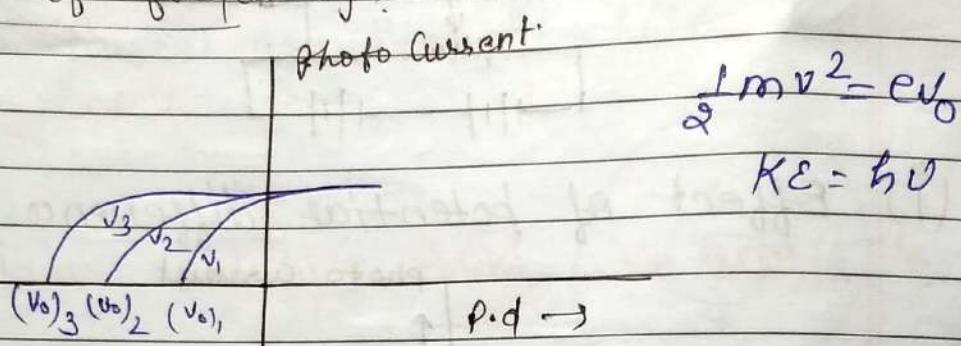
{

(ii) Effect of intensity :

The no. of photo electron ejected from photo sensitive plate is proportional to Intensity of the incident light.

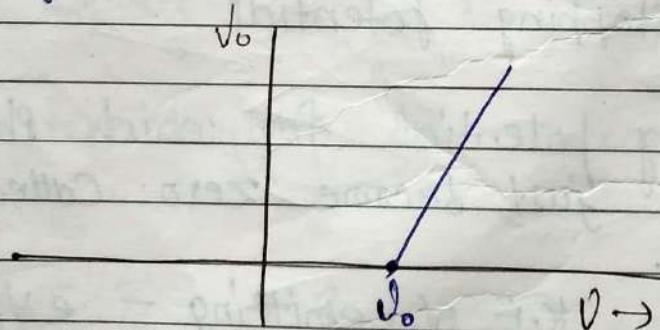


(iii) Effect of frequency!



$$V_1 < V_2 < V_3$$

Stopping potential is dependent on frequency.

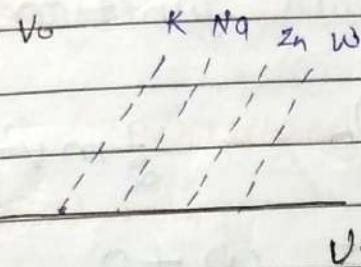


↳ Threshold frequency.

- Threshold frequency: Minimum \uparrow frequency of incident light below which the photo electric emission stop completely.
How so every the intensity of light may be called threshold frequency

Threshold frequency is the characteristic of photometal.

(iv) Effect of photometal:



$V_0 \rightarrow$ depends on nature of photo metal.

* Laws of photo electric emission:

- (1) The rate of photo emission is directly proportional to the frequency of incident radiation.
- (2) The K.E of emitted photo electron electron is independent of intensity and directly proportional to the frequency of the incident radiations.
- (3) The photo emission take place only above a certain frequency known as threshold frequency. This frequency is characteristic freq. of photo metal used.
- (4) There is no time lag between incident of radiation and emission of photo electron.

* Einstein theory of photo electric effect:

$$h\nu = \omega + \frac{1}{2}mv^2$$

ω = work function

$$\text{at } V = V_0, \frac{1}{2}mv^2 = 0$$

$$h\nu_0 = \omega + 0$$

$$\omega = h\nu_0$$

$$h\nu = h\nu_0 + \frac{1}{2}mv^2$$

$$\frac{1}{2}mv^2 = h\nu - h\nu_0$$

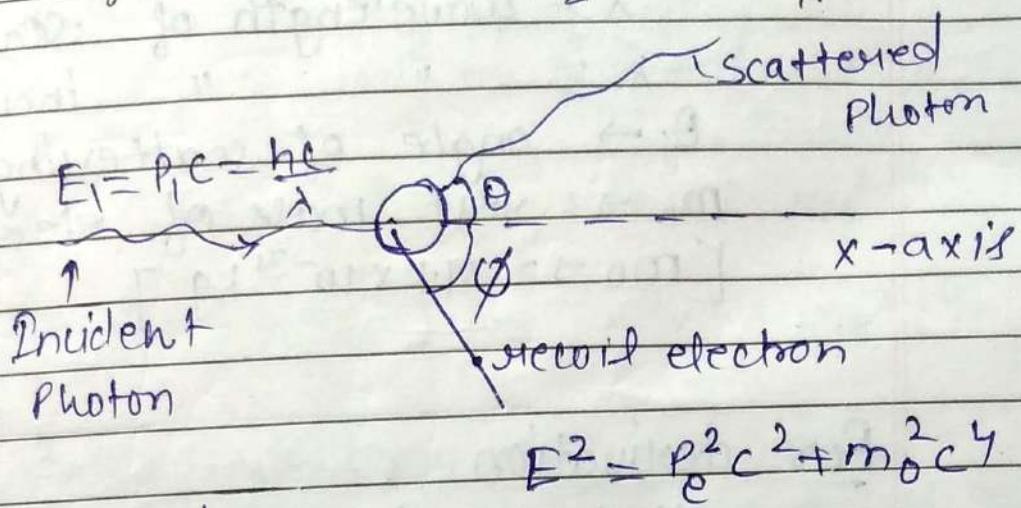
If $V < V_0$

$$h\nu < h\nu_0$$

$$\frac{1}{2}mv^2 = h\nu - h\nu_0$$

~~Imp.~~~~* Compton effect:~~

$$E_2 = p_2 c = \frac{hc}{\lambda'}$$



$$p_1 = \frac{h}{\lambda}, \quad p_2 = \frac{h}{\lambda'}$$

$E \rightarrow$ Total relativistic energy of electron

$$E^2 = p^2 c^2 + m_0^2 c^4$$

$E_0 = m_0 c^2 \rightarrow$ rest mass energy

$$E_K = (m - m_0)c^2 \rightarrow K.E \text{ of } e^-$$

→ when high energy ~~but~~ photon ($E > 0.5 \text{ MeV}$) is incident on a metal then the scattered photon contain not only the wavelength of incident photon but higher than the wavelength of incident photon. This phenomenon is known as Compton effect.

and the change in wave length is known as Compton shift. it is denoted by $\Delta \lambda$

$$\Delta \lambda = \lambda' - \lambda = \frac{h}{m_0 c} [1 - \cos \theta]$$

Where

λ' = wavelength of scattered photon

λ = " " incident photon

$\theta \rightarrow$ angle of scattering

$m_0 \rightarrow$ rest mass of electron

$[m_0 = 9.1 \times 10^{-31} \text{ kg}]$

for derivation

Apply the Conservation Law of $E \& P$

Applied conservation of momentum (P)

Along x axis:

$$P_1 + 0 = P_2 \cos\theta + p_e \cos\phi$$

$$P_1 - P_2 \cos\theta = p_e \cos\phi \quad \text{--- (a)}$$

Along y axis:

$$0 + 0 = P_2 \sin\theta - p_e \sin\phi$$

$$P_2 \sin\theta = p_e \sin\phi \quad \text{--- (b)}$$

By squaring and adding eq⁴ (a) and (b)

$$(P_1 - P_2 \cos\theta)^2 + P_2^2 \sin^2\theta = p_e^2 (\cos^2\phi + \sin^2\phi)$$

$$P_1^2 + P_2^2 \cos^2\theta - 2P_1 P_2 \cos\theta + P_2^2 \sin^2\theta = p_e^2$$

$$P_1^2 + P_2^2 - 2P_1 P_2 \cos\theta = p_e^2 \quad \text{--- (c)}$$

by Applying conservation of Energy

$$P_1 c + m_0 c^2 = P_2 c + \sqrt{P_e^2 c^2 + m_0^2 c^4}$$

$$(P_1 c - P_2 c) + m_0 c^2 = \sqrt{P_e^2 c^2 + m_0^2 c^4}$$

$$\left((P_1 - P_2) c + m_0 c^2 \right)^2 = P_e^2 c^2 + m_0^2 c^4$$

$$(P_1 - P_2)^2 c^2 + m_0^2 c^4 + 2(P_1 - P_2) m_0 c^3 = P_e^2 c^2 + m_0^2 c^4$$

$$(P_1 - P_2)^2 + 2(P_1 - P_2) m_0 c = P_e^2$$

$$P_1^2 + P_2^2 + 2P_1 P_2 + 2(P_1 - P_2) m_0 c = P_e^2 \quad \text{--- (2)}$$

by equating eqⁿ (1) and (2)

$$P_1^2 + P_2^2 + 2P_1 P_2 + 2(P_1 - P_2) m_0 c = P_1^2 + P_2^2 - 2P_1 P_2 \cos\theta$$

$$P_1 P_2 (1 - \cos\theta) = (P_1 - P_2) m_0 c \quad \text{--- (3)}$$

$$P_1 = \frac{h}{\lambda} \quad P_2 = \frac{h}{\lambda'}$$

$$\frac{hh}{\lambda\lambda'} [1 - \cos\theta] = \frac{h}{\lambda\lambda'} (\lambda' - \lambda) m_0 c$$

$$\lambda' - \lambda = \frac{h}{m_0 c} (1 - \cos\theta).$$

Conclusions :

(i) Compton shift depends on angle of scattering of photon.

$$\text{if } \theta = 0$$

$$\Delta\lambda = \lambda' - \lambda = 0$$

$$\lambda' = \lambda$$

there is no scattering along the direction of incident photon.

Doubt

(ii) When $\theta = 90^\circ$

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_0 c} [1 - \cos 90^\circ]$$

$$\lambda' - \lambda = \frac{h}{m_0 c} = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 3 \times 10^8}$$

$$\Delta\lambda = \lambda' - \lambda = 0.0243 \text{ Å}$$

✓ Compton wavelength $\rightarrow \lambda_c$

$$\lambda_c = 0.0243 \text{ Å}$$

Doubt
(iii)

when $\theta = 180^\circ$

$$\Delta\lambda_{\max} = \lambda' - \lambda = \frac{2h}{m_0 c}$$

$$\Delta\lambda_{\max} = 0.0486 \text{ Å}$$

* Direction of Recoil electron: (ϕ) \Rightarrow
By using eqn ④ and ⑤

$$P_1 - P_2 \cos \theta = P_e \cos \phi \quad \text{--- ④}$$

$$P_2 \sin \theta = P_e \sin \phi \quad \text{--- ⑤}$$

divide eqn ⑤ by ④

$$\tan \phi = \frac{P_2 \sin \theta}{P_1 - P_2 \cos \theta} = \frac{\frac{h}{\lambda'} \sin \theta}{\frac{h}{\lambda} - \frac{h}{\lambda} \cos \theta}$$

$$\boxed{\tan \phi = \frac{\lambda' \sin \theta}{\lambda' - \lambda \cos \theta}}$$

$$\lambda' - \lambda = \frac{h}{m_0 c} [1 - \cos \theta]$$

$$\lambda' - \lambda = \frac{2h \sin^2 \theta / 2}{m_0 c}$$

$$\tan \phi = \frac{2 \lambda \sin \theta / 2 \cos \theta / 2}{\lambda + \frac{2h}{m_0 c} \sin^2 \theta / 2 - \lambda (1 - 2 \sin^2 \theta / 2)}$$

$$= \frac{\lambda \sin \theta / 2 \cos \theta / 2}{\left[\frac{h}{m_0 c} + \lambda \right] \sin^2 \theta / 2}$$

$$\boxed{\tan \phi = \frac{\lambda \cot \theta / 2}{\lambda + \frac{h}{m_0 c}}}$$

T-Problems

- Q.1 X-Rays of wavelength 0.10 \AA° are scattered from a target.
- Find the wavelength of X-ray scattered through 45°
 - Find the max wavelength present in the scattered X-Rays.
 - Find the max. KE of the recoil e^\ominus

Solⁿ: Given = $\lambda = 0.10 \text{ \AA}^\circ$
 $\theta = 45^\circ$

(a)

$$\Delta\lambda = \lambda' - \lambda = \frac{h}{m_0 c} (1 - \cos\theta)$$

$$\lambda' = 0.0243 \left(1 - \cos 45^\circ\right) + 0.10 \text{ \AA}^\circ$$

$$\lambda' = 0.0243 \left(1 - \frac{1}{\sqrt{2}}\right) + 0.10 \text{ \AA}^\circ$$

$$\lambda' = 0.0243 \times \frac{0.414}{\sqrt{2}} + 0.10 \times 10^{-10}$$

$$\lambda' = 0.107 \text{ \AA}^\circ$$

$$(ii) \lambda'_{\max} = \lambda' - \lambda = \frac{h}{m_0 c} (1 - \cos 180^\circ)$$

$$\lambda'_{\max} = 0.0486 \times 10^{-10} + 0.10 \times 10^{-10}$$

$$= 0.148 \text{ \AA}^\circ$$

$$(iii) \text{KE of recoil } e^\ominus = E_1 - E_2$$

$$= \frac{hc}{\lambda} - \frac{hc}{\lambda'} = hc \left(\frac{\lambda' - \lambda}{\lambda \lambda'} \right)$$

$$= 6.63 \times 10^{-34} \times 3 \times 10^8 \left[\frac{0.107 \times 10^{-16} - 0.10 \times 10^{-16}}{0.10 \times 10^{-10} \times 0.107 \times 10^{-10}} \right]$$

$$= 6.63 \times 10^{-34} \times 3 \times 10^8 \left[\frac{0.107 - 0.10}{0.10 \times 0.107 \times 10^{-10}} \right]$$

$$= 19.89 \times 10^{-26} \left[\frac{0.007}{0.0107} \times 10^{-10} \right]$$

$$= \frac{19.89 \times 0.007}{0.0107} \times 10^{-16}$$

$$= 6.54 \times 10^{-15}$$

* K.E of recoil electron in Compton effect :

The K.E of recoil electron is always less than $\frac{1}{2}$ which shows that some photon always scattered

K.E = Energy of Incident photon - Energy of Scattered photon

$$= E_1 - E_2$$

$$K.E = \frac{hc}{\lambda} - \frac{hc}{\lambda'}$$

$$\therefore \lambda' - \lambda = \frac{h}{m_0 c} (1 - \cos \theta)$$

$$K.E = \frac{hc}{\lambda \lambda'} (\lambda' - \lambda)$$

$$K.E = \frac{hc}{\lambda \lambda'} \left[\frac{h}{m_0 c} \right] (1 - \cos \theta)$$

$$= \frac{hc}{\lambda \lambda'} \left[\frac{h}{m_0 c} \times 2 \sin^2 \theta/2 \right]$$

$$= \frac{2h^2}{\lambda \lambda'} \sin^2 \theta/2$$

$$K.E = \frac{2h^2 \sin^2 \theta/2}{\lambda (\lambda + \frac{2h}{m_0 c} \sin^2 \theta/2)}$$

$$K.E = \frac{hc}{\lambda^2} \left[\frac{2h/m_0 c \lambda \times \sin^2 \theta/2}{1 + \frac{2h}{m_0 c \lambda} \sin^2 \theta/2} \right]$$

for maximum

$$\sin \theta/2 = 1$$

$$K.E = \theta = 180^\circ$$

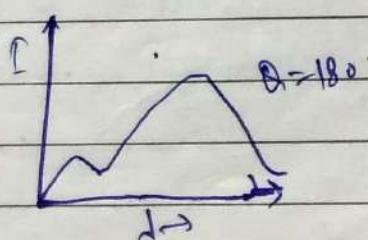
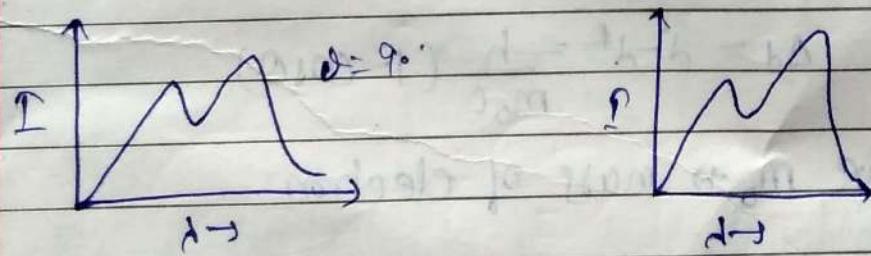
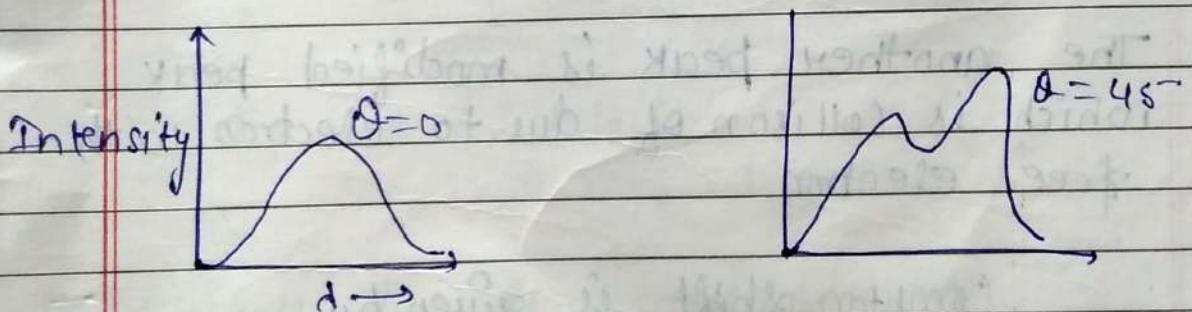
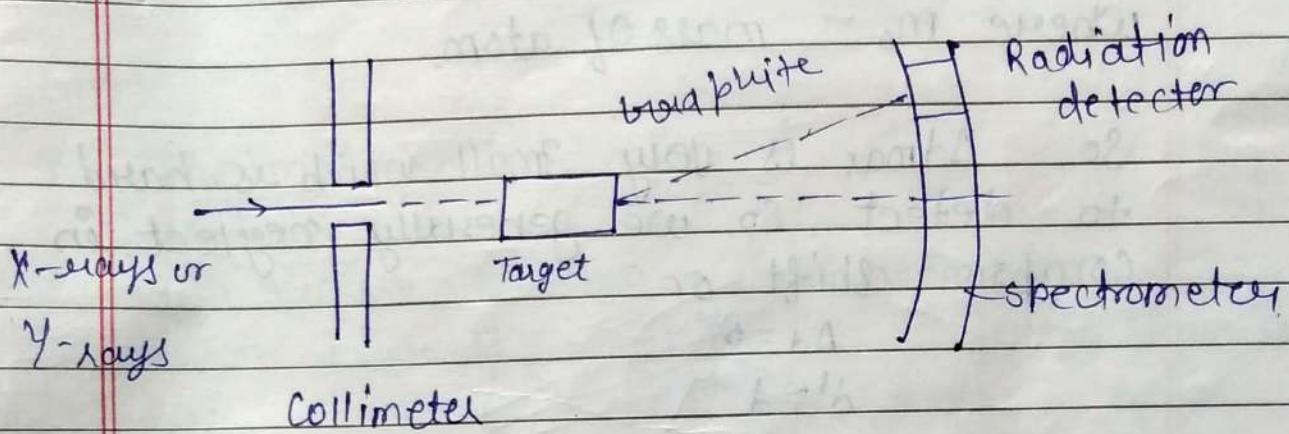
$$\text{let } \frac{h}{m_0 c \lambda} = x$$

$$K.E = \frac{hc}{\lambda} \left[\frac{2\alpha}{1+2\alpha} \right]$$

$$\therefore KE < I$$

* Experimental verification of Compton effect.

Presence of unmodified radiation with modified radiation in Compton effect.



ii) In Compton radiation in polar diagram we get two peak in which one is unmodified peak which is due to collision of photon with bound electron

Part unmodified peak

$$\Delta d = d - d' = \frac{h}{m_0 c} [1 - \cos \theta]$$

where m_0 - mass of atom.

So, Δd_{max} is very small which is hard to detect, so, we generally neglect in Compton shift or

$$\Delta d = 0$$

$$d' = d$$

ii) The another peak is modified peak which is collision of due to electron with free electron.

Compton shift is given by

$$\Delta d = d - d' = \frac{h}{m_e c} (1 - \cos \theta)$$

where $m_e \rightarrow$ mass of electron

and its maximum value is Δd_{\max} which is detectable and cannot be neglected.

$$\Delta d_{\max} = 0.0486 \text{ nm}$$

Compton shift is not visible in visible light
 4.86×10^{-5}

$$= \frac{0.0486}{2044} \approx -0.00024 = 0.0069$$

28/08/18

* Thermal Radiation:

Newton's Law of Cooling:

It is applicable when there is small temp. diff.

b/w obj. & surround. $E = \sigma T^4$ — Perfectly black body
 Engs. $E = \sigma e T^4$ → normal object

$$E = \sigma e [T - T_0]$$

$T - T_0 \Rightarrow$ Temp. difference

* Kirchoff's Law of Thermal Radiations:

$$E_\lambda = \frac{e_\lambda}{a_\lambda}$$

$E_\lambda \Rightarrow$ Emissivity of Perfectly black body.

$e_\lambda \Rightarrow$ Emissivity of normal body

$a_\lambda \Rightarrow$ absorptivity " " "

→ The ratio of Emissive Power to absorptive Power of any Body at a particular temp and for a given wavelength of light is equal to the emissive Power of Perfectly black body.

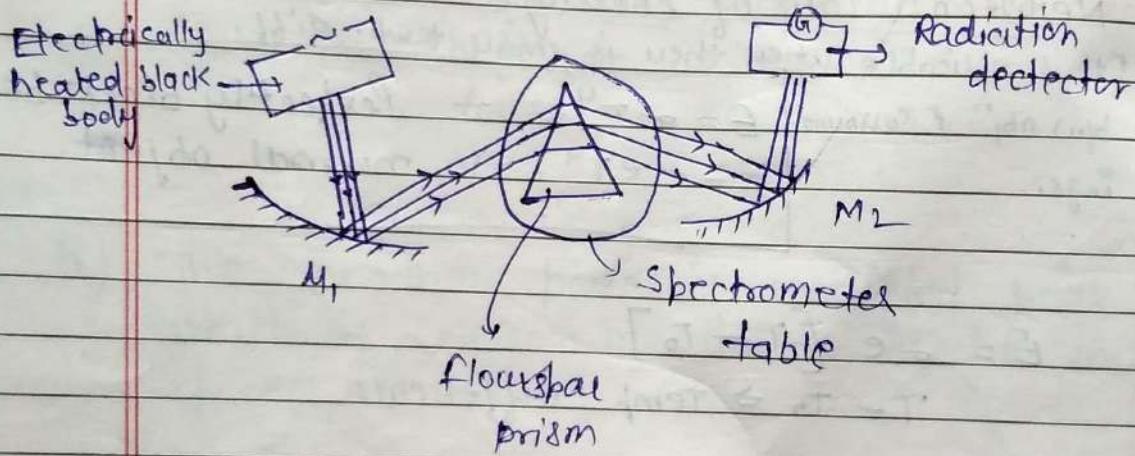
As we know that

$$\boxed{e_A = \alpha_A}$$

(1)

Expt:

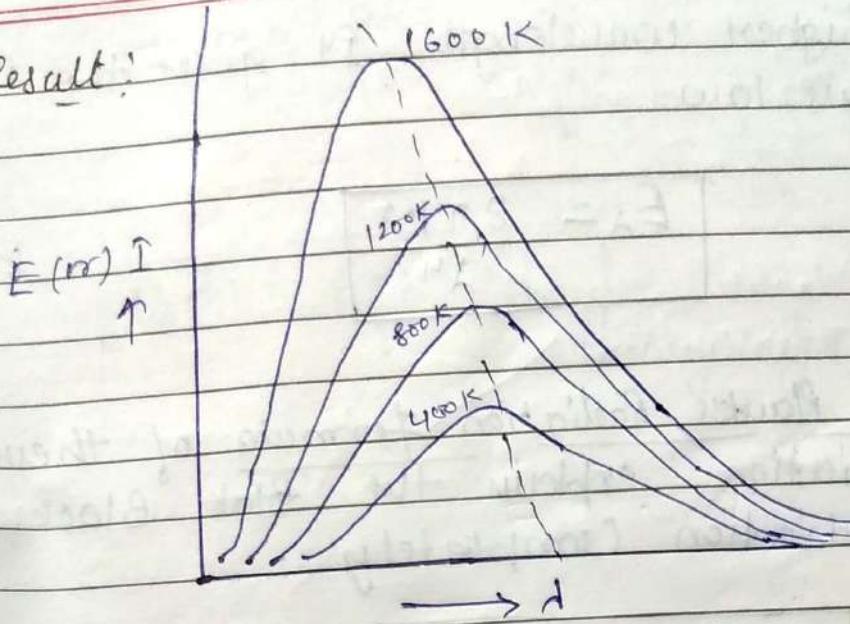
* Black Body Radiation spectrum:



$M_1 \& M_2 \rightarrow$ convex mirror

Experimental set up.

Result:



- (i) from the graph it is clear that Energy is not uniformly distributed at a particular temp.
- (ii) At a particular temp. the area under the curve gives the total energy radiated per second at that particular wavelength and it is given by Stephan's law

$$E \propto T^4 \Rightarrow E = \sigma T^4$$

- (iii) At a particular temp. the maximum Energy As we change the temp. the maximum Energy Shifts towards the lower wavelength. which is given by

$$\lambda_m \cdot T = \text{constant}$$

+ Wein's Law

1) for higher wavelength, it gives the Rayleigh-Jeans law

$$E_\lambda = \frac{8\pi kT}{\lambda^4}$$

$$E_\lambda = U_\lambda$$

→ The Planck's Radiation formula of thermal radiation explain the Black Body radiation completely.

$$U_{\lambda d\lambda} = \frac{8\pi h c}{\lambda^5} \frac{d\lambda}{e^{hc/\lambda KT} - 1}$$

energy density

For Lower wavelength or shorter wavelength
 $\lambda \ll 1$ $e^{hc/\lambda KT} \gg 1$

$$U_{\lambda d\lambda} = \frac{8\pi h c}{\lambda^5} \times e^{-hc/\lambda KT} d\lambda$$

by calculating the integral of last eqn
it gives the Wien's law of thermal radiation

For higher wavelength:

$$e^{-hc/\lambda KT} = 1 + \frac{hc}{\lambda KT} + \dots$$

$$U_d \lambda = \frac{8\pi hc}{\lambda^4} \frac{d\lambda}{\left[1 + \frac{hc}{\lambda RT} + \dots \right]}$$

$$U_d \lambda = \frac{8\pi k T}{\lambda^4} d\lambda$$

Rayleigh Jean's law.
To make

VM

Wave Mechanics

(*) Duality principle:

Light
EM radiation

photo electric effect / Particles
Compton effect / Particles

Interference] - wave
diffraction
Polarization] - wave

→ Light sometime behave as a Particle and
Same time as a wave which shows
the dual nature of light and it is
also known as Duality principle.

• de Broglie wave / Matter wave (or) de Broglie wavelength :

de Broglie extending duality principle for
show all macroscopic as well as microscopic
particle.

- Acc. to de Broglie a material Particle
in motion has a wave associated
with it and the wavelength of this
wave is given by

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

$\lambda \rightarrow$ de Broglie wavelength

$P \rightarrow$ momentum of particle

$m \rightarrow$ mass of particle

$v \rightarrow$ velocity of particle.

• Different forms of de Broglie wavelength

(i) If K.E of a free particle is given.

$$\begin{aligned} E &= E_K \\ &= \frac{1}{2} \frac{mv^2}{m} \cdot m \\ &= \frac{1}{2} \frac{(mv)^2}{m} \\ &= \frac{1}{2} \frac{p^2}{m} = \frac{p^2}{2m} - \textcircled{A} E \end{aligned}$$

$$P = \sqrt{2mE}$$

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

(ii) if a particle is accelerated with Potential difference of V volt.

$$E_K = qV$$

$q \rightarrow$ charge of particle

$$\frac{p^2}{2m} = qV$$

$$P = \sqrt{2mqV}$$

$$\lambda = \frac{h}{P} = \frac{h}{\sqrt{2mqV}}$$

Viii) If Particle in thermal equilibrium:

$$E_K = \frac{3}{2} K_B T$$

$K_B \rightarrow$ Boltzmann Constant
 $T \rightarrow$ absolute temp. (K)

$$\frac{P^2}{2m} = \frac{3}{2} K_B T$$

$$P = \sqrt{3m K_B T}$$

$$\boxed{\lambda = \frac{h}{\sqrt{3m K_B T}}}$$

(iv) Relativistic form of de-Broglie wavelength

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

If Particle is moving near about velocity of light

$$m = m_0$$

$$\sqrt{1 - v^2/c^2}$$

$$\lambda = \frac{h \sqrt{1 - v^2/c^2}}{m_0 v}$$

* Detection of matter waves:

(i) For macroscopic Particle / bodies:

Let us consider a ball of mass 10 gm is moving with velocity 10 m/s the

de Broglie wavelength associated with ball

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{10 \times 10^{-3} \times 10} = 6.63 \times 10^{-33} \text{ m}$$

It is a very small value it can which can not be measurable.

(ii) for microscopic particle:

Let an e^- is moving with velocity 10^5 m/s the de Broglie wavelength associated with e^-

$$\lambda = \frac{h}{p} = \frac{h}{mv} = \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31} \times 10^5} \\ \lambda \approx 6.6 \times 10^{-9} \text{ m}$$

It is measurable

From above two cases it is clear that in case of macroscopic particle de Broglie wavelength has very small value which can be neglect.

* Properties of matter waves:

- (1) $\lambda = \frac{h}{p} = \frac{h}{mv}$ if $v = 0$
 $\lambda \rightarrow \infty$

It shows that matter waves always associated with moving particles

(ii) matter waves can be generate by charge or uncharge particle.

(iii) It is neutral in nature.

(iv) Velocity of matter waves depends on the velocity of matter particle

(v) matter waves are not Electromagnetic waves

a) matter waves are neutral in nature whereas E.M waves generate from the charge particle

b) Velocity of matter waves depends on the velocity of particle whereas E.M waves have diff. velocity in diff. medium.

c) Velocity of E.M waves is equal to c whereas the velocity of matter waves is always greater than c.

(vi) Velocity of matter waves is greater than the velocity of light.

$$\lambda = \frac{h}{p} = \frac{h}{mv} \quad (i)$$

$$v_p = \nu \cdot h \quad (A)$$

$$E = h\nu$$

$$E = mc^2$$

$$mc^2 = \hbar\nu$$

$$\nu = \frac{mc^2}{\hbar} \quad \text{(ii)}$$

$\lambda \propto V \rightarrow \text{(i)} \& \text{(ii)} \rightarrow A$

$$V_p = \frac{mc^2}{\hbar} \cdot \frac{\hbar}{mv}$$

$$= V_p = \frac{c^2}{V}$$

$$V \ll c$$

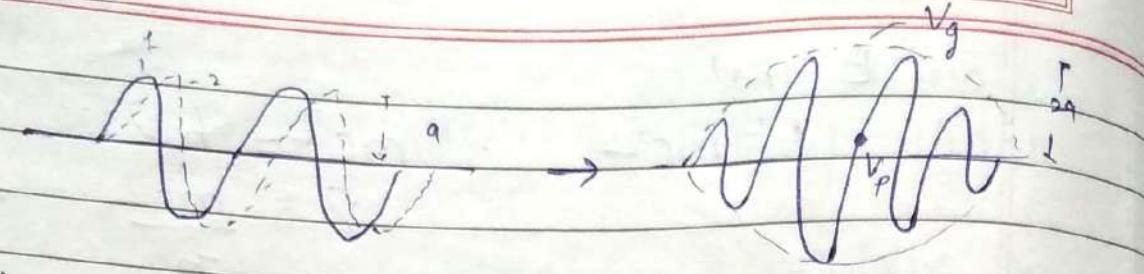
matter waves

$$V_p > c$$

To solve this contradiction Schrödinger gives the concept of wave packet acc. to which a moving particle is always associated with a group of wave whose velocity is known as velocity of group wave.

* Wave packets:

wave packet is a group of wave having slightly diff. frequencies and wave length but their phase and Amplitude are such that they interfere constructively over a small region of space where the particle can be located. Outside of the region they interfere distractively and Amplitude reduce to zero



* Expression of group velocity and phase velocity
 let us consider a wave packet is consist of two waves of having same anti amplitude but slightly diff angular velocity ω_1 and ω_2 and wave vector k_1 and k_2

$$K_1 = \frac{2\pi}{\lambda}$$

The displacement of each wave is given by

$$y_1 = a \sin(\omega_1 t - k_1 x)$$

$$y_2 = a \sin(\omega_2 t - k_2 x)$$

the resultant displacement

$$Y = y_1 + y_2$$

$$= a [\sin(\omega_1 t - k_1 x) + \sin(\omega_2 t - k_2 x)]$$

$$= 2a \left[\sin \left[\left(\frac{\omega_1 + \omega_2}{2} \right) t - \left(\frac{k_1 + k_2}{2} \right) x \right] \cos \left[\left(\frac{\omega_1 - \omega_2}{2} \right) t - \left(\frac{k_1 - k_2}{2} \right) x \right] \right]$$

$$y = 2a \cos \left[\left(\frac{\omega_1 - \omega_2}{2} \right) t - \left(\frac{k_1 + k_2}{2} \right) x \right] \sin \left[\left(\frac{\omega_1 + \omega_2}{2} \right) t - \left(\frac{k_1 - k_2}{2} \right) x \right]$$

modified amplitude.

Let us consider

$$\frac{\omega_1 - \omega_2}{2} = \Delta\omega$$

$$\frac{k_1 - k_2}{2} = \Delta k$$

$$\frac{\omega_1 + \omega_2}{2} = \bar{\omega} \quad \frac{k_1 + k_2}{2} = \bar{k}$$

$$y = 2a \cos [\Delta\omega t - \Delta k x] \sin (\bar{\omega}t - \bar{k}x)$$

Now for group velocity $\Delta\omega t - \Delta k x = 0$

$$V_g \Rightarrow \frac{\omega}{t} = \frac{\Delta\omega}{\Delta k}$$

if wave packet is consist of more than 2 waves then

$$\Delta\omega = d\omega, \Delta k = d\bar{k}$$

$$V_g = \frac{d\omega}{d\bar{k}}$$

$V_g \rightarrow$ group velocity.

For phase velocity $\omega t - kx = 0$

$$\frac{\omega}{t} = \frac{\omega}{k} \rightarrow \text{average of all the angular velocity}$$

\hookrightarrow average of all the wave vector

$$V_p = \frac{\omega}{k}$$

Phase Velocity.

* group Velocity:

It is the velocity with which over all the shapes of the wave amplitude known as modulation or at which the wave packet moves in the space

It is denoted by v_g .

$$v_g = \frac{dw}{dk} \quad (1)$$

* Phase velocity:

The average velocity of monochromatic individual waves in the medium within in the wave packet is known as phase velocity

It is denoted by v_p

$$v_p = \frac{\omega}{k}$$

* Relation b/w group velocity and phase velocity

$$\text{As } v_g = \frac{dw}{dk} \neq v_p = \frac{\omega}{k}$$

$$v_g = \frac{d}{dw} [v_p \cdot k]$$

$$v_g = v_p + k \frac{dv_p}{dk} \quad \text{--- (1)}$$

$$\lambda = \frac{c}{\omega} = \frac{2\pi d}{\lambda}$$

$$V_g = V_p - \frac{\lambda d V_p}{d \lambda}$$

(i) if velocity of wave depends on the wavelength

then

$$V_g < V_p$$

(ii) if velocity does not depend on λ

then

$$V_g = V_p$$

Hypothetical case

* Relation b/w group velocity and particle velocity.

$$V_g = \frac{d\omega}{dk}$$

$$= \frac{d(E/\hbar)}{d(P/\hbar)}$$



$$E = \hbar v$$

$$= \frac{\hbar \cdot \omega}{2\pi}$$

$$E = \hbar \omega$$

$$\textcircled{B} \quad E = \frac{P^2}{2m}$$

$$V_g = \frac{dE}{dp}$$



$$P = \hbar k$$

$$P = \frac{\hbar}{2\pi} \cdot k$$

Linear non-relativistic Particle

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

$$E = \frac{p^2}{2m}$$

$$dE = \frac{dp}{dm} dp$$

$$\frac{dE}{dp} = \frac{p}{m} = \frac{mv}{m} \rightarrow \text{D}$$

$$\frac{dE}{dp} = v$$

$$\boxed{Vg = V}$$

(ii) Relativistic Case:

$$E^2 = p^2c^2 + m_0^2c^4$$

$$dE dE = 2pc^2 dp + 0$$

$$\frac{dE}{dp} = \frac{pc^2}{E}$$

$$P = mv = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}} v$$

$$\frac{dE}{dp} = \frac{p c^2}{E} = \frac{mv c^2}{mc^2}$$

$$\frac{dE}{dp} = v \quad \boxed{Vg = V}$$

$$E^2 = p_e^2 c^2 + m_0^2 c^4$$

DATE: / 20
PAGE No:

→ What is the phase velocity of a non relativistic free particle.

$$V_g = V$$

$$V_p - \frac{d\phi}{dt} \frac{dp}{d\lambda} = V$$

$$V_p = \frac{c^2}{\lambda}$$

$$V_p = V + \frac{d\phi}{dt} \frac{dp}{d\lambda}$$

$$V_p = \frac{V}{2} \text{ or } V_g/2$$

$$V_p = V \cdot \lambda$$

$$= \frac{\omega}{\lambda} \text{ (from)}$$

$$\frac{1}{2}mv^2 = h\nu \quad \frac{h\nu}{\lambda} = \frac{mc^2}{\lambda}$$

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

$$V_g = V$$

$$= \frac{\omega \cdot \lambda}{2\pi} = \frac{\omega}{\lambda} - \frac{\omega}{2\pi}$$

$$\frac{h\nu}{\lambda} = \frac{mc^2}{\lambda}$$

$$V_p = V \cdot \lambda$$

$$V_p = \frac{1}{2}mv^2 \cdot \lambda$$

$$\frac{1}{2}mv^2 = \frac{c}{\lambda}$$

$$\frac{mv^2}{\lambda} = V$$

$$V_g = V$$

$$E = \hbar\omega : \omega = \frac{E}{\hbar}$$

$$V_p = \frac{E \cdot \frac{h}{\lambda}}{\hbar \cdot \rho} = \frac{E}{\rho} = \frac{E}{\rho}$$

$$\frac{E}{\rho} = \frac{p_e^2/2m}{\rho} = \frac{p_e^2}{2m} = \frac{mv^2}{2m} = \frac{V}{2}$$

$$V_p = \frac{V}{2} = \frac{V_g}{2}$$

Ques.

The Photo electric threshold wavelength of

A is 5000 A° . Find

- the value of work function in eV
- K.E of the photo electrons in eV is altered by wavelength 4000 A° .

Soln.

$$\lambda_0 = 5000 \text{ A}^\circ$$

$$E = [h\nu_0] + K.E.$$

$$W = h\nu_0 \quad \nu_0 =$$

$$= \frac{h\nu}{\lambda_0} = \frac{h\nu}{\lambda_0}$$

$$= \frac{6.62 \times 3 \times 10^{-34}}{5000 \times 10^{-70}}$$

$$= 6.62 \times 3 \times 10^{-16}$$

$$= \frac{19.86 \times 10^{-19}}{5}$$

$$= 3.97 \times 10^{-19}$$

$$= \frac{19.86 \times 10^{-19}}{3.97}$$

$$\text{in } e^\Theta \text{ volt: } \frac{3.97 \times 10^{-19}}{1.6 \times 10^{-19}} = \frac{3.97}{160} = \frac{397}{160}$$

$$= 2.47 \text{ volt}$$

$$K.E. = h\nu$$

$$K.E. = W + K.E.$$

$$\frac{19.86 \times 10^{-19}}{5000 \times 10^{-70}} - 2.47 = K.E.$$

$$\frac{19.86 \times 10^{-19}}{5 \times 10^{-9}} = 3.97 \times 10^{-10} = 3.$$

$$\frac{19.86 \times 10^{-16}}{4500 \times 10^{12}} = 2.4 \approx 1.1$$

$$\frac{-16 \times 10^{-13}}{-19 \times 10} = 19.86 \times 10^{-9} - 2.4 = 1.8$$

$$\frac{4.96 \times 10^{-9}}{1.6 \times 10^{-9}} = \frac{4.96}{1.6} = \frac{4.96}{1.6} = 3.1$$

$$\frac{4.96 \times 10^{-9}}{1.6 \times 10^{-9}} = 3.1 - 2.4 = 0.76 = 0.31$$

(2)

In a photo electric emission from a given target the velocity of emitted electrons is 1×10^6 m/s then light of wave length 2.5×10^{-7} m is used.

- Calculate
- velocity of emitted electrons with light of wavelength 5×10^{-7}
 - work function of photo cell cathode in ev.

$$v_e = 1 \times 10^6, \lambda = 2.5 \times 10^{-7}$$

$$\boxed{v_e = 3.16 \times 10^6 \text{ m/s}}$$

$$\frac{1}{2} m v_e^2 = h v_2 - h v_0$$

$$\frac{1}{2} m v_2^2 = h v_2 - h v_0$$

$$\begin{aligned} E_{h.v} &= h v_0 - h v_2 \\ h v_2 &= h v_0 - E_{h.v} \end{aligned}$$

$$\frac{1}{2} m (v_1^2 - v_2^2) = h (v_1 - v_2)$$

$$E = \frac{1}{2} m v^2$$

$$\frac{1}{2} \times 9.1 \times 10^{-31} (10^6 - v_2^2) = 6.63 \times 10^{-34} (0.6 \times 10^{18})$$

$$v_2^2 = 10^6 - 8.19 \times 10^{13}$$

~~stn~~

In rough
1.3

Q. the work function of K is φ ev
 then when U.V light of $\lambda = 3500 \text{ Å}^{\circ}$
 falls on K Surface calculate the
 maximum K.E of emitted K .
 in ev

$$\omega = \varphi \text{ ev.}$$

$$\lambda = 3500 \text{ Å}^{\circ}$$

$$\frac{hc}{\lambda} - \omega = KE.$$

$$\text{Conv. } \frac{6}{\text{in ev.}} \frac{19.86}{3500 \times 10^{-10}} - 2 \text{ ev} = KE$$

Q. Calculate the de Broglie wavelength associated
 with an e^- of K.E 4.55 ev

$$d = \frac{h}{p} \quad \frac{p^2}{qm} = 4.55 \text{ eV}$$

$$p^2 = 2 \times 4.55 \times m$$

$$d = 6.6 \quad p^2 = 9.00 \text{ eV}$$

$$p^2 = 9 \times 9.1 \times 10^{-31}$$

$$= 81.9 \times 10^{-31}$$

$$= \frac{81.9 \times 10^{-31}}{1.6 \times 10^{-19}}$$

$$= \frac{81.9}{16} \times 10^{-12}$$

$$= 51.1 \times 10^{-12} \text{ eV.}$$

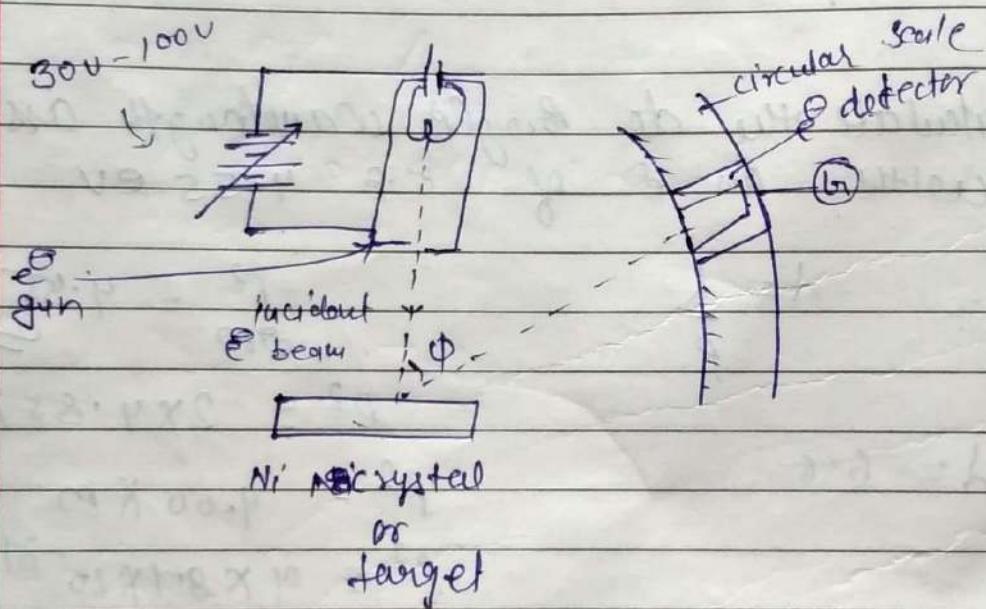
Q. A proton and an α are during the same K.E how do their de-Broglie wave length.

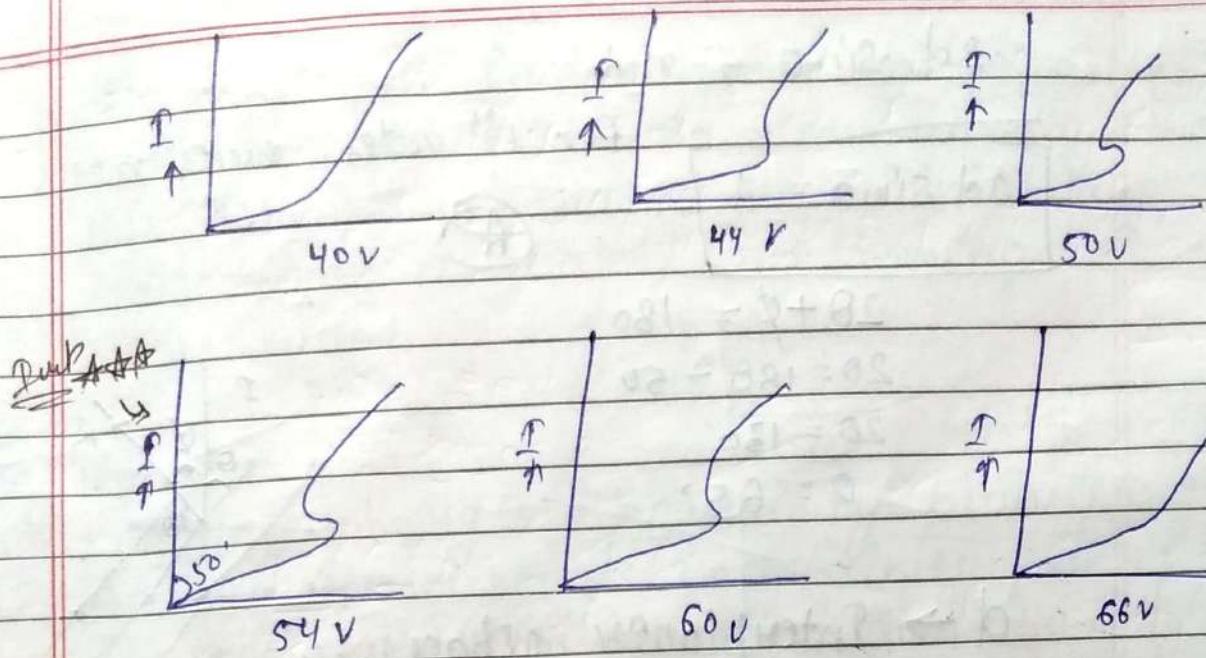
$$d = \frac{h}{p} = d = \frac{h}{mv}$$

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

* Experimental Verification of matter waves:
by

~~Dmp~~ Davission Daymer Experiment.





Polar diagrams

- the polar curves only explain if we assume that there is always wave associated with the electron.
- At low voltage (40V) there is a smooth curve b/w current and angle of scattering of electron.
- By increasing the voltage there is deflection in smoothness of curve which is due to association of matter waves with e.
- this deviation or deflection is most less at 54 volt and scattering angle of 50°
- By using the Bragg's equation of x-ray diffraction

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

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

for 1st order when $n=1$

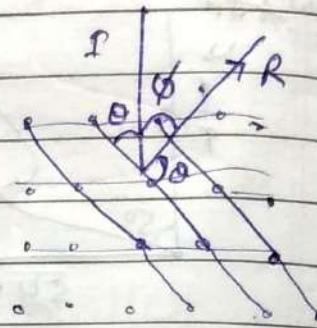
(A)

$$2\theta + \phi = 180^\circ$$

$$2\theta = 180^\circ - 50^\circ$$

$$2\theta = 130^\circ$$

$$\theta = 65^\circ$$



$d \rightarrow$ Interplanar spaces.

For Ni crystal $d = 0.91 \text{ \AA}$

From eqn (A)

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

$$\lambda = 0.91 \times 10^{-10} \times \sin 65^\circ = \lambda$$

$$\lambda \approx 1.65 \text{ \AA}$$

why de-Broglie wavelength of matter waves

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

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

$$V = 54 \text{ Volt}$$

$$\lambda = \frac{6.63 \times 10^{-34}}{\sqrt{2 \times 9.11 \times 10^{-31} \times 1.67 \times 10^{-19} \times 54}}$$

$$\lambda \approx 1.67 \text{ \AA}$$

the wavelength coming from eqn A and B are nearly equal so, we can say that our assumption that there is always some value associated with moving object are correct.

~~Statement~~

Uncertainty

~~QMP~~ With Heisenberg's Uncertainty principle
 Acc. to Heisenberg's uncertainty principle if it is impossible to determine simultaneously the exact position and momentum of a particle. there is always some uncertainty either in the value of momentum or position.

→ If $\Delta p \rightarrow$ uncertainty in momentum
 $\Delta x \rightarrow$ " " Position

then

$$\Delta p \cdot \Delta x = \frac{\hbar}{2} \quad \text{or} \quad > \frac{\hbar}{2}$$

$$\boxed{\begin{aligned} \Delta p_x \cdot \Delta x &= \frac{\hbar}{2} \\ \Delta p_y \cdot \Delta x &= 0 \end{aligned}} \quad (R)$$

$$\frac{\hbar}{2\pi} = \frac{h}{2\pi} \approx 1.05 \times 10^{-34} \text{ J sec}$$

use for Num. - C

$$\Delta E \cdot \Delta t = \frac{\hbar}{2}$$

$$\Delta J \cdot \Delta \theta = \frac{\hbar}{2}$$

$\Delta E \rightarrow$ uncertainty in Energy

$\Delta t \rightarrow$ uncer. " time

$\Delta J \rightarrow$ " " Angular momentum.

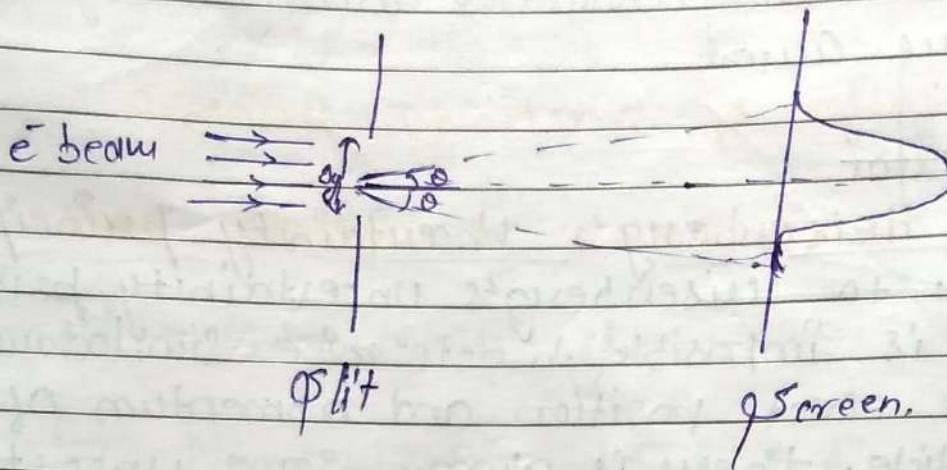
$\Delta \theta \rightarrow$ " " Angle.

T.S is chemically conjugate.

DATE: / 20

PAGE No

- * Experimental illustration of uncertainty principle:
by e^- diffraction!



→ the maximum uncertainty in the position of e^- at the slit = Δy (width of slit)

$$e \sin \theta = d$$

By first order differentiation

$$\Delta y \sin \theta = d$$

$$\Delta y = \frac{d}{\sin \theta} \quad \text{--- (1)}$$

→ Uncertainty in momentum:

$$\Delta p_y = 2p \sin \theta$$

$$\Delta p_y = \frac{2h}{\lambda} \sin \theta \quad \text{--- (2)}$$

$$\Delta y \cdot \Delta p_y = \frac{d}{\sin \theta} \cdot \frac{2h}{\lambda} \sin \theta = \Delta h$$

$$\text{Radius} = 1\text{ fm} \approx 1 \times 10^{-15}\text{ m}$$

DATE: / 20
PAGE No

$$\Delta y \cdot \Delta p_y = \alpha h$$

$$\Delta y \cdot \Delta p_y > \frac{\hbar}{2} \text{ or } \geq \frac{\hbar}{2}$$

* Application of Uncertainty principle:

1. ~~e⁻ can not reside inside the nucleus.~~ ^{Imp}
2. Energy of e⁻ in a potential box.
3. Finite width of spectral lines.
4. Binding energy of H atom
5. " " " atom.
6. " " " Harmonic Oscillation ^(y, t, ω)

~~e⁻ can not reside inside the nucleus.~~

Let us assume that e⁻ resides inside the nucleus

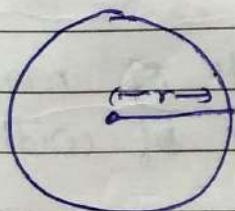
radius of any nucleus of an atom $\approx 10^{-14}\text{ m}$.

the maximum uncertainty in position of e⁻ inside the nucleus $= \Delta x_{\text{max}} = 2 \times 10^{-14}\text{ m}$ — (1)

From uncertainty principle

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

$$\Delta P_{\text{min}} = \frac{\hbar}{\Delta x_{\text{max}}}$$



$$E_0 = m_0 c^2 \\ = 0.51 \text{ MeV}$$

$$\Delta P = \frac{\hbar}{2 \times 10^{-14}} = 1.05 \times 10^{-34}$$

$$\Delta P_{\min} = 5.275 \times 10^{-21} \text{ kgm/sec} \quad -(ii)$$

From Relativistic total energy of e^- in terms of momentum

$$E^2 = p^2 c^2 + m_0^2 c^4 \\ = (5.275 \times 10^{-21})^2 (3 \times 10^8)^2 + (0.51)^2 (9.1 \times 10^{-31})^2 (3 \times 10^8)^4$$

2nd term have very small value
(So, Neglect)

$$E_{\min}^2 = p^2 c^2$$

$$E_{\min} = p c = 5.275 \times 10^{-21} \times 3 \times 10^8 = 9.8 \text{ MeV}$$

From experiment the maximum energy of an electron is 3-4 Mev. And according to our assumption minimum energy required to reside inside the nucleus should be 9.8 Mev, so our assumption is wrong.

Q. Energy of an e^- in a 1D Potential box:

Let us consider a particle of mass m exist in a potential box of width L

width of box = L

mass of particle = m

10^{-8} sec \rightarrow time.

Bohr radius = 0.53 Å

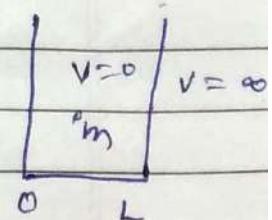
DATE: / 20

PAGE No

[E.]
[2]

According to uncertainty principle

$$\Delta p_{\min} \Delta x_{\max} = \frac{\hbar}{L} \quad \text{--- (1)}$$



$$\Delta x_{\max} = L$$

$$\Delta p_{\min} = \frac{\hbar}{L}$$

then total Energy of particle $E_{\min} = \frac{p^2}{2m}$

$E_{\min} = \frac{\hbar^2}{2mL^2}$

3. finite width of spectral line:
Acc. to uncertainty principle

$$\Delta E_{\min} \cdot \Delta t_{\max} = \frac{\hbar}{L}$$

$$\Delta t_{\max} = 10^{-8} \text{ sec.}$$

$$\Delta E_{\min} = \frac{\hbar}{10^{-8}} = 1.05 \times 10^{-26} \text{ Joule}$$

As energy has a finite value it shows that energy spectrum has finite width of each spectrum line.

4. Bohr's radius or binding energy of H atom:

Let us consider Δp and Δx_{\max} are the uncertainty in momentum and position of e^- in 1st orbit.

Acc. to uncertainty principle

$$\Delta P_{\min} \cdot \Delta x_{\max} = \hbar$$

$$\Delta P_{\min} = \frac{\hbar}{\Delta x_{\max}}$$

then the minimum total Energy of e^- in
1st orbit

$$E = K_R E_K + P.E$$

$$= \frac{p^2}{2m} - \frac{ze^2}{\Delta x}$$

$$E = \frac{\hbar^2}{8m \Delta x_{\max}^2} - \frac{ze^2}{\Delta x} \quad \rightarrow \textcircled{2}$$

For minimum or maximum value of E

$$\frac{dE}{dx} = 0, \quad \frac{d^2E}{dx^2} = +ve$$

Differentiate eqn $\textcircled{2}$ with respect to Δx
from eqn $\textcircled{2}$

$$\frac{dE}{dx} = \frac{-2\hbar^2}{8m \Delta x^3} - \frac{ze^2}{\Delta x^2} = 0$$

$$\frac{\hbar^2}{m \Delta x^2} = \frac{ze^2}{\Delta x^2} \Rightarrow$$

$$\Delta x = \frac{\hbar^2}{mze^2}$$

$$\Delta x = 0.53 \text{ Å}$$

it is Bohr's radius ~~cutis~~ which is the radius of 1st orbit for hydrogen atom and its value is 0.53 Å

$$\frac{d^2E}{d\Delta x^2} = \text{true.}$$

for

Binding Energy.

$$\frac{d^2E}{d\Delta x^2} = \frac{3\hbar^2}{m\Delta x^4} - \frac{ze^2}{\Delta x^3}$$

Subst. the value of Δx

$$\frac{d^2E}{d\Delta x^2} = \frac{3\hbar^2}{m \times (0.53\text{ Å})^4} - \frac{ze^2}{\Delta x^3}$$

$$= \frac{3 \times 1.05 \times 10^{-34}}{9.1 \times 10^{-31} (0.53\text{ Å})^4} - \frac{e \times 1 \times (1.6 \times 10^{-19})^2}{1}$$

$$= \text{true}$$

It shows that it is the minimum energy required for an e^- to bind with the ~~nucleus~~ nucleus of hydrogen atom.

$$\textcircled{Q} - \Delta E_{\min} = (1-15z) \text{ eV.}$$

for $n = 1$

$$E_{\text{min}} = (1 - 15) \text{ eV}$$

$$= 14 \text{ eV.}$$

* Binding Energy of an atom:

$$\frac{d^2E}{dx^2} = +ve$$

$$\frac{d^2E}{dx^2} = \frac{3\hbar^2}{m dx^4} - \frac{2ze^2}{dx^3}$$

Substitute $dx = \frac{\hbar^2}{m^2 e^2}$

$$= +ve$$

$$E_{\text{min}} = (1 - 15z) \text{ eV.}$$

* Binding Energy of Harmonic Oscillation:

26/09/18

* Wave function (ψ). Born's Explanation of wave function: $\Psi(r, t)$:

(a)

- (1) Wave function ~~for~~ is represented by $\Psi(r, t)$
- (2) It represents the state of particle at a particular time in a wave packet.
- (3) $\Psi(r, t)$ is a complex quantity, which has no physical significance
- (4) $\Psi(r, t) \times \Psi^*(r, t) = \text{Probability} \rightarrow (\text{Born's expl.})$

$\Psi^*(r, t)$ = Complex Conjugate of Ψ .

$$(5) \int_{-\infty}^{\infty} \Psi^* \Psi d\tau = 1 \quad \text{--- (1)}$$

when we calculate the Probability of in Complete Space then it is equal to 1 and it is given by eq^y (1)

$$d\tau = dx dy dz.$$

this eq^y is also known as normalized condition of wave Ψ

Ques:

(b) Necessary Conditions of wave Ψ :

(1) wave Ψ should be Normalized.

Satisfy

$$\int_{-\infty}^{\infty} \Psi^* \Psi d\tau = 1$$

(iii) wave ψ should be single valued

(iv) wave ψ should be continuous.

(iv) " " " " finite

$$\Psi = e^{-ix}$$

* Schrödinger wave eq^y:

~~Time~~

Time independent
(e moves in a particular orbit).

Time dependent

~~Time~~ Time independent Schrödinger wave eq^y:

Schrödinger Time Ind. eq^y is the Potential diff. of wave ψ in terms of two variables.

- In time independent Schrö. wave eq^y Potential Energy is only the function of position.
- Let us consider a system of stationary wave associated with the particle which is moving with velocity v .
- In general wave eq^y is given by

$$\frac{d^2y}{dx^2} = \frac{1}{v^2} \frac{d^2y}{dt^2}$$

In terms of wave function (ψ)

$$\frac{d^2\psi}{dx^2} = \frac{1}{v^2} \frac{d^2\psi}{dt^2} \quad \textcircled{A}$$

$$\left. \begin{array}{l} v \rightarrow \text{particle velocity} \\ v = v_0 \end{array} \right]$$

Let us assume that the sol^y of eq^y \textcircled{A}

$$\Psi(x, t) = \Psi_0 e^{-i\omega t}$$

[f^y of x]

Now if this is the sol^y of eq^y \textcircled{A}
then it should satisfy the eq^y \textcircled{A}

$$\frac{d\Psi}{dx} = \frac{d\Psi_0}{dx} e^{-i\omega t}$$

$$\frac{d^2\Psi}{dx^2} = \frac{d^2\Psi_0}{dx^2} e^{-i\omega t} \quad \textcircled{B}$$

$$\frac{d\Psi}{dt} = -i\omega \Psi_0 e^{-i\omega t} \quad (i^2 = -1)$$

$$\frac{d^2\Psi}{dt^2} = -\omega^2 \Psi_0(x) e^{-i\omega t} \quad \textcircled{C}$$

Sub the eq^y \textcircled{B} and \textcircled{C} in eq^y \textcircled{A}

$$\frac{d^2\Psi_0}{dx^2} e^{-i\omega t} = \frac{1}{v^2} (-\omega^2 \Psi_0(x) e^{-i\omega t})$$

$$\left(\frac{d^2\Psi_0(x)}{dx^2} + \frac{\omega^2}{v^2} \Psi_0(x) \right) e^{-i\omega t} = 0$$

moment show
 $\neq 0$

$$e^{-i\omega t} \neq 0$$

$$\frac{d^2 \Psi_0(n)}{dx^2} + \frac{\omega^2}{V^2} \Psi = 0$$

$$\frac{d^2 \Psi}{dx^2} + \frac{\omega^2}{V^2} \Psi = 0$$

$$\omega = \frac{2\pi}{T} \quad \omega = 2\pi f$$

$$\omega = 2\pi \frac{V}{L}$$

$$\frac{\omega}{V} = \frac{2\pi}{L} \quad d = \frac{h}{P}$$

$$\frac{\omega}{V} = \frac{2\pi}{L} \cdot P$$

$$\frac{\omega}{V} = \frac{P}{L} \quad \text{sub in } (B)$$

$$\frac{d^2 \Psi}{dx^2} + \frac{P^2}{L^2} \Psi = 0$$

Now total Energy of Particle.

$$E = \frac{P^2}{2m} + V \quad V \rightarrow \text{Potential energy}$$

$$P^2 = \Phi m(E - V)$$

$$\boxed{\frac{d^2 \Psi}{dx^2} + \frac{\Phi m(E - V)}{L^2} \Psi = 0}$$

1D

If the particle moving in 3D space.

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} + \frac{2m}{\hbar^2} [E - V] \psi(x, y, z, t) = 0$$

if Particle is a free particle

$$\left[\frac{\partial^2 \psi}{\partial x^2} + \frac{2m}{\hbar^2} E \psi = 0 \right] \quad V=0$$

Q.1 Find the energy of a proton in electrostatic potential which has de-Broglie wavelength 1.2 Å

$$d = 1.2 \text{ Å} = 1.2 \times 10^{-10} \text{ m}$$

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

$$E = \frac{p^2}{2m}$$

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

$$\begin{aligned} & \cancel{1.6 \times 10^{-21}} \quad \cancel{(5.52 \times 10^{-24})^2} \\ & \quad \cancel{2 \times (9.1 \times 10^{-31})} \\ & = \frac{30.4 \times 10^{-48}}{18.2 \times 10^{-31}} \\ & = 1.67 \times 10^{-17} = \end{aligned}$$

$$= \frac{6.63 \times 10^{-34}}{1.2 \times 10^{-10}} \times 10^{-24}$$

$$= 5.52 \times 10^{-24}$$

$$\begin{aligned} & = 1.67 \times 10^{-17} \\ & \cancel{30.4 \times 10^{-48}} = \cancel{9.5 \times 10^{-21}} \\ & \quad \cancel{18.2 \times 10^{-31}} \\ & = 5.9 \times 10^{-2} \\ & = 0.059 \text{ eV} \end{aligned}$$

$\lambda = 1.054$

DATE: / 20
PAGE No

(v) An e^- moves speed 500 m/s with an accuracy of 0.01% . Calculate the certainty with which its position can be located.

$$\Delta p_{\text{max}} \times \Delta n_{\text{min}} = \frac{\hbar}{2} \quad \checkmark$$

$$\Delta n_{\text{min}} = \frac{\hbar}{\Delta p_{\text{max}}}$$

$$\Delta n = \frac{1.054 \times 10^{-34}}{mv}$$

$$= \frac{1.054 \times 10^{-34}}{9.1 \times 10^{-31} \times 500 \text{ m/s}}$$

$$= \frac{1.05 \times 10^{-34}}{9.1 \times 10^{-31} \times 5}$$

$$= \frac{1.05 \times 10^{-3}}{45.5}$$

$$\Delta n = 0.02 \times 10^{-3} \times 1 \text{ m}$$

$$= 0.02 \times 10^{-3}$$

$$0.2 \text{ Ang}$$

$$\Delta p =$$

0.116

0.1 cm

0.42×10^{-27}
mass of e^-
 1.67×10^{-27}

$2 \times 1.6 \times 10^{-27}$
A. S.

Q. An e^- is confined of length $10^{-8}m$ calculate the minimum uncertainty in its min velocity

$$\Delta P = ?$$

$$m \times v \times \frac{\Delta p}{\hbar} = 1.054 \times 10^{-34}$$

$$m \times v = \frac{1.054 \times 10^{-34}}{10^{-8}}$$

$$v = \frac{1.054 \times 10^{-34}}{10^{-8} \times 9.1 \times 10^{-31}}$$

$$\begin{array}{l} \text{39} \\ \text{34} \\ \hline \text{5} \end{array} \quad v = \frac{1.054}{9.1} \times 10^{-34+31+8}$$

$$= 0.11 \times 10^5 \text{ m/s}$$

Q. A Nucleon is confined to a nucleus of $A = 52$ Kev $\lambda = 5 \text{ fm}$ calculate the minimum K.E of the Nucleon.

Q. An e^- and Proton have the same velocity compare the wavelength and the phase and group velocities of their de-Broglie waves.

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

$$\lambda_1 = \frac{h}{m_1 E} \quad e^-$$

$$\lambda_2 = \frac{h}{m_2 E} \quad \text{Proton}$$

$$\frac{\lambda_1}{\lambda_2} = \frac{m_2}{m_1}$$

$$\frac{\lambda_1}{\lambda_2} = \frac{1.6 \times 10^{-27}}{9.1 \times 10^{-31}}$$

$$= \frac{1.6}{9.1} \times 10^4$$

$$\boxed{\frac{\lambda_1}{\lambda_2} = 0.17 \times 10^4}$$

$$V_p = \frac{\omega}{R} = \frac{2\pi v}{2\pi \frac{L}{T}} = \frac{vL}{T}$$

Q. At what speed the de-Broglie wave associated with a particle is equal to twice the wavelength ✓

$$\lambda = 2 \times 0.0243 \times 10^{-10}$$

$$\lambda = 0.0486 \times 10^{-10}$$

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

$$\frac{h}{mv} = 0.0486 \times 10^{-10}$$

$$v = \frac{h}{m} \times 0.0486 \times 10^{-10}$$

$$= \frac{6.63 \times 10^{-34}}{9.1 \times 10^{-31}} \times 0.0486 \times 10^{-10}$$

$$= 0.73 \times 10^{-3} \times 0.0486 \times 10^{-10}$$

$$\frac{c}{\sqrt{8}} = 0.035 \times 10^{-13}$$

$$\frac{2.3 \times 10^8}{\sqrt{8}} = 1341$$

$$\sqrt{1 - \frac{v^2}{c^2}} = \frac{v}{c}$$

$$1 - \frac{v^2}{c^2} = \frac{v^2}{c^2}$$

$$\frac{4v^2}{c^2} + \frac{v^2}{c^2} = 1$$

$$\lambda = 2 \lambda_c$$

$$\frac{K}{mv} = \frac{2K}{m_0 c}$$

$$\frac{\frac{K}{mv} v}{\sqrt{1 - \frac{v^2}{c^2}}} = \frac{\lambda}{m_0 c} \Rightarrow \frac{2}{c} = \frac{8v^2}{c^2} = 1$$

$$v = \frac{c}{\sqrt{8}}$$

* Schrodinger time dependent eq^y:

(1) From Schrodinger time independent:

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2} [E - V] \psi = 0 \quad \text{---(i)}$$

From time independent eq^y eliminate total energy in terms of variation of time

Now

$$\psi = \psi_0 e^{i\omega t}$$

$$\frac{d\psi}{dt} = \psi_0 e^{-i\omega t} (-i\omega) \quad \text{(---ii)}$$

$$\frac{d\psi}{dt} = -i\omega \psi$$

We know that

$$E = \hbar\omega$$

$$\omega = \frac{E}{\hbar}$$

$$\frac{d\psi}{dt} = -\frac{iE}{\hbar} \psi$$

$$-\frac{\hbar}{i} \frac{d\psi}{dt} = E\psi$$

multiply by i)

$$-\frac{\hbar^2}{m} \cdot \frac{d\psi}{dt} = \Sigma\psi - (ii)$$

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2} [E - V] \psi = 0$$

$$-\frac{\hbar^2}{2m} \cdot \frac{d^2\psi}{dx^2} + V\psi = E\psi - (iii)$$

Substitute $\Sigma\psi$ from (ii) to (iii)

$$-\frac{\hbar^2}{2m} \cdot \frac{d^2\psi}{dx^2} + V\psi - i\hbar \frac{d\psi}{dt}$$

$$-\frac{\hbar^2}{2m} \nabla^2\psi + V\psi = i\hbar \frac{d\psi}{dt}$$

where

∇^2 = Laplacian operator

$$\nabla^2 = \frac{d^2}{dx^2} + \frac{d^2}{dy^2} + \frac{d^2}{dz^2}$$

$$H\psi = \Sigma\psi$$

\hat{H} \rightarrow Hamiltonian operator

$$\hat{H} = -\frac{\hbar^2}{2m} + \nabla^2 + V$$

(3) Schrödinger time dependent eq^q:

Let us consider a particle is moving with velocity v and there are waves associated with particles and wave eq^q of these wave are given by

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

Now let $\psi = e^{i(\omega t - kr)}$

(i) is the solution of eq^q (1) then

$$\frac{d\psi}{dx} = ik\psi \quad k = \frac{2\pi}{\lambda}$$

$$\frac{d^2\psi}{dx^2} = -\frac{P^2}{\lambda^2} \psi \quad = \frac{2\pi P}{\hbar}$$

$$P^2 = \frac{-\hbar^2}{\psi} \frac{d^2\psi}{dx^2} \quad K = \frac{P}{\lambda}$$

$$\frac{d\psi}{dt} = -i\omega\psi$$

$$\frac{d\psi}{dt} = -\frac{P}{\hbar}\psi$$

$$E = -\frac{i\hbar}{\psi} \frac{d\psi}{dt} \quad \text{--- (3)}$$

total Energy

$$E = K.E + P.E$$

$$E = \frac{p^2}{2m} + V \quad \textcircled{A}$$

Substituting value from ② and ③ to

\textcircled{A}

$$i\hbar \frac{d\psi}{dt} = -\frac{\hbar^2}{2m} \frac{d^2\psi}{dx^2} + V$$

$$\boxed{i\hbar \frac{d\psi}{dt} = -\frac{\hbar^2}{2m} \frac{d^2\psi}{dx^2} + V\psi}$$

for a free Particle

$$i\hbar \frac{d\psi}{dt} = -\frac{\hbar^2}{2m} \frac{d^2\psi}{dx^2}$$

* Application of Schrodinger eqn:

- (1) Particle in one dimension Potential box
- (2) Particle in 3 D Potential box.

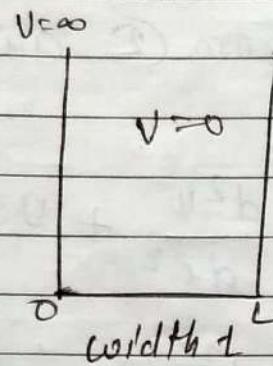
* (i)

Particle in one D Potential Box!

With help of Schrodinger eqn we can find the energy value and energy function of a particle

Let us consider a particle mass 'm' is confined in R one dim. Potential box of width L.

Given $V=0$, $0 < n < L$
 $V=\infty$, $n < 0, n > L$



Schrodinger time independent eq^y of particle

$$\frac{d^2\psi}{dx^2} + \frac{2mE\psi}{\hbar^2} = 0 \quad \text{at } V=0 \text{ inside the box}$$

$$\text{Let } \frac{2mE}{\hbar^2} = k^2 \quad \text{--- (A)}$$

$$\frac{d^2\psi}{dx^2} + k^2\psi = 0$$

Sol^y of above eq^y

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

To find the value of A and B we use boundary condition and normalize condition.

$$\Psi = 0 \text{ at } n=0 \quad (i)$$

$$\Psi = 0 \text{ at } n=2 \quad (ii)$$

Now apply the first boundary condition on eqn B

$$0 = A \sin kx_0 + B \cos kx_0$$

$$0 = B$$

i: $\Psi = A \sin kx$
from (i)

$$0 = A \sin kL$$

A can't be zero so,

$$\sin kL = 0$$

$$kL = n\pi, n \neq 0$$

$$\text{or } k = \frac{n\pi}{L} \quad \text{--- (3)}$$

Put value of k in (1)

$$\frac{\partial^2 \Psi}{\partial x^2} = \frac{n^2 R^2}{L^2}$$

$$\text{or } E_n = \frac{n^2 R^2 \pi^2}{2^2 2m}$$

E_n = eigen value

$\int_{-\infty}^{\infty}$

$$\int (A \sin kn \cdot A \sin kn) dk = 1$$

 \int_0^L

$$A^2 \int_0^L \sin^2 kx dk = 1$$

$$\frac{A^2}{2} \times L = 1$$

$$A = \sqrt{\frac{2}{L}}$$

this is the eigen function of
particle for each particle

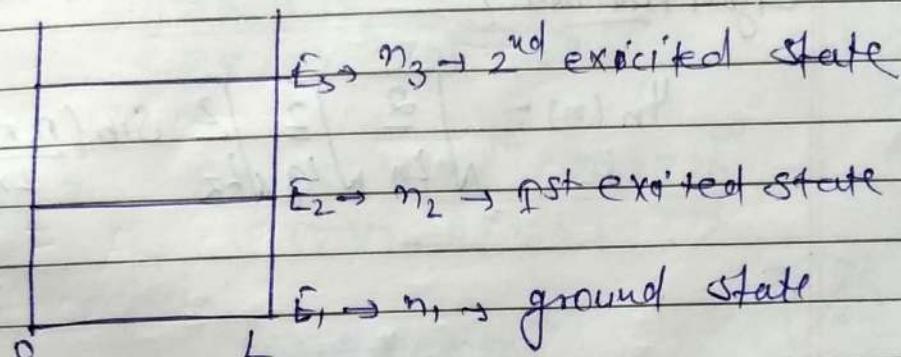
Eigen values!

$$E_n = \frac{n^2 \hbar^2}{8mL^2} \quad \text{or} \quad \frac{n^2 \pi^2 \hbar^2}{8mL^2}$$

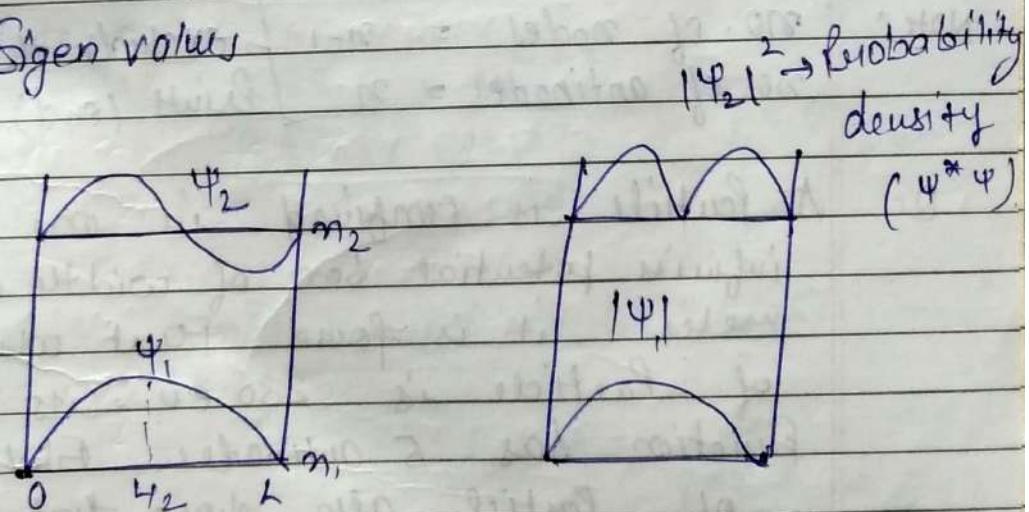
Eigen functions'

$$\Psi_n = \sqrt{\frac{2}{L}} \sin\left(\frac{n\pi}{L}x\right)$$

* Graphical representation of Eigen fⁿ & Eigen values:



Eigen values



* Eigen function and eigen values of a particle of a 3 D Potential box:

Eigen Value :

$$E_n = \frac{\hbar^2}{8m} \left[\frac{n_x^2}{L_x^2} + \frac{n_y^2}{L_y^2} + \frac{n_z^2}{L_z^2} \right]$$

Eigen Function :

$$\Psi_n(x) = \sqrt{\frac{2}{L_x}} \sqrt{\frac{2}{L_y}} \sqrt{\frac{2}{L_z}} \sin\left(\frac{n_x \pi x}{L_x}\right) \sin\left(\frac{n_y \pi y}{L_y}\right) \sin\left(\frac{n_z \pi z}{L_z}\right)$$

Note : no. of nodes = $n-1$] exclude the exterior
 no. of antinodes = n .] prints (end).

- Q. A particle is confined in one dimen. infinite potential box of width of 0.2×10^{-9} meter. It is found that colour energy of particle is 230 eV. Its eigen function has 5 antinodes. Find the mass of particle also show that it can never have energy = 1 keV.

Sol: width = 0.2×10^{-9}
 Energy = 230 eV = $230 \times 1.6 \times 10^{-19}$
 antinodes = 5 = n.
 $m = ?$ $E \neq 1 \text{ keV}$

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

$$E = n^2 E_1$$

$$E = \frac{4.35 \times 10^{-67} \times 25}{8 \times m \times 0.2 \times 10^{-9}}$$

$$m = \frac{8 \times 368 \times 10^{-19} \times 0.2 \times 10^{-9}}{4.35 \times 10^{-67} \times 25}$$

$$= \frac{108.78 \times 10^{-67}}{}$$

$$E = \frac{h^2}{8 m v^2}$$

$$m = 9.32 \times 10^{-31} = \frac{888.8 \times 10^{-28}}{108.75 \times 10^{-67}}$$

$$E = \frac{1}{2} m v^2$$

$$m = 9.32 \times 10^{-31} = 5.41 \times 10^{-31}$$

G.

$$\textcircled{1} \quad m = \frac{n^2 h^2}{8 E \times L^2} = \textcircled{15} \times 4.39 \times 10^{-67}$$

$$E = \frac{h^2}{8 m L^2}$$

$$E_1 = 1.47 \times 10^{-18}$$

$$= 4.39 \times 10^{-67}$$

$$E = n^2 E_1$$

$$= \frac{8 \times 9.32 \times 10^{-31} \times (0.2 \times 10^{-9})^2}{}$$

$$n^2 = \frac{E_1}{E}$$

$$= \textcircled{14}^2$$

Q.

An e^\ominus is bound in 1 D Potential box of width 9.5×10^{-7} m assuming the height of box to be infinite, calculate the lowest two (concrete) energy value of e^\ominus

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

$$E_1 = \frac{h^2}{8mL^2}$$

$$E_2 = \frac{4h^2}{8mL^2}$$

$$E_1 = \frac{(6.63 \times 10^{-34})^2}{8 \times 9.1 \times 10^{-31} \times (2.5 \times 10^{-10})}$$

$$= \frac{4.39 \times 10^{-67}}{182 \times 10^{-41}} = 2.41 \times 10^{-69}$$

$$8 \times 9.1 \times 10^{-31} \times 6.25 \times 10^{-20}$$

$$E_1 = 2.41 \times 10^{-20}$$

$$E_2 = \frac{4.39 \times 10^{-67}}{485 \times 10^{-51}} = 4.82 \times 10^{-20}$$

$$E_1 = 9.6 \times 10^{-19}$$

$$E_2 = 4 \times 10^{-19} = 38.4 \times 10^{-19}$$

(Q) Calculate the Energy diff b/w the ground state and first excited state for an electron in one dim. box of length

$$10^{-8} \text{ cm}$$

$$E_1 = \frac{42}{8\pi^2 L^2}$$

$$10^{-8} \times 10^{-2}$$

$$10^{-16}$$

$$= \frac{(6.63 \times 10^{-34})^2}{8 \times 9.1 \times 10^{-31} \times (10^{-16})^2}$$

$$= \frac{(6.63 \times 10^{-34})^2}{8 \times 9.1 \times 10^{-31} \times 10^{-20}}$$

$$= \frac{4.39 \times 10^{-67}}{72.8 \times 10^{-51}} = 0.06 \times 10^{-16}$$

$$\cancel{6.03} \times 10^{-18}$$

$$= 0.06 \times 10^{-16}$$

~~1.6 × 10⁻¹⁶~~

$$0.018$$

$$\frac{n^2 h^2}{8mL^2} = \frac{p^2}{2m}$$

DATE: / 20
PAGE No

Q. An electron is confined to move b/w two rigid walls separated by 10^{-9} m . Find the de-Broglie wavelength corresponding to the first 3 allowed energy states at the corresponding Energies.

$$l = 10^{-9}\text{ m}$$

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

$$\lambda = \frac{h}{P} = \frac{h}{mv} = \frac{h}{\sqrt{2meE}}$$

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

METHOD - 2

$$\lambda_1 = \frac{2L}{n}$$

$$\lambda_1 = \frac{2 \times 10^{-9}}{1} = 2 \times 10^{-9}$$

$$\lambda_2 = \frac{2 \times 10^{-9}}{2} = 1 \times 10^{-9}$$

$$\lambda_3 = \frac{2 \times 10^{-9}}{3} = \frac{0.25 \times 10^{-9}}{0.67 \times 10^{-9}}$$

$$P_1 = \frac{h}{\lambda} = \frac{6.63 \times 10^{-34}}{2 \times 10^{-9}}$$

Probability

DATE: / 20
PAGE NO

Q A Particle is moving in 1 D Potential Box of width 25A° Calculate the Probability of finding the Particle with it an interval of 5A° at the center of box when it is in its lowest Energy State

~~Ans = 0.4~~ Probability = $\Psi_{(m)}^* \Psi_{(n)}$

$$= \int_0^{2L} \sin\left(\frac{n\pi x}{L}\right) \int_0^{2L} \sin\left(\frac{m\pi x}{L}\right)$$

$$n = \frac{\pi}{2}$$

P. An

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

Unit - 2

DATE : / 20
PAGE NO

Free electron Thor Theory :

↓ ↓ ↓
Classical free Quantum Bond
electron theory free e^- theory

classical e^- theory !

It is developed by Drude & Lorentz
in 1900

It is Based on the assumption that Free
electron obeys the classical Mechanics Law
it not give the value of specific heat
of Semiconductor materials.

It also not explain the electrical and

(3) Band theory / Zone theory :

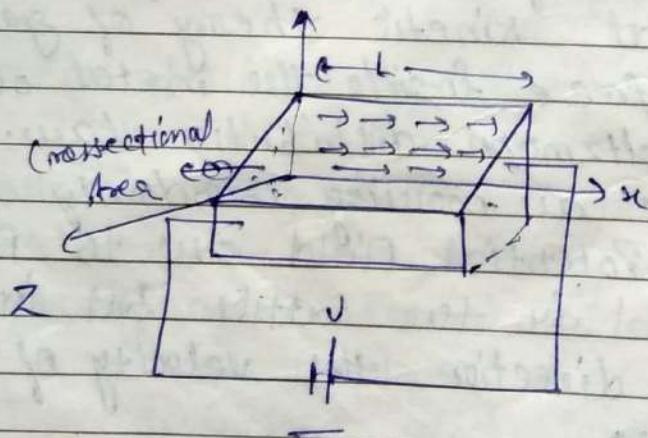
- (1) It is derived by Bloch in 1928
- (2) It is based on the assumption that e^- moves in a periodic potential provided by Lattice.
- (3) It explain almost all the physical Property of material.
- (4) It completely explain the mech' of semi-conductor and Insulator.

* Postulates of classical free e^- theory :

1. The valence e^- of metallic atoms are free to move about the hole volume of the metal.
2. These free e^- are moving randomly in any direction and make collision with positive ions fixed in the lattice or other free electrons. As this collision is elastic so, there is no loss of energy.
3. The moment of free e^- obeys the laws of classical kinetic theory of gasses
4. Velocity of free e^- inside the metal obeys the maxwell boltzmann distribution law.
5. The free e^- are moving randomly in a constant Potential field due to positive ions fixed in the lattice but in a particular direction the velocity of free e^- is zero.

6. When an electric field is applied to the metal the free e^- slightly modify their random motion and slowly get drifted in a direction opposite to the applied electric field. and acquire additional velocity which is called drift velocity
7. In absence of electric field distance travelled b/w two collision is called mean free path and denoted by (λ) . and time taken by an e^- b/w two successive collision are known as mean free time and collision time and denoted by (τ) .
Average velocity of free e^- is called V_{rms}
Velocity also known as thermal velocity
8. In this model it is assume that
Collision time = Relaxation time and
thermal velocity = drift velocity

* Electrical Conductivity of metal (σ):
Let us assume



Let us consider a piece of metal whose length is L and area A . A voltage (V) is applied around the cross-sectional area of metal.

$$E = \frac{V}{L} \Rightarrow V = EL$$

$$V \propto I \quad V = IR$$

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

$$I = \frac{El}{R} \quad R = \frac{el}{A}$$

$$I = \frac{El \times A}{\rho l} = \frac{EA}{\rho}$$

$$\frac{I}{A} = \frac{E}{\rho}$$

$$J = \frac{I}{A} = \frac{E}{\rho} \quad \text{as } \sigma = \frac{1}{\rho}$$

then

$$J = \sigma E \quad \text{ohm Law}$$

If n is the concentration of e^- in the metal then total no. of e^- in metal.

$$= n A \times L$$

then the total charge present in metal

$$Q = n A L \times e \quad \text{--- (1)}$$

the time travel by e^- in the metal

L_d

$$t = \frac{L_d}{V_d} \quad (2)$$

then current flowing in the metal
is given by

$$I = Q = -n A k e \times V_d$$

$$\boxed{I = -n e V_d}$$

$$\frac{I}{A} = -n e V_d$$

$$\boxed{J = -n e V_d} \rightarrow (A)$$

Value of V_d is determined by using the condition of steady state acc. to which

Velocity loss during collision

= Velocity gain by applied electric field

if at $t=0$

v_0 is the velocity of an e^-

then

when
is

the

To Concl

Now

then in absence of E.F

$$\langle V_0 \rangle = 0$$

Final

when E.F is applied the final velocity of e is V_f then after time t is equal to t

$$t = T$$

$$V_f = V_0 + a \cdot T$$

then average value of V_f = avg. value of $\frac{V_0 + aT}{2}$

$$\langle V_f \rangle = \langle V_0 \rangle + aT$$

$$V_f = aT$$

$$V_d = aT \quad \text{--- (3)}$$

To calculate the value of a using the condition as

$$F = -eE$$

$$Ma = -eE$$

$$a = -\frac{eE}{m}, \quad \text{Sub in eqn 3}$$

L ④

$$\boxed{V_d = -\frac{eE \cdot T}{m}} \quad . \quad B$$

Now, Sub this value V_d in & eqn 4.

$$\boxed{J = \frac{ne^2TE}{m}}$$

$$\text{at } J = \sigma E$$

$$\sigma t = ne^2 \tau$$

$$m$$

$$\sigma = \frac{ne^2 \tau}{m}$$

(c)

$$f = \frac{1}{\tau}$$

It shows that the conductivity of any metal depends on the collision time

and collision time depends on free temp.

So, resistivity and conductivity is also dependent on temp.

The Conductivity in terms of temp.:

$$\text{as } \sigma = V_{rms} \cdot \tau$$

$\tau \rightarrow$ mean free path.

It is the avg. dist. travelled by an e^- b/w any two successive collision.

$$\tau = \frac{d}{V_{rms}} \quad (5)$$

As acc. to classical theory when metal is in a state of absolute temp. of T , then K.E of e^- is given by

$$E_k = \frac{3}{2} k_B T$$

Case - 1

en

to

semi \rightarrow T

DATE: / 20
PAGE No

$$\frac{1}{2} m v_{\text{rms}}^2 = \frac{3}{2} k_B T$$

$$V_{\text{rms}} = \sqrt{\frac{3 k_B T}{m}}$$

Substitute the eq⁴ in

(5)

$$T = \frac{d}{\sqrt{\frac{3 k_B T}{M}}} \quad \textcircled{D}$$

Sub the value of T in C eq⁴

$$\sigma = \frac{n e^2}{m} \times \frac{d}{\sqrt{\frac{3 k_B T}{m}}}$$

$$\boxed{\sigma = \frac{n e^2 d}{\sqrt{3 m k_B T}}}$$

Final eq⁴ of electrical conductivity.

Case-1

As temp. increase the conductivity decrease the reason is as by increasing the temp. thermal energy provide the energy to an e^- to vibrate from their esp position and they start to interact with Bound e^- as well as scattered E .

(2) As we for long mean free path & conductivity is high it is due to less no. of e^- collides with the other e^- in the atom.

d. A uniform ~~copper~~ wire has

resistivity of $1.45 \times 10^{-8} \Omega \text{m}$
at room temp. for an electric field along along the core of 1 V/cm compute the average of V_d of an e^- assuming that there are 5.8×10^{28} conduction $e^- \text{ m}^{-3}$ also calculate the mobility and ~~mean~~ average collision time of e^-

$$P = neA\mu$$

$$(V_d = \frac{P}{neA})$$

$$V_d = \frac{eE}{m}\tau$$

$$\mu = \frac{ne^2\tau}{m}$$

$$\tau = \frac{m}{\sigma ne^2}$$

$$\sigma = ?$$

$$f = 1.45 \times 10^{-8} \text{ cm}$$

$$n = 5.8 \times 10^{28} \text{ / m}^3$$

48
31
17

$$E = 1 \text{ V/cm} = 100 \text{ V/m}$$

$$\mu = ? \quad T = ?$$

$$T = \frac{m}{ne^2 f}$$

8-
32
8
8
64

$$= \frac{9.1 \times 10^{-31}}{5.8 \times 10^{-8} (1.6 \times 10^{-19})^2 \times 1.45 \times 10^{-8}} \\ = 2.56 \times 10^{-32}$$

$$= \frac{9.1 \times 10^{-31}}{21.52 \times 10^{-42}}$$

$$= \frac{0.42 \times 10^{-17}}{4.22 \times 10^{-44}} = 4.22 \times 10^{-44} \text{ Sec}$$

$$\mu = \frac{1}{ne} = \frac{1}{8.8 \times 10^{-12}}$$

$$27 \quad = \frac{1}{1.45 \times 10^{-8} \times 8.8 \times 10^{-12} \times 1.6 \times 10^{-19}}$$

$$= \frac{1}{13.45 \times 10^1} = \frac{1}{134.5} =$$

$$= 7.43 \times 10^{-3} \text{ m}^2/\text{Vscc.}$$

a)

$$V_d = \mu \times E$$

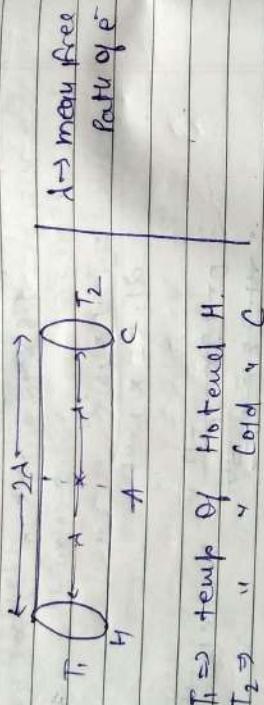
$$= 0.742 \times 10^{-3} \times 100 = 0.742 \text{ m/s}$$

* Thermal conductivity in metal :-

Thermal energy is transfer by two media

$\kappa =$

Transfer of
free e^-
lattice vibration
(phonon).



$T_1 \Rightarrow$ temp of Hot end H.
 $T_2 \Rightarrow$ " " Cold C

$\delta d \rightarrow$ distance b/w H & C

$\lambda \rightarrow$ " of both end from
it is at centre of tube, $d \rightarrow H A \propto \lambda C$

Amount of heat transfer from hot end (H)
to cold end (C)

$$Q \propto \text{Area of face } A$$

$$\propto \text{temp. gradient b/w H & C} \left[\frac{T_1 - T_2}{2\lambda} \right]$$

$$\propto \text{Hm of flow (t)}$$

$$Q = \frac{KA(T_1 - T_2)}{d} t \quad (\text{W})$$

K = quantity of heat transmitted
or
Coefficient of thermal conductivity

$$K = \frac{Qd}{A(T_1 - T_2)t} \quad (\text{W})$$

Unit = W/m K .
 watt/meter kelvin .

As temp. at H is higher than C
average K.E. of e^- at $H = \frac{3}{2} K_B T$

Similarly

$$\text{average K.E. of } e^- \text{ at } C = \frac{3}{2} K_B T_2$$

Let n = no. of conduction e^- in metal
 v = root mean square velocity of e^-

If we assume that these are equal
probability for e^- to move in all
the 6 direction so on.

average of $1/6 n e^-$ can travel in any
direction

DATE: / 20
PAGE NO.

So, no. of crossing /area/time
Q_c

$$\text{At point } A = \frac{1}{6} n_0$$

Now,
heat energy transferred /area/time
from H → C

= no. of crossing point A ×
average F.E. of e⁻ moving from H → C

$$\text{So, } Q_H = \frac{1}{6} n_0 \times \frac{3}{2} k_B T_1$$

$$= \frac{1}{4} n_0 k_B T_1 \quad (\textcircled{2})$$

the energy transferred /area/time
from C → H

$$Q_c = \frac{1}{4} n_0 k_B T_2 \quad (\textcircled{3})$$

Heat energy transferred /area/time
from across point A / sec

$$Q = Q_H - Q_c$$

$$Q = \frac{1}{4} n_0 k_B (T_1 - T_2) \quad (\textcircled{4})$$

Substitute Q from eq⁴ (A) \rightarrow

$$\frac{K(T_1 - T_2)}{\alpha A} = \frac{1}{4} \pi V K_B (T_1 - T_2)$$

$$A = 1, t = 1$$

$$K = \frac{1}{2} \pi V K_B \quad \text{--- (D)}$$

Now, from classical free electron theory the electronic specific heat capacity of metal

$$C_e = \frac{3}{2} R \quad \text{as } R = \frac{1}{2} K_B$$

$$C_e = \frac{3}{2} \pi K_B$$

$$\frac{2C_e}{3} = \pi K_B$$

Substitute in K_B in eq. (D)

$$K = \frac{1}{2} \pi V K_B \quad \boxed{K = \frac{1}{3} C_e V}$$

$$2C_e \quad K = \frac{1}{3} \pi V \frac{2C_e}{3} = \frac{2}{3} C_e V$$

$$K = \frac{1}{2} C_e V$$

It shows thermal conductivity

In terms of electronic specific heat

$K \propto \sigma$ either say eq (D) & (E)

* Wiedemann - Franz law:

Acc. to this law, ratio of thermal conductivity (K) to electrical conductivity (σ) is proportional to temp. (T) for a large no. of metal

$$\frac{K}{\sigma} \propto T$$

$$\frac{K}{\sigma T} = L \quad \text{--- (A)}$$

L = Proportionality Constant known as Lorentz no.

$$L = \text{Lorentz no} = 2.44 \times 10^{-8} \text{ W} \cdot \text{A}^2 \text{ K}^2 \text{ at}$$

293 at
(experimental value)

as

$$k = \frac{1}{2} m v k_{B} \sigma$$

$$\sigma = \frac{n e^2 \tau}{m}$$

$$\text{So, } \frac{K}{\sigma} = \frac{\frac{1}{2} m v K_B T}{n e^2 C}$$

$$= \frac{m v K_B T}{n e^2 C} = \frac{1}{2} m^2 v K_B$$

as $\lambda = v \tau$

$$\frac{K}{\sigma} = \frac{m v^2 K_B}{2 e^2}$$

$$K.E \text{ of } \vec{e} = \frac{1}{2} m v^2 = \frac{3}{2} K_B T$$

$$\frac{K}{\sigma} = \frac{3}{2} K_B T \times \frac{K_B}{e^2}$$

$$\frac{K}{\sigma} = \frac{3}{2} \left(\frac{K_B}{e} \right)^2 T$$

$$L = \frac{K}{\sigma T} = \frac{3}{2} \left(\frac{K_B}{e} \right)^2$$

$$L = \frac{K}{\sigma T} = \frac{3}{2} \left(\frac{1.38 \times 10^{-23}}{1.6 \times 10^{-19}} \right)^2$$

$$L = \frac{3}{2} \left(\frac{1.38 \times 10^{-23}}{1.6 \times 10^{-19}} \right)^2$$

$$= 1.11 \times 10^8 \text{ W/m}^2/\text{K}^2$$

This value of Lorentz no. is half of experimental value of Lorentz no. and this discrepancy in theoretical value can be rectified by using quantum theory.

Now, acc. to Quantum theory, thermal conductivity in metals is modified by considering the electron specific heat and given by

$$K = \frac{m\pi^2 k_B T^2}{3m}$$

So,

$$L = \frac{K}{\sigma T}$$

$$L = \frac{m\pi^2 k_B^2 T^2}{3m} \times \frac{1}{ne^2 C T}$$

$$L = \frac{\pi^2}{3} \times \left(\frac{k_B}{e} \right)^2$$

$$= \frac{\pi^2}{3} \times \left(\frac{1.38 \times 10^{-23}}{1.6 \times 10^{-19}} \right)^2$$

$$L = 2.447 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-2}$$

Ques: A copper wire of length 0.5 m and diameter 0.55 mm. Hence the resistance of 0.09 Ω at 20°C. If thermal conductivity of copper at 20°C is 390 Watt/mK calculate the Lorenz no. Also compare the this value with value predicted by classical free electron theory.

Sol: $l = 0.5 \text{ m}$
 $\text{diameter} = 0.55 \text{ mm} = 0.55 \times 10^{-3} \text{ m}$

$$R = 0.09 \Omega \text{ at } 20^\circ\text{C} \rightarrow T = (273 + 20) = K$$

$$K = 390 \text{ W/mK}$$

$$\therefore L = ?$$

& compare the value of L with Classical theory.

$$L = \frac{K}{\sigma T}$$

$$R = \frac{SL}{A}$$

$$\sigma = \frac{KA}{L}$$

$$\sigma = \frac{l}{RA} = \frac{0.5}{0.09 \times 0.55 \times 10^{-3}}$$

$$\sigma = \frac{l}{RA}$$

$$= \frac{0.5}{0.09 \times 0.55} \times 10^3$$

$$\sigma = \frac{l}{RA} = \frac{0.5}{0.09 \times \left(\frac{0.55 \times 10^{-3}}{2} \right)^2 \times \pi}$$

$$\sigma = 5.78 \times 10^7 \text{ S/m.}$$

$$L = \frac{K}{\sigma T} = \frac{390}{5.78 \times 10^7 \times 293} =$$

$$= 0.23 \times 10^{-7} \text{ Wm/K.} = 2.3 \times 10^{-8} \text{ Wm/K.}$$

R

$$\text{Classical value} = [1.11 \times 10^{-8}]$$

The classical value is 1.11×10^{-8} Volt.s/k
which shows that the classical value
is half of their value.

Q. Calculate the drift velocity and
thermal velocity of conduction electrons
in copper at a temp. of 300K
when copper wire of length 2m and
Resistance = 0.02 ohm carries the current
of 15A. and μ (mobility) = 4.3×10^{-3} m²/Vs
 $L = 2m$
 $T = 300K$

$$I = neAv_0$$

$$v_0 = \frac{I}{neA} = \frac{15}{1 \times 1.6 \times 10^{-19} \times$$

$$v_0 = 4E$$

$$E = \frac{V}{L}$$

$$= 4.3 \times 10^{-3} \times 0.15$$

$$E = \frac{I R}{L}$$

$$= 0.64 \times 10^{-3} \text{ m/s}$$

$$= \frac{1.5 \times 0.02}{2}$$

$$v_0 = \frac{3k_B T}{m} = \frac{3 \times 300 \times}{9.1 \times 10^{-31}}$$

$$= 0.01 \times 15 \\ = 0.15$$

$$K_B = 1.38 \times 10^{-23}$$

DATE: / 20
PAGE No

$$\int_{9.1 \times 10^{-31}}^{900 \times 1.38 \times 10^{-23}}$$

-23 + 31

8

$$\int 136.4 \times 10^{-88}$$

$$= 1.16 \times 10^{-78} \text{ m/s}$$

(14) $v_p = \left(\frac{2\pi s}{p_0} \right)^{1/2}$

$$v_g = v_p - \lambda \frac{dv_p}{d\lambda}$$

~~28~~ $\frac{p^2}{2m} = E$

(15) $E = 15 \text{ keV}$

$$p = \sqrt{2mE}$$

$$\Delta p \cdot \Delta n = \hbar/2$$

$$\Delta p = \frac{\hbar}{\Delta n} = \frac{\Delta p}{p} \times 100$$

Ans:

$$\epsilon = \frac{mc^2}{\lambda}$$

(16)

$$\frac{h}{p} = \frac{hc}{\epsilon} = \frac{1}{p} = \frac{c}{\epsilon}$$

$$p = \frac{\epsilon}{c}$$

(16)

$$E^2 = p^2 c^2 + m_0^2 c^4$$

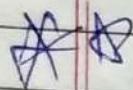
$$E^2 = p^2 c^2$$

$$E = pc$$

useful only
for photon.

$$\text{Energy of photon} = E = pc = \frac{hc}{\lambda}$$

only photon moves velocity of light.



Electron doesn't exist in nucleus

22/09/18

* Draw backs of classical free e^- theory:

1. Theoretical value of specific heat capacity does not match with the experimentally observed value.
2. At low temp., the electrical Conductivity (σ) and thermal Conductivity (K) vary in different ways. Therefore,
 $K/\sigma T$ is not constant at these temp., but acc. to classical free e^- theory it is Constant.
3. Classical theory states that e^- absorb the supplied energy, but quantum state that only few electrons absorb the supplied energy.
4. The concept of Compton effect, black body radiation cannot be explained on this basis of classical theory.
5. Ferromagnetism cannot be explained by this theory.

* Quantum free e^- theory:

- (1) It was developed by Sommerfeld's in 1928
- (2) It follows the de-Broglie hypothesis of matter waves and Schrödinger matter wave eqy.
- (3) It based on Fermi-Dirac Statistics of e^- distribution
- (4) Potential energy of an e^- is periodic. Free e^- find themselves in a potential which is constant everywhere inside the metal but outside is very high.
- (5) In metal, energy levels are filled in accordance with Pauli's exclusion principle

~~Probabilistic~~ Fermi-Dirac distribution function
 (also known as occupation probability)

(1) In quantum free e^- theory e^- are distributed among the various quantum state at any given temperature according to Fermi-Dirac dist. function

The following considerations are used in the development of the statistics

$$e^{-\infty} = 0$$

$$e^{\infty} = \infty$$

1) Indistinguishability of the electron.

2) Electron wave nature.

3) The Pauli exclusion Principle

According to which:

The probability that a particular state E is occupied by an electron is given by -

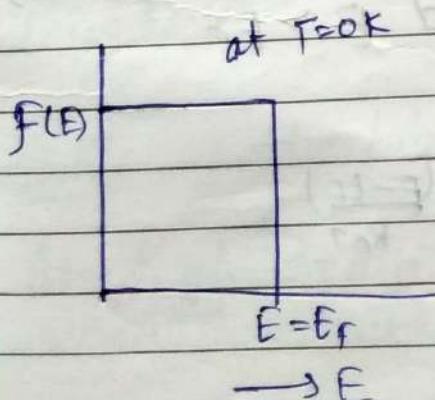
$$f(E) = \frac{1}{1 + e^{\frac{(E - E_F)}{k_B T}}} \quad \textcircled{A}$$

$f(E)$ = Probability that a orbit of Energy E is populated in an ideal e^- gas in thermal eqs.

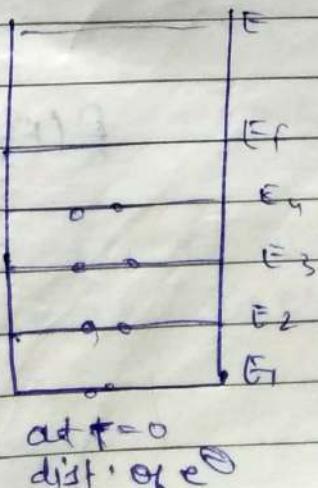
k_B = Boltzmann Constant $(1.38 \times 10^{-23} \text{ J/K})$

T = Absolute temperature.

E_F = Fermi energy or Fermi level.



Fermi flat at 0K.



Effect of temp. on Fermi function!

Case i) At absolute zero ($T=0K$)
 $\& E < E_F$

$$F(E) = \frac{1}{1 + e^{\frac{(E - E_F)}{k_B T}}}$$

$$F(E) = \frac{1}{1 + e^{\frac{(E - E_F)}{k_B T}}} \quad \checkmark$$

$$F(E) = \frac{1}{1 + e^{-\infty}}$$

~~$F(E) = 1$~~

i.e all the Energy level below the E_F are fully occupied by e^- that is there 100% probability of finding an electron below the Fermi Energy level.

Case ii)

At absolute zero ($T=0K$)
 and $E > E_F$

$$F(E) = \frac{1}{1 + e^{\frac{(E - E_F)}{k_B T}}}$$

$$F(E) =$$

$$f(\epsilon) = \frac{1}{1 + e^{\frac{\epsilon - E_F}{k_B T}}} = \frac{1}{\infty}$$

$$f(\epsilon) = 0$$

- Energy levels above the E_F is not occupied by e^- i.e. 0%. Probability of finding the e^- above the Fermi Energy level at $T=0K$.

Case III

At absolute zero ($T > 0K$) & $E = E_F$

$$f(\epsilon) = \frac{1}{1 + e^{\frac{(E - E_F)}{k_B T}}}$$

$$f(\epsilon) = \frac{1}{1 + e^0} = \frac{1}{1+1} = \frac{1}{2}$$

$$f(\epsilon) = 0.5$$

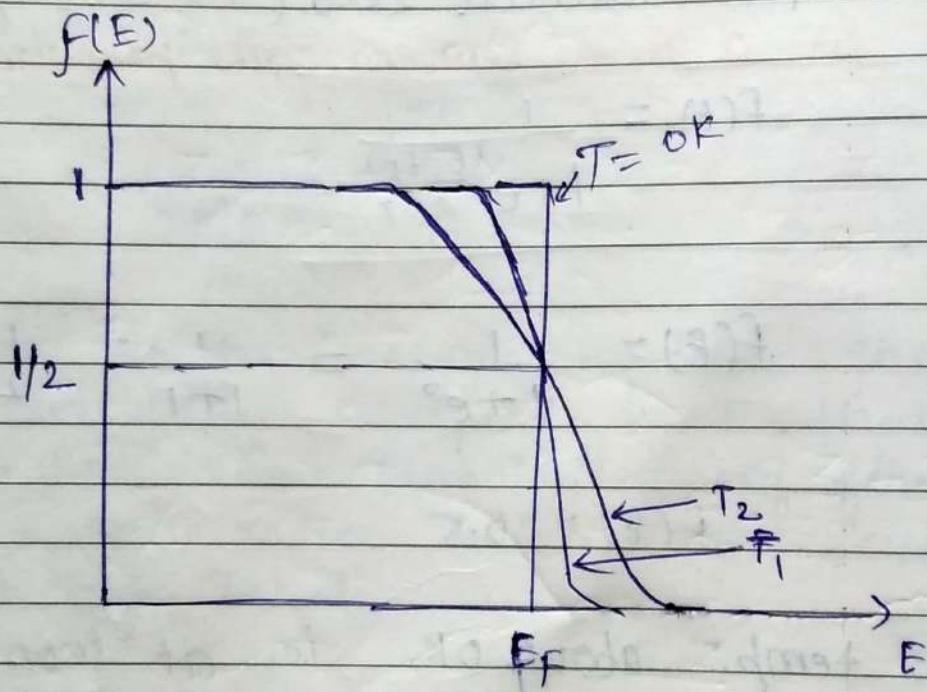
At temp. above 0K, ie at room temp. & $E = E_F$ only 50% Probability for an e^- to occupy Fermi energy level.

Case IV At high temp. $k_B T \gg E_F$

At high temp. e^- are excited to vacant level above Fermi energy

level, i.e. Probability of finding the e^- above E_F become greater than zero.

- at high temp. e^- lose their quantum mechanical character and obeys the Boltzmann dist. f^n .
- At high temp. both quantum & classical Statistic give similar result



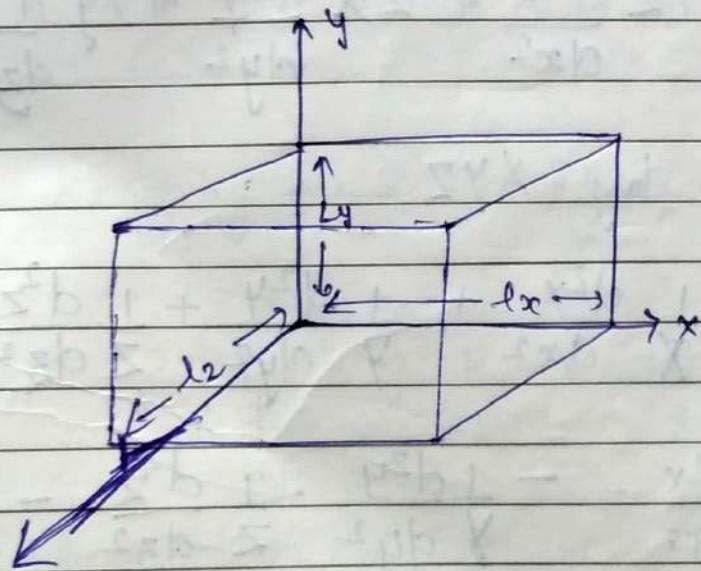
Fermi - Dirac distribution f_T at diff. temp.

* quantum free e^- theory:

Acc. to quantum free e^- theory e^- 's have discrete energy states in a metal and this discrete energy state are characterised by quantum no.

In quantum free e^- theory moment of e^- inside the metal can be consider as moment of an e^- in a 3D Potential box.

* e^- in a Three-Dimensional potential box:



l_x, l_y, l_z are length of box
in x, y, z dirn.

$$V = 0$$

$$0 < x < l_x$$

$$= 0$$

$$0 < y < l_y$$

$$= 0$$

$$0 < z < l_z$$

~~NP+~~ : 10 Marks

Schrodinger time independent eq⁴ for ψ
inside the box: 30

$$\nabla^2 \psi + \frac{2mE}{\hbar^2} \psi = 0$$

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{\partial^2 \psi}{\partial z^2} + \frac{2mE}{\hbar^2} \psi_{(x,y,z)} = 0$$

L [f]

$$\psi(x,y,z) = X(x) Y(y) Z(z)$$

it satisfy the eq⁴ ①

$$YZ \frac{\partial^2 X}{\partial x^2} + ZX \frac{\partial^2 Y}{\partial y^2} + XY \frac{\partial^2 Z}{\partial z^2} + \frac{2mE}{\hbar^2} XYZ = 0$$

divide by XYZ

$$\frac{1}{X} \frac{\partial^2 X}{\partial x^2} + \frac{1}{Y} \frac{\partial^2 Y}{\partial y^2} + \frac{1}{Z} \frac{\partial^2 Z}{\partial z^2} + \frac{2mE}{\hbar^2} = 0$$

$$\frac{1}{X} \frac{\partial^2 X}{\partial x^2} = - \frac{1}{Y} \frac{\partial^2 Y}{\partial y^2} - \frac{1}{Z} \frac{\partial^2 Z}{\partial z^2} - \frac{2mE}{\hbar^2}$$

$$\text{let } \frac{1}{X} \frac{\partial^2 X}{\partial x^2} = k_x \quad \text{--- ①}$$

$$-\frac{1}{Y} \frac{\partial^2 Y}{\partial y^2} - \frac{1}{Z} \frac{\partial^2 Z}{\partial z^2} - \frac{2mE}{\hbar^2} = k_x$$

Date _____
Page No. _____DATE: / 20
PAGE NO.

$$\frac{1}{y} \frac{d^2y}{dy^2} = -\frac{1}{z} \frac{d^2z}{dz^2} - \frac{2mE}{\hbar^2} - k_x$$

Let $\frac{1}{y} \frac{d^2y}{dy^2} = k_y \quad \rightarrow \textcircled{1}$

$$-k_x - \frac{1}{z} \frac{d^2z}{dz^2} - \frac{2mE}{\hbar^2} = k_y$$

Let $\frac{1}{z} \frac{d^2z}{dz^2} = k_z, \quad \frac{1}{z} \frac{d^2z}{dz^2} = -k_x - k_y - \frac{2mE}{\hbar^2} \quad \textcircled{2}$

$$-k_x - k_y - \frac{2mE}{\hbar^2} = k_z$$

$$k_x + k_y + k_z = -\frac{2mE}{\hbar^2} \quad \textcircled{2}$$

$$k_x = -\frac{2mE_x}{\hbar^2} \quad ; \quad k_y = -\frac{2mE_y}{\hbar^2}$$

$$k_z = -\frac{2mE_z}{\hbar^2}$$

By Solving $\textcircled{1}$

$$\frac{1}{x} \frac{d^2x}{dx^2} = k_x$$

$$\frac{d^2x}{dx^2} - k_x x = 0$$

$$X(x) = A \sin [Bx + C]$$

where A, B and C are constants

A is calculate by using the Normalised cond.
B and C calculate by using the Boundary condition of wave function.

Boundary condition

$$(i) x=0, x=0$$

$$(ii) x=0, x=L_x$$

by (i) boundary condition,

$$A \neq 0$$

$$0 = A \sin[B \cdot 0 + C]$$

$$\sin C = 0$$

$$C = 0^\circ$$

$$X(x) = A \sin Bx$$

by (ii) boundary condition,

$$0 = A \sin B L_x$$

$$A \neq 0$$

$$\sin B L_x = 0$$

$$B L_x = n\pi$$

$$n \neq 0$$

$$n = 1, 2, 3, \dots$$

$$B = \frac{n\pi}{L_x}$$

$$n \neq 0, n = 1, 2, 3, \dots$$

$$X(x) = A \sin \left(\frac{n\pi x}{L_x} \right)$$

use the normalised condition $\int_{-l_x}^{l_x} |x(m)|^2 dx = 1$

$$\int_0^{l_x} x(m) \cdot x^*(m) dx = 1$$

$$A^2 \int_0^{l_x} \left[\sin^2 \left(\frac{n\pi}{l_x} x \right) \right] dx = 1$$

$$A^2 \int_0^{l_x} \left[1 - \frac{\cos 2n\pi x}{2} \right] dx = 1$$

$$\frac{A^2}{2} \left[x - \frac{\sin 2n\pi x}{2n\pi} \right]_0^{l_x}$$

$$= \frac{A^2}{2} \left[l_x - \frac{l_x \sin(2n\pi l_x)}{2n\pi} \right] = 1$$

$$\frac{A^2}{2} [l_x - 0] = 1$$

$$A^2 = \frac{2}{l_x} \Rightarrow A = \sqrt{\frac{2}{l_x}}$$

$$x(m) = \sqrt{\frac{2}{l_x}} \sin \left(\frac{n\pi}{l_x} x \right) \quad \text{(A)}$$

Similarly by using eqn ⑥ and ⑦
we get

$$y = \sqrt{\frac{2}{l_y}} \sin\left(\frac{n\pi}{l_y}\right) y$$

$$z = \sqrt{\frac{2}{l_z}} \sin\left(\frac{n\pi}{l_z}\right) z$$

and

$$\psi = X(m) \cdot Y(n_y) \cdot Z(n_z)$$

$$= \sqrt{\frac{2}{l_x}} \sqrt{\frac{2}{l_y}} \sqrt{\frac{2}{l_z}} \sin\left(\frac{n\pi}{l_x}\right)_x \cdot \sin\left(\frac{n\pi}{l_y}\right)_y \cdot \sin\left(\frac{n\pi}{l_z}\right)_z$$

For Eigen Value or Energy values.

$$X(m) = \sqrt{\frac{2}{l_x}} \sin\left(\frac{n\pi}{l_x}\right)_x \quad \textcircled{A}$$

$$\frac{d^2X}{dx^2} - K X = 0$$

diff eqn \textcircled{A} twice w.r.t. x.

$$\frac{dX(m)}{dx} = \sqrt{\frac{2}{l_x}} \left(\frac{n\pi}{l_x}\right) \cos\left(\frac{n\pi}{l_x}\right)_x$$

~~calculate
prob
semi direct~~

Substitute.

again differentiate

$$\frac{d^2x}{dx^2} = -\sqrt{\frac{2}{l_n}} \left(\frac{n\pi}{l_n}\right)^2 \sin\left(\frac{n\pi}{l_n}x\right)$$

$$\frac{d^2x}{dx^2} + \left(\frac{n\pi}{l_n}\right)^2 \cdot x_{(n)} = 0$$

$$K = \left(\frac{n\pi}{l_n}\right)^2 \Rightarrow K = \frac{n^2\pi^2}{l_n^2} \quad (B)$$

Now substitute the values of K from

(B) to (2)

$$k_x + k_y + k_z = -\frac{2mE}{\hbar^2}$$

$$-\left[\frac{n^2\pi^2}{l_n^2} + \frac{n^2\pi^2}{l_y^2} + \frac{n^2\pi^2}{l_z^2}\right] = -\frac{2mE}{\hbar^2}$$

$$E = \frac{\hbar^2\pi^2}{2m} \left[\frac{n_x^2}{l_n^2} + \frac{n_y^2}{l_y^2} + \frac{n_z^2}{l_z^2} \right]$$

$\downarrow \rightarrow Q$

This is the complete eigen value of E in a 3D potential box

→ Density of States

DATE: / 20
PAGE NO.

which shows that each energy state has a quantum no and diff eigen function.

D_f also represent the motion of e^\ominus inside the metal in different quantum state.

(2) * Density of States $\hat{N}(E) \Rightarrow$
 D_f is denoted by $\hat{N}(E)$

D_f is used to find the no. of States per unit volume in energy range b/w E and $E+dE$

and its unit is $/m^3 \text{eV}$ or $/m^3 \text{eV}$

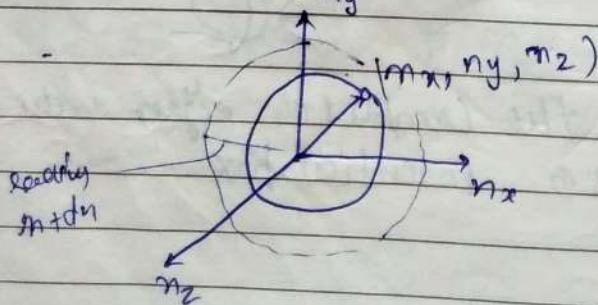
let us consider three dimensional space with coordinates n_x, n_y and n_z

In this coordinate system, there is vector \vec{n}

$$\text{whose value is } \vec{n} = \sqrt{n_x^2 + n_y^2 + n_z^2}$$

magnitude at a point

The -



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

DATE: / /
PAGE NO.

The each point of this sphere is correspond to a unit cell cubical cell.

So, the total no. of points inside the sphere is equal to volume of sphere

$$= \frac{4}{3} \pi n^3$$

The energy state available in one octant of this sphere is equal to

$$\textcircled{a} = \frac{1}{8} \times \frac{4}{3} \times \pi n^3 \quad m > 0 \\ \qquad \qquad \qquad n > 0$$

Energy state with in one octant of sphere of radius $= (n + dn)$

and Energy $= E + dE$

Energy state of octant of the sphere of radius $(n + dn)$ & energy $(E + dE)$

$$= \frac{1}{8} \times \frac{4}{3} \pi (n + dn)^3$$

Now the energy state available b/w

$$E \text{ & } E + dE = \left[\frac{1}{8} \times \frac{4}{3} \pi [(n + dn)^3 - n^3] \right]$$
$$N(E) =$$

$$N(E) = \frac{1}{6} \left[h^3 + dn^3 + 3dn^2 dn + 3dn^2 - n^3 \right]$$

$$N(E) = \frac{\pi}{6} \times 3n^2 dn \quad \begin{cases} \text{neglect higher order of } \\ \text{order of } dn \end{cases}$$

$$N(E) = \frac{\pi}{2} \times n^2 dn \quad \text{--- (1)}$$

Now let us suppose e is confined in a cubical metal piece of size a.

Then acc. to quantum theory the energy

$$\text{of } e^\oplus = E = \frac{8ma^2}{\epsilon m \alpha^2}$$

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

differentiate

$$\delta n dn = \frac{8ma^2 dE}{h^2}$$

Now substitute the value of δn in eqⁿ (1)

$$N(E) = \frac{\pi}{2} \times \left(\frac{8ma^2 E}{h^2} \right)^{1/2} \times \frac{8ma^2}{\epsilon m \alpha^2 h^2}$$

$$= \frac{\pi}{8\alpha^3} \left(\frac{8\pi m^2}{h^2} \right)^{3/2} E^{1/2} dE$$

$$= \frac{\pi}{4} \frac{\alpha^3}{h^3} \cdot 2^3 (2m)^{3/2} E^{1/2} dE$$

$$N(E) = \frac{2\pi}{h^3} \alpha^3 (2m)^{3/2} E^{1/2} dE \quad [from]$$

Acc. to Pauli's exclusion principle in a one energy state there are two electrons which can occupy the energy state one with spin up and one with spin down

so, the total no. of energy states = $2N(E)$

Energy density density b/w $E \pm \Delta E$

$$N(E) \Delta E = \frac{4\pi}{h^3} \alpha^3 (2m)^{3/2} E^{1/2} \cdot \Delta E$$

Volume

If for cubical metal
 $\alpha = 1 \quad \alpha^3 = 1$

$$N(E) \Delta E = \frac{4\pi}{h^3} (2m)^{3/2} E^{1/2} \Delta E$$

* Carrier concentration in terms of semi-energy: denote (n_c)

$n_c = \text{no. of } e^- \text{ per unit volume in the energy interval } E + dE$

$$n_c = \int N(\epsilon) f(\epsilon) d\epsilon$$

Substitute the value of $N(\epsilon)$ and $f(\epsilon)$

$$n_c = \int_{E_f}^{\infty} \frac{4\pi (2m)^{3/2}}{\hbar^3} E^{1/2} \times \frac{1}{1 + e^{(E - E_f)/kT}} dE$$

below Fermi Energy states

At $T=0K$, $E(E_f) = 1 \rightarrow$ Energy state completely occupied

$$n_c = \int_{E_f}^{\infty} \frac{4\pi (2m)^{3/2}}{\hbar^3} E^{1/2} dE$$

$$n_c = \int_0^{E_f} \frac{4\pi (2m)^{3/2}}{\hbar^3} E^{1/2} dE$$

$$n_c = \frac{4\pi}{\hbar^3} (2m)^{3/2} \int_0^{E_f} E^{1/2} dE$$

$$n_c = \frac{4\pi}{\hbar^3} (2m)^{3/2} \left[\frac{2}{3} E^{3/2} \right]_0^{E_f}$$

$$n_c = \frac{4\pi}{3} (2m)^{3/2} \times \frac{2}{3} [E_F^{3/2} - 0]$$

$$n_c = \frac{8\pi}{3h^3} (2m)^{3/2} E_F^{3/2}$$

Learn.

- * For Fermi energy in terms of Conc of e^- at $t = 0K$

$$E_F^{3/2} = \frac{3n_c}{8\pi} \cdot \frac{h^3}{(2m)^{3/2}}$$

Taking $\sqrt[3]{}$ root on both sides

$$E_F = \frac{\hbar^2}{2m} \left(\frac{3n_c}{8\pi} \right)^{2/3}$$

DATE: / 20
PAGE NO

Q At low temp., copper has a free e^- concentration of $8.45 \times 10^{28}/m^3$ using the free e^- model. Find the Fermi energy of solid copper

$$\text{Conc}^y = 8.45 = n_c$$

$$E_F = \frac{\hbar^2}{8\pi m} \left(\frac{3n}{8\pi} \right)^{2/3}$$

$$E_F = \frac{(6.63 \times 10^{-34})^2}{2 \times 9.1 \times 10^{-31}} \times \left(\frac{3 \times 8.45 \times 10^{28}}{8 \times 3.14} \right)^{2/3}$$

$$= 6.63$$

$$= \frac{4.39 \times 10^{-67}}{1.82 \times 10^{-30}} \times \left(\frac{6.42 \times 10^{58}}{25.12} \right)^{2/3}$$

$$1.125 \times 10^{-18}$$

$$= 2.41 \times 10^{-37} \times \left(\frac{6.42 \times 10^{58}}{25.12} \right)^{2/3}$$

$$\sigma = \frac{me^2\tau}{m}$$

$$\sigma = me$$

$$J = -eE$$

$$J = -nevA$$

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

$$I = \tau X V$$

DATE: / / 20
PAGE NO:

Q. A conduction wire has a resistivity of 1.64×10^{-8} ohm at room temp. The Fermi energy for such a conductor is 5.8 eV. There are 5.8×10^{28} eV/m³. Calculate.

i) relaxation time mobility,

$$\rho = 1.64 \times 10^{-8}$$

$$n = 5.8 \times 10^{28}$$

$$\frac{1}{\rho} = \frac{ne^2\tau}{m}$$

$$\frac{1}{\rho} = \frac{5.8 \times 10^{28} \times (1.6 \times 10^{-19})^2 \times \tau}{9.1 \times 10^{-31}}$$

$$\frac{1}{1.64 \times 10^{-8}} = \frac{5.8 \times 10^{28} \times (1.6 \times 10^{-19})^2}{9.1 \times 10^{-31}} \times \tau$$

$$\tau = \frac{9.1 \times 10^{-31}}{1.64 \times 10^{-8} \times 5.8 \times 10^{28} \times (1.6 \times 10^{-19})^2}$$

$$\tau = 3.73 \times 10^{-14} \text{ s.}$$

$$\sigma = ME$$

$$M = \frac{\sigma}{ne} = \frac{1}{1.64 \times 10^{-8} \times 5.8 \times 10^{28} \times 1.6 \times 10^{-19}}$$

$$= 6.65 \times 10^{-3} \text{ Am}$$

$$\frac{1}{1.64 \times 10^{-8}} = \rightarrow 1.6 \times 5.8 \times 10^{28} \times 1.6 \times 10^{79}$$

$$V_d = \frac{1}{1.64 \times 10^{-8} \times 5.8 \times 10^{28} \times 1.6 \times 10^{79}}$$

$$= 6.5 \times$$

$$= 0.056$$

$$\underline{\text{Velocity of } e^\ominus} = ?$$

$$\frac{25.12}{1.31 \times 10^{-66}}$$

$$\sigma = \frac{ne^2}{m} \tau$$

$$K_B =$$

DATE: / 20
PAGE No

$$\text{Fermi Energy} = \frac{1}{2}mv^2$$

$$v^2 = \frac{qF(E)}{m}$$

$$V = \sqrt{\frac{2EF}{m}}$$

$$V = \sqrt{\frac{2 \times 5.3 \times 1.6 \times 10^{-19}}{9.1 \times 10^{-31}}}$$

$$V = 13.63 \times 10^5$$

$v_F \times T$ = mean free path

$$5.09 \times 10^{-2} \text{ m}$$

Q. Fermi energy in silver is 5.5 eV at 0 K
calculate the no. of free e⁻ per unit volume,
and probability of occupation of e⁻'s
with 5.7 eV in silver at the same
temp.

n_c and $F(E)$

$$F(E) = \frac{1}{e^{(E-E_F)/kT}}$$

$$n_c = \frac{8\pi}{3h^2} (2m)^{3/2} (EF)^{3/2}$$

$$= \frac{8 \times 3.14}{3 \times (6.63 \times 10^{-34})} \left(\frac{2 \times 9.1 \times 10^{-31}}{(5.5 \times 1.6 \times 10^{-19})} \right)^{3/2}$$

$$= \frac{8 \times 3.14}{2 \times 10^{-28}} - 2.957 \times 10^{-53}$$

$$n_c = 5.87 \times 10^{28} \text{ m}^{-3}$$

Energy band gap

2.4 eV $\times 10^3$
DATE: / 20
PAGE NO.

then Semiconductors

$$F(E) = \frac{1}{e^{(E-E_F)/kT}}$$

$$= \frac{1}{1 + e^{(3.2 \times 10^{-20})}} = \frac{1}{1 + e^{-8}} = 0$$

Q2

Calculate Fermi energy and Fermi temp. in a metal. Given that Fermi velocity of electron in the metal is $0.86 \times 10^6 \text{ m/s}$

$$\text{Soln: } E = \frac{1}{2}mv^2$$

$$E = \frac{1}{2} \times 9.1 \times 10^{-31} \times (0.86 \times 10^6)^2 \text{ J}$$

$$= 3.363 \times 10^{-25} = 3.365 \times 10^{-19} \text{ J}$$

$$\text{Fermi Energy: } E_F = 2.103 \text{ eV}$$

$$E_F = k_B T_F$$

$$T = \frac{E_F}{k_B}$$

$$= \frac{3.363 \times 10^{-25}}{1.36 \times 10^{-23}} = 24385.36$$

Avg
2

$$N = 10^{23}/\text{cc}$$

$$k_B = 1.36 \times 10^{-23}$$

$$\boxed{E_F = k_B T}$$

holes in valency band

DATE: / / 20
PAGE NO:

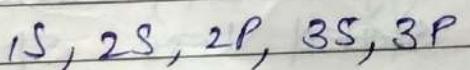
Q. At 1000 temp. Copper has a free e[⊖] cm³ of $8.45 \times 10^{-28} \text{ cm}^3$ using the free e[⊖] model find Fermi energy of solid copper.

	Semicon	
Conductor	-	0
Semiconductor	-	< 3 eV
Insulator	-	> 3 eV

→ Direct or Indirect Conductor!

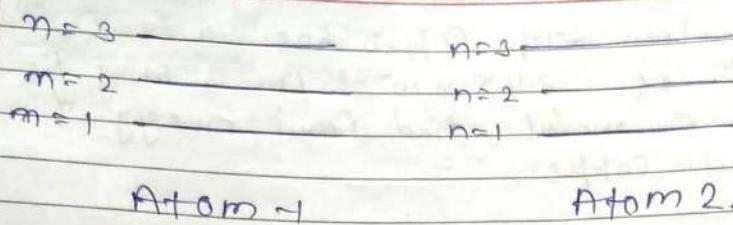
* Band theory of a solid:

- A solid is formed by bringing together isolated single atoms.
- Each atom when isolated has a discrete set of energy levels



as all the N atoms approach one another to form a solid and In general

$$N \approx 10^{23}/\text{cc}$$



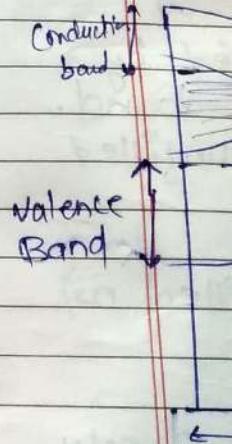
when the distance b/w two atoms is less than interatomic distance. then the Energy levels of atoms are splitted into n distinct levels.

So, this is form a almost continuous band.

The crystal of Energy level very close to one another is known as Energy band.

Amount of splitting is different for different energy levels, lower Energy level. are ~~stated less~~ splitted less than the higher Energy level.

It is due to as the lower energy levels are not influence ~~are~~ by the presence of nearby atom, whereas as higher Energy level interact strongly with the nearby atom.



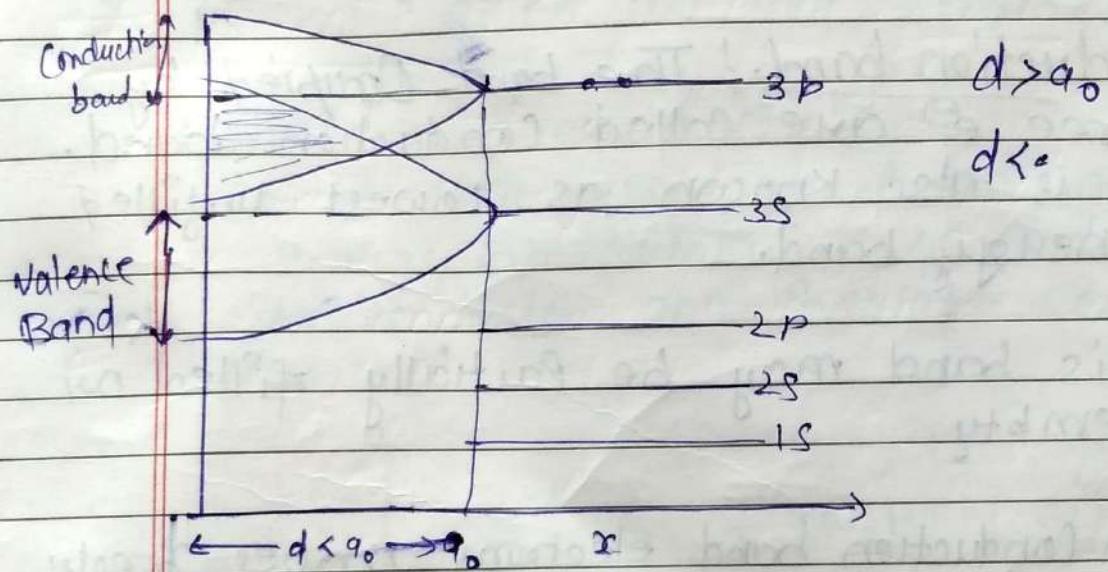
- Each band has a total ~~of N~~ individual electrons Energy levels . and each level contain the two ~~2N~~

$$2(2l+1)N \text{ electrons}$$

\hookrightarrow It's due to spin quantum no. ($s = \pm \frac{1}{2}$)

where N is the no. of energy levels.
and $l \rightarrow$ orbital Quantum no.

- This band theory needs leads to the classification of theory into conductor , insulator and semiconductor.



- e⁻'s in the Outermost shell are called Valance electrons and the Band.
form by a series of Energy levels containing the valance δ are known as valance band theory

* Valence band :

The band which is occupied by the valence electron or band occupied having the highest band energy are known as Valence band.

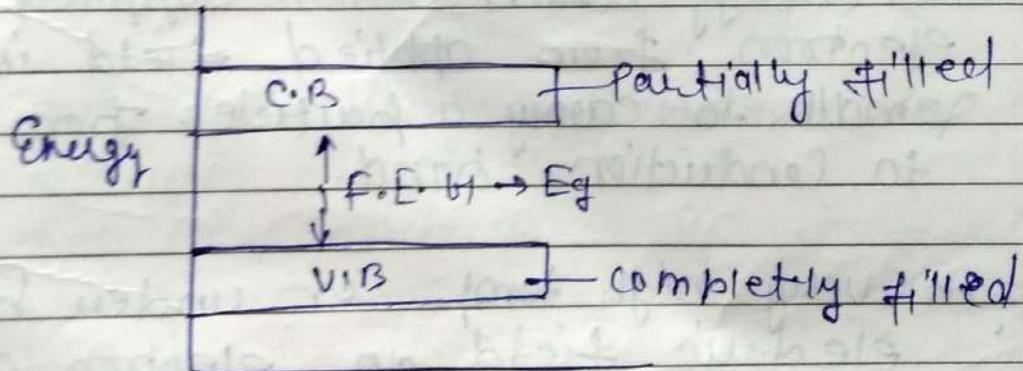
Properties:

- Valence band may be partially or fully filled depends on the nature of Crystall.
- Valence band never be empty.
- * Conduction band : The band Occupied by free e⁻ are called conduction band.
It is also known as lowest unfilled energy band.
- This band may be Partially filled or empty.
- In Conduction band electrons moves freely.
- If has empty conduction band it means there is no conduction current

* Forbidden Energy gap:

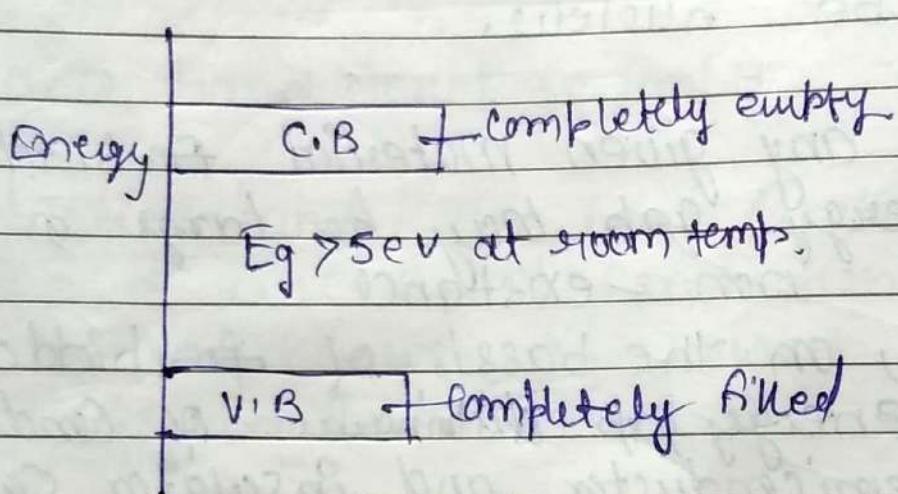
The separation b/w C/B and V/B is known as forbidden Energy gap.

- There is no allowed energy state in this gap it means there is no e^- normally exist in this gap.
- Greater the Forbidden Energy Gap more tightly the valence e^- are bound to be nucleus.
- For any given material forbidden energy gap may be large or small or non-existence
So, on the basis of forbidden energy gap difference of conduction Semiconductor and Insulator can be described



* Insulators: In insulators Valence e's are tightly bound with the Parent atom

- Practically no electron in the conduction band and valence band is completely filled
- Valence and conduction band are near about greater than 5ev apart



- The energy which can be supplied to an electron from applied field is too small to carry a particle from valency to conduction band.
- At very high temp. or under high electric field an electron can jump to conduction band this is by some material which is insulator at room temp become conductor at high temp. this is called breakdown of insulating material.

* Semiconductor:

- For Semiconductor near about absolute zero temp. the valence band is completely filled and no e^- in conduction band so no current flow in semiconductor at OK temp. and it behave as an Insulator.

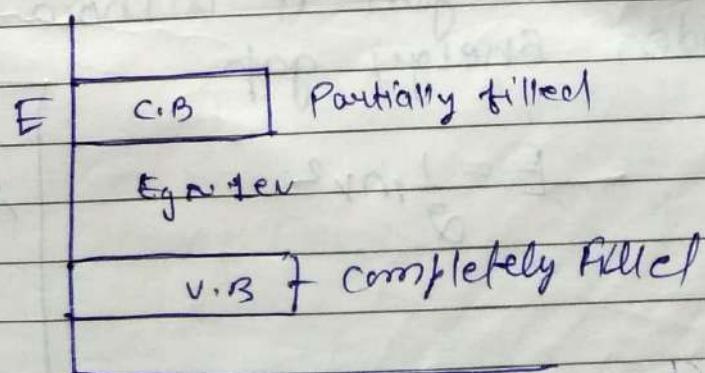
- If provided energy

$$E \geq E_g \approx 1 \text{ eV.}$$

then e^- can be lifted to conduction band by imparting some energy.

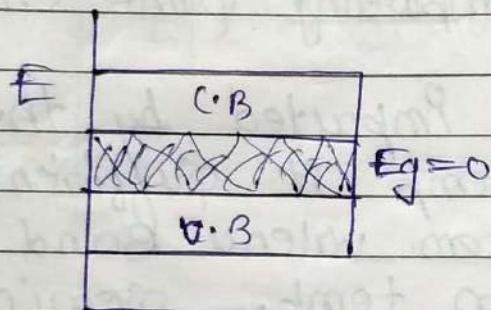
- The energy imparted by the heat at room temp. is sufficient to lift e^- from valence band to C.B and at room temp. semiconductor are capable of conducting current.

- The conductivity of semiconductor is nearly $\sigma \approx 10^2 - 10^7 \text{ S/cm}$.



* Conductor: There is no forbidden gap
B/w V.B and C.B

- V.B and C.B are overlapped
- e^- in conductor C.B moves randomly through out the solid that is the region that e^- are known as free electrons.
- Due to overlapping of V.B and C.B is slightly pot. difference across conductors causes free electron to constituent current



* forbidden band gap:

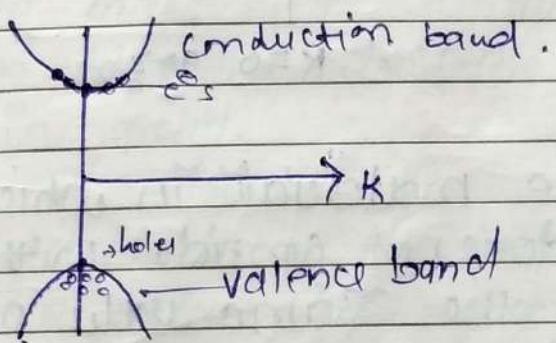
The energy b/w C.B and V.B are known as forbidden gap and there is no Energy \leftrightarrow Level b/w V.B and C.B due to this region it is known as forbidden energy gap

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

$$\begin{aligned} P &= \pi R \\ A &= \frac{\pi}{P} \\ K &= \frac{2\pi}{\lambda} \end{aligned}$$

~~band gap semiconductor~~

- * Direct energy band gap. (laser use)
the Direct Semiconductor Can be explained by reduced zone of E-K diagram.



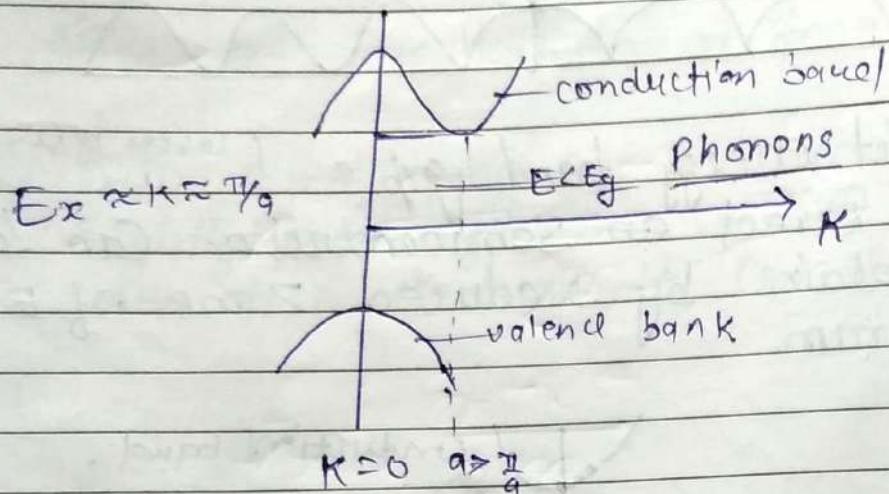
The material in which In E-K diagram the minima of Conduction band coincide with the maxima of valence band at the same value of K. then it is known as direct band gap s/c

- e^- can jump from Conduction to valence band directly by emitting a photon of Energy = E_g

$$E = E_g$$

- In direct band Semiconductor there is no change in \mathbf{k}

* Indirect g.s.c: (for optical properties)
can also be explain by using the reduced zone of EK diagram.



The material in which minima of CB does not coincide with maxima of VB at the same value of \mathbf{k} is known as indirect semiconductors.

- Indirect g.s.c e^- does not jump directly from C.B to V.B due to this it suffer a change in energy and momentum.
- In indirect g.s.c change in \mathbf{k} as well energy which is given to the lattice in form of heat.

* Effective mass = (m^*)

The experimentally determined e^- mass is slightly different than the free mass in solid.

This experimentally determined e^- mass is known as effective mass

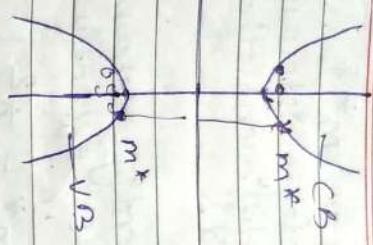
$$m^* = \frac{\hbar^2}{\left(\frac{d^2E}{dk^2}\right)}$$

- The difference in eff. mass of e^- to the free mass of e^- is due to the interaction b/w the drifting e^- 's and atoms in solid.

- Eff. mass depends on the location of e^- in the allow Energy band

- For the crystal in which energy band is nearly full the negative charge and negative mass vacancy may be consider as positive charge and positive negative mass particle is known as holes

- The value of $\frac{d^2E}{dk^2} \rightarrow$ Curvature of Energy Level.



As $\rho f = \frac{P^2}{2m}$

$$f = \frac{\hbar^2 k^2}{2m}$$

$$\frac{dE}{dk} = \frac{\hbar^2 k}{m}$$

$$m^* = \frac{\hbar^2}{k}$$

$$\frac{d^2 E}{dk^2} = \frac{\hbar^2}{m}$$

* Semiconductors:

Intrinsic

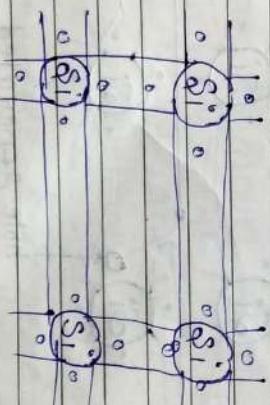
Extrinsic

- σ is independent on temp. → They are impure SiC
- It is generally not used → σ can be increased for device formations by doping some elements.
- They are pure semiconductor → σ may be independent on temp. they are widely used in formation of devices.

Intrinsic

* Intrinsic, dependent of T/Cs;

(b) at $T = 0K$



- At $T = 0$ all the e^- s are tightly bound with Semiconductor atom whereas valence electron are unpaired in covalent bonding

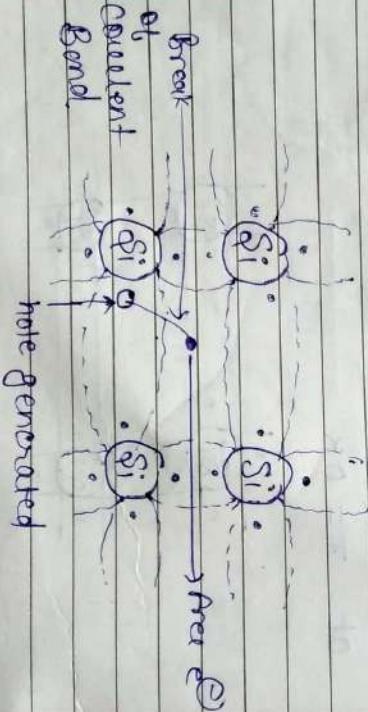
and at $T=0$ covalent bonding is very strong and there is no free electron in conduction band and semiconductor behaves as an insulator.

C.B. empty

Eg $\approx 1.1 \text{ eV}$

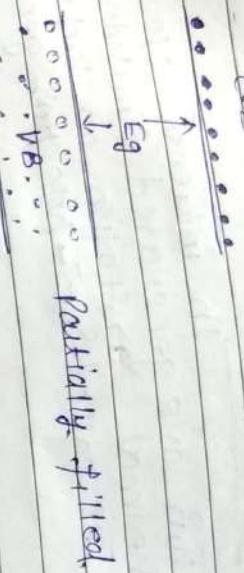
"i.e." completely filled & bound by covalent bonding.
 $T = 0 \text{ K}$

(2) at $T > 0 \text{ K}$



note generated

- Partially filled



+70

- At $T \geq 0K$ Some covalent Bond Break due to thermal Energy and valence

e^- become free higher the temp.

more bonds are broken and

e^- 's are free to move randomly

in the void space b/w the atoms.

in the crystal.

- when an e^- moves from V.B to C.B

- when a valency is created in broken

a valency is created and this valency is

covalent bond and this valency is

known as holes.

- when a free e^- is generated simultaneously a hole is created so, e^- and holes always generate in pair.

- ionization and recombination.

Generation and Recombination

* Generation

In intrinsic S/C e^- and hole pair are generated simultaneously due to thermal agitation or temperature. This is called e^- -hole pair generation.

Generation

Covalent bond + thermal energy $\rightarrow e^-$ + holes

Energy

At any temperature the no. of e^- generated is equal to no. of hole produced & concn of e^- in C.B. is equal to concn of holes in V.B.

- Recombination

e^- in conduction band loss its energy due to collision with other particles in the lattice and falls into the valence band. Then free e^- falls into V.B. It meets with hole at this process is called recombination.

e^- + hole

\rightarrow Covalent + Energy

free e^- transforms into valence e^- and ruptures covalent bond. Since in this energy is stored pair disappears and

or
Sh

At
e.

and released Energy in form of thermal Energy.

At the given temp. Rate of generation is equal to rate of recombination

(With respect to electrons)

C.R

generation \downarrow recombination \uparrow

\downarrow \uparrow V.B

INCREASING

* Intrinsic Conductivity
 At any temp. no. of generated per unit volume is equal to no. of holes generated per unit volume

$$n = p = n_i \rightarrow \text{intrinsic density}$$

on intrinsic concn.

at a temp + avg. K.E

$$\frac{1}{2} m v_{th}^2 = \frac{3}{2} k T$$

In presence of electric field in steady state condition moment of e^- opposite to the electric field and moment of holes along the dir'n of electric field.

The net moment of e^- and holes is called drift and the mean velocity is known as drift velocity and it is given by

$$V_d = \mu E$$

the current density due to e^-

$$J_e = neV_d$$

and due to hole

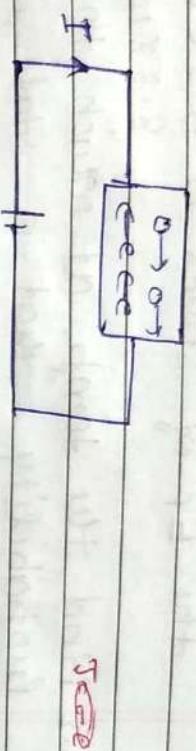
$$J_h = peV_d$$

the conductivity

$$\sigma = \frac{J}{E} = \frac{neV_d}{V_d \cdot m} = \frac{e \cdot n \cdot m}{m}$$

$$\sigma_e = ne \mu$$

$$\sigma_h = pe \mu_h$$



and the total current

$$I = J_e + J_h$$

$$= n_e v_d + p_e v_d$$

$$J = (n_e v_d + p_e v_d)$$

$$J = n_e e E (\mu_e + \mu_h)$$

$$\text{And } \sigma = n_e e^2 (\mu_e + \mu_h)$$

- As variation of mobility with temp. is very small. so, the variation of conductivity is directly proportional to $n_e(T)$

$$\sigma(T) \propto n_e(T)$$

$$\sigma(T) \propto n_i(T).$$

At what temp we can expect a 10% probability that e^- in a silver atom is energy which is 1% above the Fermi energy.

The E_F of Silver is 5.5 eV

$$8.8 \times 10^{-19} \text{ J}$$

Find the temp. at which there is 1% probability that a state with energy $E_F + 1\%$ is occupied given that

$$E_F = 1.5 \text{ eV}$$

$$= 2.4 \times \cancel{(8.5 \times 10^{-19})}$$

$$\textcircled{1} \quad f(E) = \frac{1}{1 + e^{(E-E_F)/k_B T}}$$

$$\frac{1}{100} = \frac{1}{1 + e^{(E-2.4 \times 10^{-19})/k_B T}}$$

4.605

$$T = \frac{2 \times 1.36 \times 10^{-23}}{3.02 \times 10^{-19} - 3.084 \times 10^{-19}} \\ = \frac{6.26 \times 10^{-23}}{6.4 \times 10^{-20}}$$

$$= 9.78 \times 10^{-4}$$

$$F(\varepsilon) = \frac{1}{1 + e^{E-E_F/k_B T}}$$

$$\frac{1}{100} = \frac{1}{1 + e^{\frac{8 \times 10^{-20}}{1.38 \times 10^{-23} T}}} \\ = \frac{1}{1 + e^{\frac{2.04 \times 10^{-19}}{1.38 \times 10^{-23} T}}}$$

$$1 + e^{\frac{8 \times 10^{-20}}{1.38 \times 10^{-23} T}} = 100$$

$$e^{\frac{8 \times 10^{-20}}{1.38 \times 10^{-23}}} = 100 - 1$$

$$e^{\frac{8 \times 10^{-20}}{1.38 \times 10^{-23}}} = 99$$

$$\frac{8 \times 10^{-20}}{T \times 1.38 \times 10^{-23}} = \ln 99$$

$$T = \frac{8 \times 10^{-20}}{4.59 \times 1.38 \times 10^{-23}}$$

$$= \frac{8 \times 10^{-20}}{6.33 \times 10^{-23}} = 1263.8$$

Soln

$$\frac{10}{100} = \frac{1}{1+e^{\frac{E-E_F}{K_B T}}}$$

$$E_F = 5.5 \text{ eV} = 8.8 \times 10^{-19}$$

$$E = 8.8 \times 10^{-19} = 8.8 \times 10^{-21}$$

$$1 + e^{-\frac{8.712 \times 10^{-19}}{1.38 \times 10^{-23}}} = 10$$

$$e^{-\frac{8.712 \times 10^{-19}}{8.7 \times 10^{-19}}} = 9$$

$$T = -8.712 \times 10^{-19} = 2.019$$

$$T = \frac{-8.712 \times 10^{-19}}{8.7 \times 10^{-19}} = 2.019$$

$$e^{-\frac{8.712 \times 10^{-19}}{1.38 \times 10^{-23} \times T}} = 9$$

$$-\frac{8.712 \times 10^{-19}}{1.38 \times 10^{-23} \times T} = 2.019$$

$$T = -\frac{8.712 \times 10^{-19}}{2.019 \times 1.38 \times 10^{-23}} = 2.019$$

$$= 8.712 \times 10^{-19}$$

$\theta =$

$$\frac{1}{10} = \frac{1}{1 + e^{\frac{E - E_F}{k_B T}}}$$

$$\frac{1}{10} = \frac{1}{1 + e^{\frac{8.88 \times 10^{-9} - 8.80 \times 10^{-9}}{1.38 \times 10^{-23} \times T}}}$$

$$1 + e^{\frac{0.08 \times 10^{-9}}{1.38 \times 10^{-23} \times T}} = 10$$

$$= 2.19$$

 \underline{T}

$$T = \frac{579.7}{2.19} = 264.7.$$

Reason of step 10: $E_F - E_F/2 = E_F/2$ Step 9: $e^{(E_F - E_F/2)/k_B T} = e^{E_F/2 k_B T}$ $A_2 = 14.12 \text{ mJ}$ (ii) $-3.6 \times 10^3 \text{ J/m}^2$

Intense S.C
Carrier Concentration & density of charge carriers:

As in semiconductor e^- and holes are charge particles so, they together are called charge carriers

Carrier Concentration is equal to no. of e^- in C.B per unit volume

$$\text{Carrier conc}^n = \text{no. of } e^- \text{ in C.B/vol.} \rightarrow n$$
$$= \text{no. of holes in V.B/vol.} \rightarrow p$$

e^- density of ϵ cmcⁿ in conduction band

No. of electrons whose energy lies b/w energy interval E and $E + dE$ in conduction band is given by

$$dn = N(\epsilon) f(\epsilon) dE$$

Now $N(E) = \frac{4\pi}{\hbar^3} (2m_e^*)^{3/2} E^{1/2} dE$ - (A)

In conduction band for Energy $E > E_c$

$$N(E) = \frac{4\pi}{\hbar^3} (2m_e^*)^{3/2} (E - E_c)^{1/2} dE - (A)$$

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

For $E > E_c$ in conduction band

$$E - E_F \gg kT$$

then eq^y (B) is as

$$f(E) = e^{-[E - E_F]/kT}$$

Now Substitute the value of $f(E)$ and
N(E)dE in eq^y (A)

then

$$n = \int_{E_c}^{\infty} \frac{4\pi}{\hbar^3} (2m_e^*)^{3/2} (E - E_c)^{1/2} \cdot e^{-(E - E_F)/kT} dE$$

$$n = \frac{4\pi}{\hbar^3} (2m_e^*)^{3/2} \int_{E_c}^{\infty} (E - E_c)^{1/2} e^{-(E - E_F)/kT} dE$$

$$\int_0^{\infty} x^{1/2} e^{-x} dx = \frac{\sqrt{\pi}}{2}$$

DATE: / /
PAGE No:

$$n = \frac{4\pi (2m_e^*)^{3/2}}{h^3} e^{-\frac{(E_c - E_f)}{kT}} \int_{-\infty}^{\infty} (E - E_c)^{1/2} \times e^{-\frac{(E - E_c)}{kT}} dE$$

$$\text{Now } \frac{E - E_c}{kT} = x$$

$$\text{when } E \rightarrow E_c \\ x=0$$

$$\frac{dE}{kT} = dx$$

$$n = \frac{4\pi (2m_e^*)^{3/2}}{h^3} e^{-\frac{(E_c - E_f)}{kT}} \int_0^{\infty} x^{1/2} (kT)^{1/2} \cdot e^{-x/(kT)} dx$$

$$= \frac{4\pi}{h^3} (2m_e^*)^{3/2} e^{-\frac{(E_c - E_f)}{kT}} (kT)^{3/2} \int_0^{\infty} x^{1/2} e^{-x/kT} dx \quad (2) \text{ Comc}$$

$$n = \frac{4\pi}{h^3} (2m_e^* kT)^{3/2} e^{-\frac{(E_c - E_f)}{kT}} \cdot \frac{\sqrt{\pi}}{2}$$

$\downarrow n$

N_c

N_c - is

if
b/p
Valence

where
en

and

$$n = \alpha \left[\frac{2 m_e^* kT}{h^2} \right]^{3/2} e^{-\frac{(E_c - E_f)}{kT}}$$

$$n = N_c e^{-\frac{(E_c - E_f)}{kT}} \quad L$$

$N_c \rightarrow$ effective density of state in C.B

N_c is a constant

$$N_c = 2 \left(\frac{2 \pi m_e^* kT}{h^2} \right)^{3/2}$$

(2) Conc^y of holes in valence band:

if $dP \rightarrow$ no. of holes whose energy lies
b/w energy interval E and $E + dE$ in
valence band then $dP =$

$$dP = N(E) [1 - f(E)] dE \quad ①$$

where $N(E)dE \Rightarrow$ density of states in the
energy interval E and $E + dE$

and $[1 - f(E)]$ is state of Energy which
is Vacant.

$$\int_{-\infty}^{\infty} a^{1/2} e^{-ax^2} dx = \frac{\sqrt{\pi}}{2}$$

DATE: / 20
PAGE No.

It means it is not occupied by an electron.

$$\begin{aligned}[1 - f(\varepsilon)] &= 1 - \frac{1}{1 + e^{(E - E_F)/KT}} \\ &= 1 - \left[1 + e^{-(E - E_F)/KT} \right]^{-1} \\ &= 1 - \left[1 - e^{-(E - E_F)/KT} \right] \\ 1 - f(\varepsilon) &= e^{-(E - E_F)/KT}\end{aligned}$$

Now substitute the value in eq⁴ ①

then E_v

$$f dp = \frac{4\pi}{h^3} (2m_h^*)^{3/2} (E_v - E)^{1/2} e^{-(E - E_F)/KT} dE$$

no. of holes in CB

$$p = \frac{4\pi}{h^3} (2m_h^*)^{3/2} e^{-\frac{(E_p - E_v)}{KT}} \int_{-\infty}^{E_v} (E_v - E)^{1/2} e^{-(E_v - E)/KT} dE$$

let $\frac{E_v - E}{KT} = x$

$dE = -dx$

$dE = -KTdx$

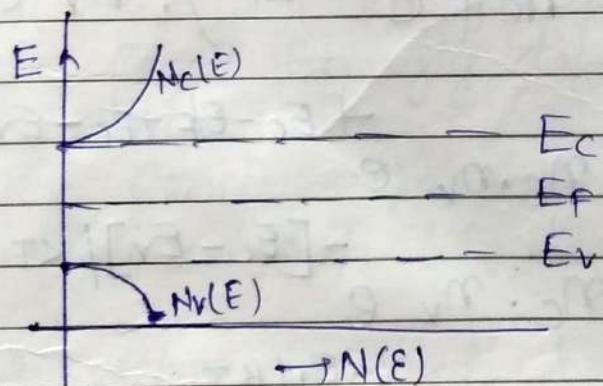
$$= \frac{4\pi}{h^3} (2m_h^*)^{3/2} e^{-\frac{(E_F - E_v)}{KT}} \int_0^{\infty} \frac{1}{2} \frac{3}{(KT)} e^{-x} dx$$

$$= \frac{4\pi}{h^3} (2m_h^*)^{3/2} (KT)^{3/2} e^{-\frac{(E_F - E_v)}{KT}} \frac{\sqrt{\pi}}{2}$$

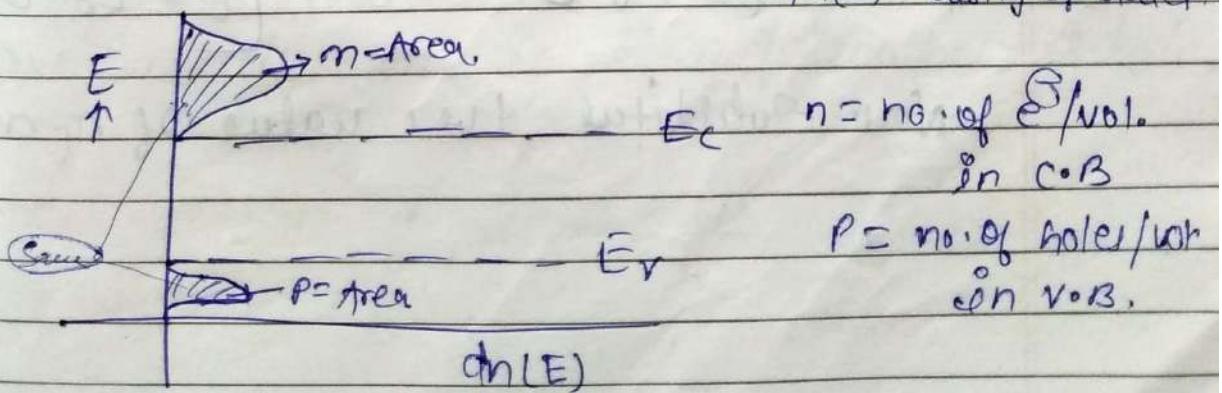
$$p = 2 \left[\frac{2\pi m_h^* KT}{h^2} \right]^{3/2} e^{-\frac{(E_F - E_v)}{KT}}$$

$$p = N_v e^{-\frac{(E_F - E_v)}{KT}} \quad \text{L}$$

Here N_v is the effective density of states in valence band



$N(E)$ = density of states.



$n_i^0 =$

* Intrinsic conc' of charge carriers:

Intrinsic carrier conc':
At any temp. T , no. of electrons

no. of electron generated = no. of holes generated

$n = p = n_i^0$
where n_i^0 is calculated the intrinsic density
of intrinsic conc'.

$$\text{Ques } n_i^0 = n \cdot p \quad \text{---} \circ$$

Now, substitute the value of n and p
~~in eqn~~

$$\begin{aligned} n_i^0 &= n_c \left(e^{-\frac{(E_C - E_F)}{kT}} \right) \cdot n_v e^{-(E_F - E_V)/kT} \\ &= n_c \cdot n_v e^{-[E_C - E_F + E_F - E_V]/kT} \\ &= n_c \cdot n_v e^{-[E_C - E_V]/kT} \\ n_i^0 &= n_c \cdot n_v e^{-E_g/kT} \quad [E = E_C - E_V] \end{aligned}$$

Now substitute the value of n_c and n_v

- then it is intrinsic
- Intrinsic level
- Intrinsic temperature
- Intrinsic Energy
- And one more are left

$$n_i^o = 2 \left(\frac{2\pi kT}{h^2} \right)^{3/2} (m_e^* m_h^*)^{3/4} e^{-Eg/kT}$$

DATE: / 20
PAGE NO:

$$n_i^o = 4 \left(\frac{2\pi m_e^* kT}{h^2} \right) \left(\frac{2\pi m_h^* kT}{h^2} \right) e^{-Eg/kT}$$

$$n_i^o = \sqrt{2 \left(\frac{2\pi m_e^* m_h^* kT}{h^2} \right)} e^{-Eg/kT}$$

$$\checkmark n_i^o = \alpha \left(\frac{2\pi kT}{h^2} \right)^{3/2} (m_e^* m_h^*)^{3/4} e^{-Eg/kT}$$

this eq⁴ gives the intrinsic carrier concn.
at temp. T

$$n_i^o = \alpha \left(\frac{2\pi m_e^* m_h^* k}{h^2} \right)^{3/2} T^{3/2} e^{-Eg/2kT}$$

then it shows that the carrier concn in
intrinsic S/C varies with temp.

Intrinsic concn is independent of fermi
level

Intrinsic concn strongly depends on the
temperature

Intrinsic concn exponentially depends on
Energy band gap (Eg)

and 2 represent that by broken of
one covalent bond to charge carriers
are produced one is e and another is hole.

Variation presence of Fermi level in Intrinsic Semiconductor.

As in Intrinsic S/C e^- and holes are generated in pair then

$$n = p = n_i$$

$$n_c e^{-[E_C - E_F]/kT} = N_V e^{-[E_F - E_V]/kT}$$

$$2 \left(\frac{2\pi m_e^* kT}{h^2} \right) e^{-[E_C - E_F]/kT} = 2 \left[\frac{2\pi m_h^* kT}{h^2} \right] e^{-[E_F - E_V]/kT}$$

$$m_e^* e^{3/2 - [E_C - E_F]/kT} = m_h^* e^{3/2 - [E_F - E_V]/kT}$$

$$e^{-[2E_F - E_C - E_V]/kT} = \left(\frac{m_h^*}{m_e^*} \right)^{3/2}$$

Taking ln of both side.

$$\frac{-2E_F + E_C + E_V}{kT} = \frac{3}{2} \ln \left(\frac{m_h^*}{m_e^*} \right)$$

If we assume that Effective mass of

$$m_e^* = m_h^*$$

then,

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

$\therefore E_C - E_V = E_g$

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

If we assume that top of V.B at a zero Energy level so, we can take

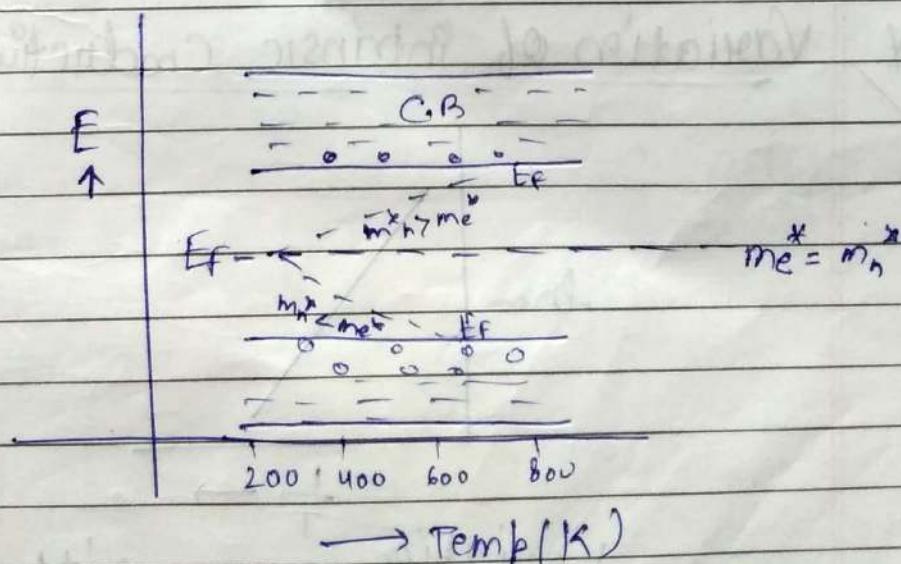
$$E_V = 0$$

then.

$$E_F = \frac{E_g}{2}$$

Dif: Fermi level is not an allowed energy level in semiconductor. It only serves as an reference energy with reference to which we specify the energy of e⁻ and holes in SIC.

* Variation of fermi level with temp. in intrinsic SIC:



Variation of E_F with temp. in intrinsic SIC

(i) if $m_h^* = m_e^*$ then .

E_F lies exactly b/w the E_C & E_V

(ii) If $m_h^* > m_e^*$ then

E_F slightly towards the C.B

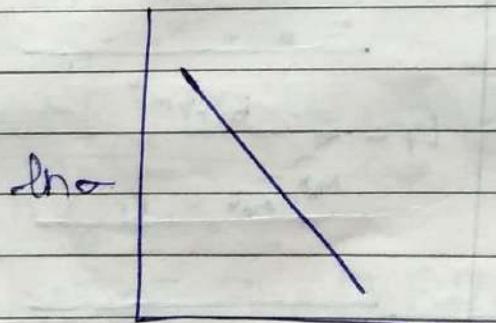
(iii) If $m_h^* < m_e^*$ then

E_F shift towards the V.B

(iv) In most of the material the shift of Fermi level on account of when $m_e^* \neq m_h^*$ is insignificant

(v) Fermi level in an intrinsic SiC may be considered as independent of temp. So, we can say that E_F lies middle of the Energy gap.

* Variation of Intrinsic Conductivity with temp.



$\frac{1}{T} \rightarrow$
Variation of σ with
temp

Extrinsic Semiconductor

DATE: / /
PAGE No.

$$A\delta \sigma = n_i^o e [M_e + M_h]$$

$$n_i^o e = (n_c n_v)^{1/2} e^{-Eg/2kT}$$

$$\sigma = (n_c n_v)^{1/2} e^{-Eg/2kT} (M_e + M_h)$$

$$\sigma = \sigma_0 e^{-Eg/2kT}$$

$$\sigma_0 = n_c n_v (M_e + M_h)^{1/2} \\ = \text{constant}$$

$$\ln \sigma = \ln \sigma_0 - \frac{Eg}{2kT}$$

Conductivity increases with temp.

* Extrinsic Semiconductor

Depends on the types of impurity added in pure semiconductor. Intrinsic semiconductor are divided into two type

Extrinsic



n-type

P-type Ex. sic

→ n type:

It is found by adding pentavalent impurity. and these impurities are known as dopant.

Ex: Phosphorous,
Arsenic
Antimony

→ P type: They are found by adding trivalent impurity and dopant are Boron
Indium
Gallium

* n type Extrinsic Semiconductors:

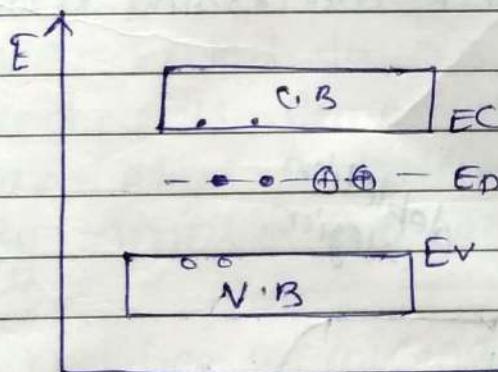
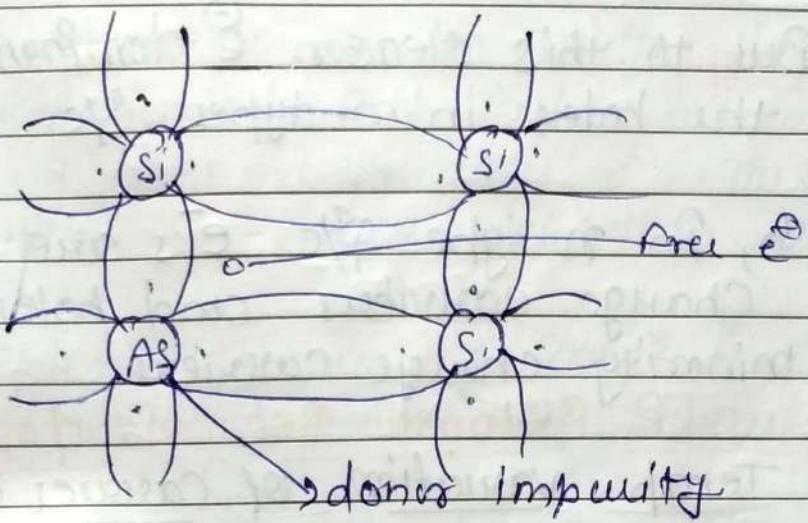
- When a small amount of Pentavalent impurity is doped in pure semiconductor it is known as n-type S/c.

- Such type of impurity which produce n-type S/c are known as donor impurities. because they are climate or provide free electrons to the S/c crystal.

- For Ex: Arsenic has five valence e^- 's and when it add in germanium crystal then four valence e^- of Arsenic formed covalent bond with the near about Germanium atom and valence e^- of Arsenic is free.

The amount of energy needed to the test this free e^- from Arsenic is very small which is near about 0.01 eV for life.

These free e^- work as a carrier charges in this system.



E banding of n types.

$E_D \Rightarrow$ Energy level of Donor Atom

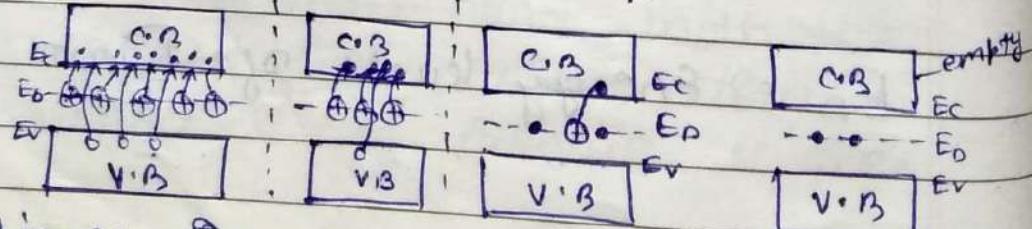
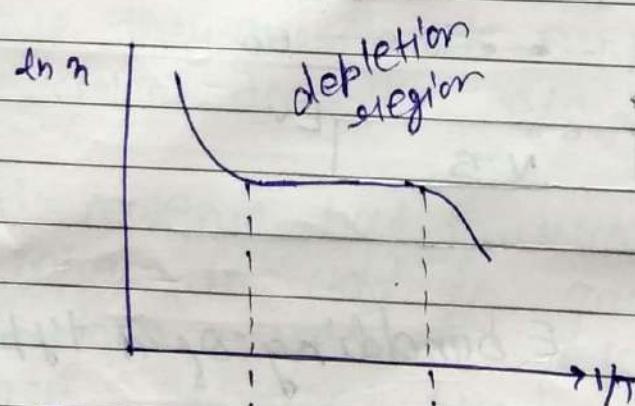
- By addition of pentavalent impurity many new free e^- are produced.
- Thermal energy of room temp. still generates a few e^- -hole pair. However no. of free e^- provided by pentavalent impurity far exceeds no. of holes.
- Due to this reason e^- dominate over the holes in n-type SiC.

So, In n-type SiC e^- 's are majority charge carriers and holes are minority charge carriers.

Ques

Temp. variation of carrier concn. in n-type SiC:

At 0K Donor atoms are not ionised it means Donor e^- are bound to the donor atom.



Variation of e^- concn with temp.
or variation of n w.r.t.

Complete full
Tink

- So, covalent bond is empty emol V.B is complete filled so, as behavior as insulator
 - Slightly elevated temp. Donor atoms are ionised at donor E^\ominus 's are go into the conduction band by getting Energy from lattice vibration and in this process holes are not produced in V.B
 - At $T = 100\text{ K}$ all the donor atoms ionised and further increase the temp. it does not produces e^\ominus . This region is called depletion region
 - In depletion region e^\ominus concⁿ in C.B is equal to concⁿ of Dopant atoms
- $$n_n \approx N_D$$
- when $T > 100\text{ K}$ Some at E^\ominus 's from V.B are excited to C.B so, in conduction band e^\ominus 's comes through either
 - i) donor atom ionisation
 - ii) By intrinsic process produce holes in V.B
 - In n-type semiconductor carriers are independent of temp. in depletion region and current in n-type sic due to negative charge carriers.

+ Carrier Conc^{in n-type} of SiC at low temp =
The concn of donor in the material = N_D

at zero K (0K) E_D is near to C.B (E_C)
and donor atom are not ionised

at $T > 0K$ E_D is near to E_F & donor
atom are ionised

by increasing the temp. the Concn of N_D^+
Pn cond - B.C.B increased.

$$n = N_D^+$$

$$n = N_D - N_D^+$$

where $N_D^+ \Rightarrow$ no. of donor atom ionised.

$n = N_D \Rightarrow N_D^+ \rightarrow \dots \dots \dots$ are left ~~ionized~~
un-ionized

$$\begin{aligned} N_D^+ &= N_D - N_D^0 \\ &= N_D [1 - f(\varepsilon_D)] \end{aligned}$$

As Fermi Level (E_F) in n-type SiC lies in
few eV above.

then ~~$f(\varepsilon_D)$~~

$$n = N_D^+ = \frac{N_D}{1 + e^{[E_F - E_D]/kT}} \quad (1)$$

Now,

Now

Now

at T

Now, Com'n of e^{ϕ} in C.B

$$n = N_c e^{-(E_c - E_F)/kT} \quad \text{--- (B)}$$

Now eqn ① and ②

$$\frac{N_D}{1 + e^{(E_F - E_D)/kT}} = N_c e^{-[E_c - E_F]/kT}$$

Now taking log both side.

$$\frac{E_D - E_F}{kT} + \frac{E_c - E_F}{kT} = \ln \frac{N_c}{N_D}$$

$$E_D - E_c - 2E_F = kT \ln \frac{N_c}{N_D}$$

$$E_F = \frac{E_D + E_C}{2} - \frac{kT}{2} \ln \frac{N_c}{N_D}$$

=

$$\frac{E_D + E_C}{2} + kT \ln \frac{N_D}{2 \left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2}}$$

at $T = 0K$

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

$$\exp \left[\frac{E_F - E_C}{kT} \right] = \exp \left[\left(\frac{E_D + E_C}{2} \right) + kT + \text{--- (C)} \right]$$

$$+ \frac{1}{2} \ln \frac{N_D}{2 \left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2}} - \frac{E_C}{kT}$$

$$= \exp \left[\frac{E_0 - E_c + \frac{1}{2} kT}{kT} \ln \frac{N_D}{2 \left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2}} \right]$$

$$= \exp \left[\frac{E_0 - E_F}{2kT} \right] \cdot \frac{N_D}{2 \left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2}}$$

AS

$$n = n_c \exp \left[\frac{E_F - E_c}{kT} \right] \quad \text{So}$$

$\therefore n = n_c \exp \left[\frac{E_D - E_c}{2kT} \right] \cdot \left[\frac{N_D}{2 \left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2}} \right]^{1/2}$

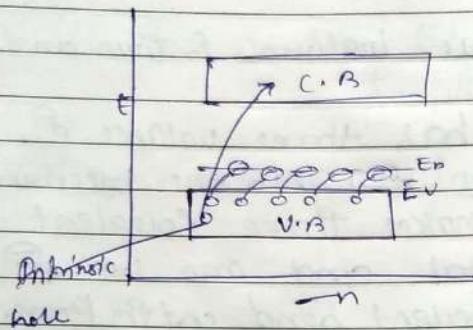
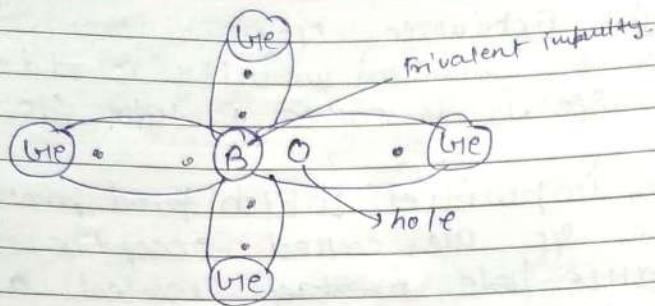
$$n = \left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2} \exp \left[\frac{E_D - E_c}{2kT} \right] \left[\frac{N_D}{2 \left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2}} \right]^{1/2}$$

or

$$n = \left(g N_D \right)^{1/2} \left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2} e^{\frac{E_D - E_c}{2kT}}$$

* P-type Extrinsic Sc:

- When a trivalent impurity is added to a pure sc. it is called P-type Sc.
- Such impurities which produce P-type Sc are called acceptor impurities because hole ~~is created~~ can accept
- The examples are Gallium, Indium and Boron
- For ex. Boron has three valence e^- . So each atom of Boron fill into the bccinium crystal and makes three covalent bond with the lattice crystal and one $lattice e^-$ can not form covalent bond with Boron atom. These Boron atom carries an additional e^- and become negative ion.
- The hole can move freely in the V.B whereas impurity is fixed in a position by the covalent bond.
- As Boron accept e^- accept the an e^- from lattice atom. So it is called acceptor and acceptor atom create hole without simultaneous generation in C.B



E band dig. of p-type SiC

- even a small amount of thermal energy can make an ϵ in the V.B move in the acceptor level due to this E_{α} is near about E_F and $E_{\alpha} - E_F$ is nearly about 0.01 eV.

at $0K = T$

E_D remain vacant and it behaves as insulator

- At normal temp. E_D remains at saturation & few ϵ are excited to

- d + ne atom are does not called

- holes can acceptor

- At $T \geq 10^3$
V.B to C.B

- In V.B th
(i) due to
(ii) by Intrinsic

- At high
temp.

- In P-type
Carrier
temp. pr

- Current

- At $T \approx 100K$ all the acceptor atoms are ionised & then further increase temp does not produce holes. and this region is called saturated region.
- holes conc' in V.B is equal to conc' of acceptor atom

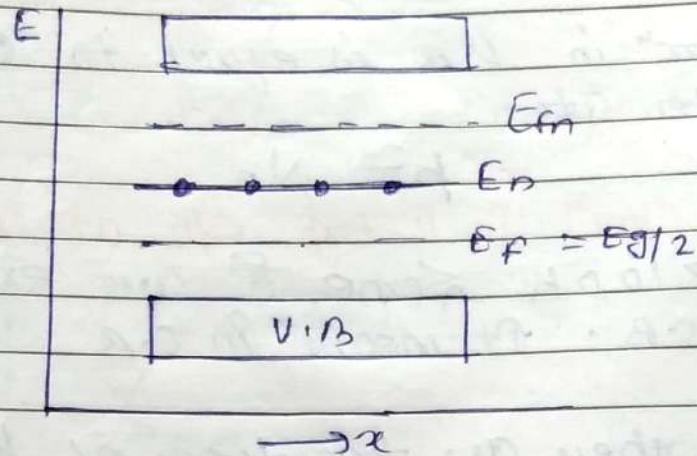
$$p \approx N_A$$
- At $T > 100K$ some e^- are excited from V.B to C.B. It means In C.B
- In V.B there are two types of holes
 - (i) due to acceptor atom ionisation
 - (ii) by intrinsic process.
- At high temp. material behaves as an intrinsic SiC

$$p = n_e = n_h$$
- In P-type SiC holes are majority charge carriers and they are independent of temp. In the depletion region
 Current in P-type SiC is due to holes ^{p mainly}

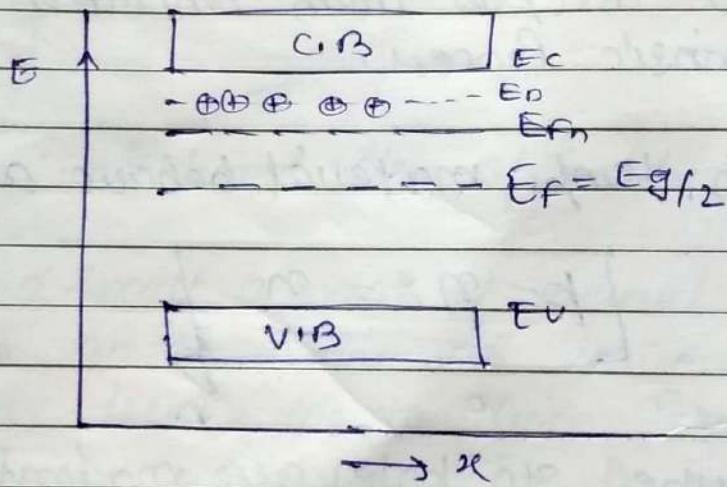
* Energy band diagram of extrinsic at 0K and 300K.

(1) n-type SIC:

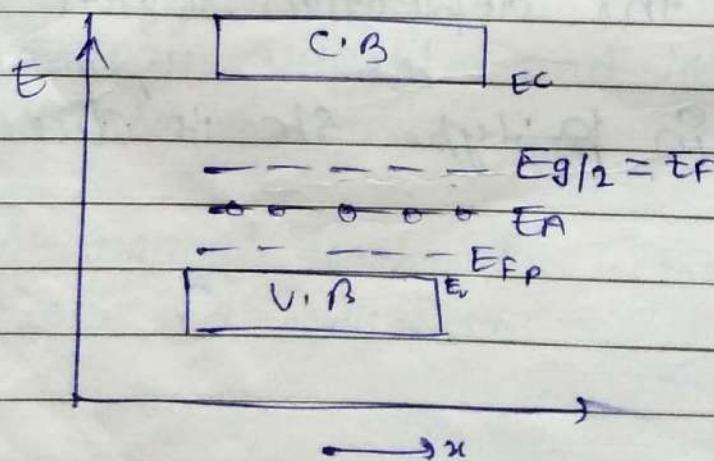
at 0K

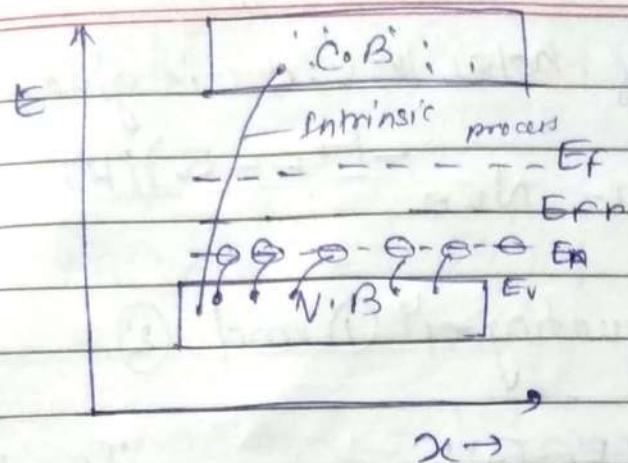


at 300K



(2) P-type SIC:





* Carrier Conc^y in P-type SiC at low temp.:

Let concⁿ of acceptor in the material is N_A

at 0K acceptor atoms are not ionised and remain at E_A

- At $T > 0K$ acceptor atoms get ionised and holes appear in valence band.

$$p = N_A^-$$

$p = \text{conc}^n$ of holes in V.B

$N_A^- = \text{No. of acceptor atoms that ionised.}$

$$N_A^- = N_A f(E_A)$$

$$p = N_A^- = N_A \times e^{(E_F - E_A)/kT}$$

$$p = N_A e^{(E_F - E_A)/kT} \quad \text{--- (1)}$$

Conc^h of holes in v.B is given by

$$p = N_v e^{-[E_F - E_V]/kT} \rightarrow ②$$

Now equating eq^h ① and ②

$$N_A e^{(E_F - E_A)/kT} = N_v e^{-[E_F - E_V]/kT}$$

by taking the log of both sides

and rearrange the terms

$$\frac{(E_F - E_A)}{kT} - \frac{(E_V - E_F)}{kT} = \ln \frac{N_v}{N_A}$$

$$E_F = \frac{E_V + E_A}{2} - \frac{kT}{2} \ln \left(\frac{N_A}{N_v} \right)$$

$$E_F = \frac{E_V + E_A}{2} - \frac{kT}{2} \ln \frac{N_A}{N_v}$$

$$E_F = \frac{E_V + E_A}{2} - \frac{kT}{2} \ln \frac{N_A}{2 \left(\frac{2\pi m^* k T}{h^2} \right)^{3/2}} \quad ③$$

at 0 K

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

$$e^{(E_V - E_F)/kT} = e^{\left(\frac{E_V}{kT} - \frac{E_V + E_A}{kT}\right)} e^{\ln\left(\frac{N_A}{2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2}}\right)^{1/2}}$$

$$p = N_A \exp\left[\frac{E_V - E_A}{kT}\right]$$

$$p = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2} \exp\left[\frac{E_V - E_A}{2kT}\right] \frac{N_A}{2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2}}$$

$$p = (q N_A)^{1/2} \left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2} \exp\left[\frac{E_V - E_A}{kT}\right]$$

It represent the majority charge carriers in p-type SC

* Extrinsic Conductivity

(1) Conductivity of n-type SC is given by

$$\sigma_n = n_n e \mu_e + p_n e \mu_h$$

$n_n \rightarrow$ concn of e^- in SC

As in n-type SC. $p_n \ll n_n$

$$\sigma_n = n_n e \mu_e$$

$$\& n_n = N_D$$

$$\boxed{\sigma_n = N_D e \mu_e}$$

② Conductivity for P-type SiC

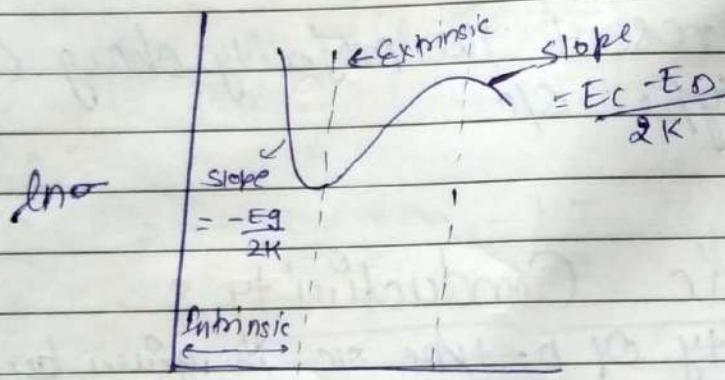
$$\sigma_p = n_p e \mu_e + p_p e \mu_h$$

$$p_p \gg n_p$$

$$p = p_p e \mu_h$$

$$p_p = N_A$$

$$\boxed{\sigma_p = N_A e \mu_h}$$



It shows the variation of σ with T in SiC

* Mass Action law:

Concⁿ of free e^- and holes are always equal in an Intrinsic SiC.

$n_i^2 = n = p$

- When n-type impurities are added to an Intrinsic SiC, Concⁿ of e^- increased similarly by adding a p-type impurity. Result in Reduction of free electrons.

- under thermal eq^b. Product of conc of free e[⊖] and holes is constant as is independent of amount of doping by donor or acceptor impurities this is known as mass action law.
- same is applicable for intrinsic q/s.
- * Fermi level in extrinsic semiconductors As carrier conc. in extrinsic q/s varies with temperature and impurities of conc. is added. so, the probability of occupancy of respective bands varies and consequently the position of fermi level changes thus with temp. and impurity conc.

In n type q/s

$$n = N_D - (E_C - E_F)/kT$$

$$n = N_D = N_c e$$

$$\text{or} \quad - (E_C - E_F)/kT$$

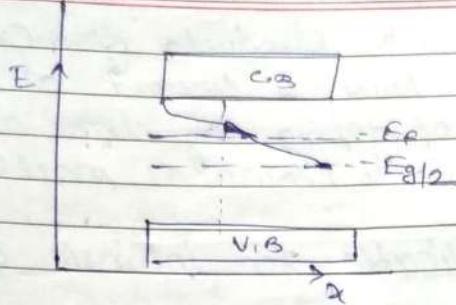
$$N_D = N_c e$$

taking the log

$$\log N_D = \log N_c - \frac{(E_C - E_F)}{kT}$$

$$\log \frac{N_D}{N_c} = \frac{E_F - E_C}{kT}$$

$$E_F = E_C - kT \log \left(\frac{N_c}{N_D} \right)$$



Now

In P type p/c

no. of Acceptor atom \gg no. of donor atom
and concn. of hole is given by

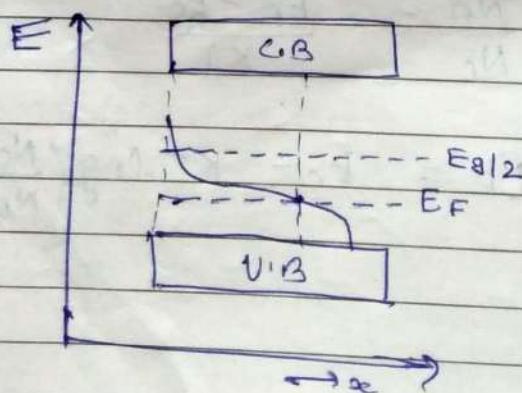
$$p = N_v e^{-[E_F - E_v]/kT}$$

taking the log of both side

$$\log p = \log N_v - \frac{[E_F - E_v]}{kT}$$

$$\log \frac{p}{N_v}$$

$$E_F = E_v + kT \ln \left(\frac{N_v}{p} \right)$$



At a
and
transfer
Or e
Acceptor

So, at
thermally

As E_F s
of Allo
be cle

* Calculat
Concn. \propto
 $\frac{1}{\ln n}$

majorities

minority

At a temp. Acceptor Atoms get ionised and V.B filled with holes created by transfer of electron to the acceptor atom. As e^- can easily move from V.B to Acceptor Energy level as compare to E_F .

So, at that temp. no. of holes- e^- pair generated thermally decreases.

As E_F representing Probability of occupancy of allowed Energy state. So E_F must be closer to V.B.

* Calculation of Minority charge carriers

Conc $n \div$

In n type of majority charge carriers

$$n_n = N_n$$

majorities $\rightarrow n_n \cdot p_n = n_i^2$

$$\boxed{p_n = \frac{n_i^2}{N_n}}$$

minority

$$\boxed{p_n = \frac{n_i^2}{n_n}}$$

Drift current: When an electric field is applied across a s/o the charge carriers move in drift motion over and above the thermal motion and produce Drift current.

e^- in conducting band produced Drift current density.

$$J_e = nev_e E$$

and holes in V.B produced the drift velocity density.

$$J_p = bv_p n_p E$$

then total drift current

$$J = J_e + J_p$$

$$J_{\text{diff}} = (pM_p + nM_e)ee$$

drift current occurs only when external electric field is present across the solid.

Diffusion Current:

In case of S/I current

in ~~extern~~ absence of E.F a spatial variation of carrier concn or carrier density is found in the S/I

and current starts to flow in it.
if we consider an arbitrary volume or arbitrary surface in a volume of a solid and if there is more charge carriers on one side then the other side or we can say that there is a concn gradient in the material.

due to the concn gradient a directional moment of carriers which continue until all the carriers are equally distributed throughout the material. any moment of charge carriers constitutes an electric current and this type of moments produced a current component known as diffusion current

diffusion current \propto conc⁴ of gradient
 \propto rate of change of conc
of charge density

the current density due to e diffusion
is equal to

$$J_e = e \cancel{D}_e \frac{dn}{dx}$$

donor density

$$J_e = e N_D \frac{dn}{dx}$$

and due to holes

$$- T - - e \cancel{D}_p \frac{dk}{dx}$$

UNIT-3

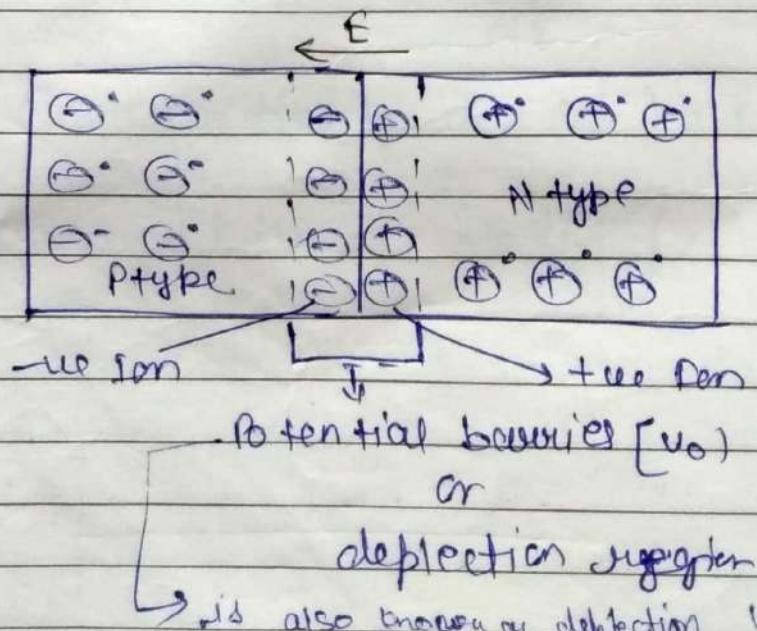
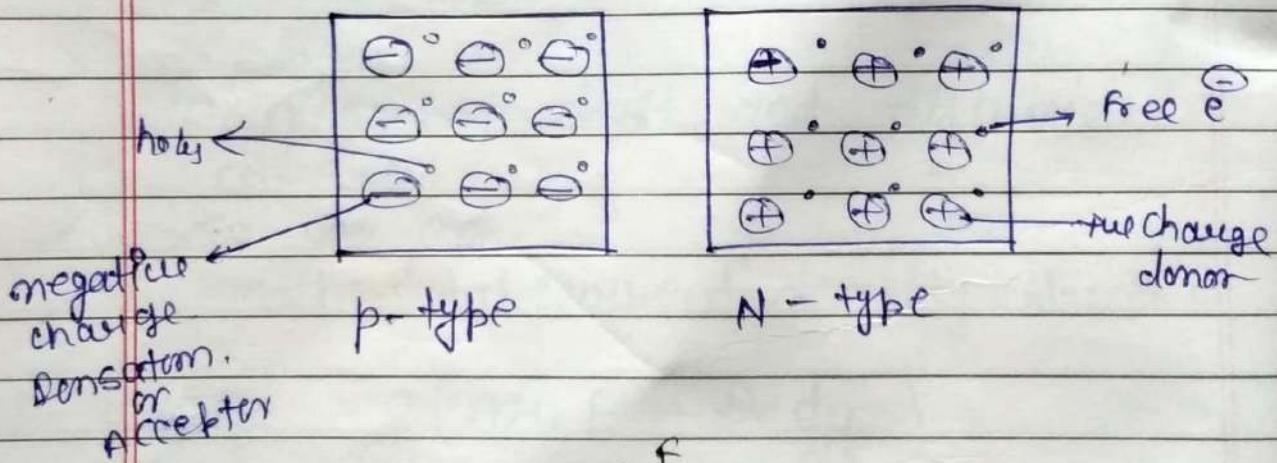
PN Junction

16/10/18

DATE: / 20
PAGE NO

PN Junction is formed from a piece (sic) by diffusing p-type material to one half side and n-type material to another half side. plane so divided by two zones is known as PN Junction.

P-type sic has negative acceptor ions and positive charge free holes which move on the p side similarly n-type sic has positive donor atoms and free electrons which move about n side.



P region has large conc' of holes and n region has large conc' of e^- due to this conc' difference holes diffuse from p to n side and e^- diffuse n to p side this process is known as diffusion.

These diffuse e^- s and holes terminate their existence by recombination.

Due to recombination process free and mobile e^- s and holes a large no. of positive ion forms in the n region near the junction and similarly a layer of negative ion in p region near the junction.

Near the negative ion on p side repeat the e^- s and positive ion on n side repeat the holes. In this way a barrier is developed which is known as potential barrier due to this barrier formation after a short time diffusion process stop and eqb achieved.

x

* Variation of Imparience of potential barrier:
potential barrier does not allow electron and holes to cross the junction and if we want that charge carriers cross the junction then an external voltage of appropriate potential has to be applied in order to overcome the opposition of barrier potential

(2) Electron

$E = \frac{q}{E}$

The following factors deciding the barrier potential

1. SiC material based
2. Intrinsic concn of silicon and b.e before doping
3. Level of doping
4. temp.

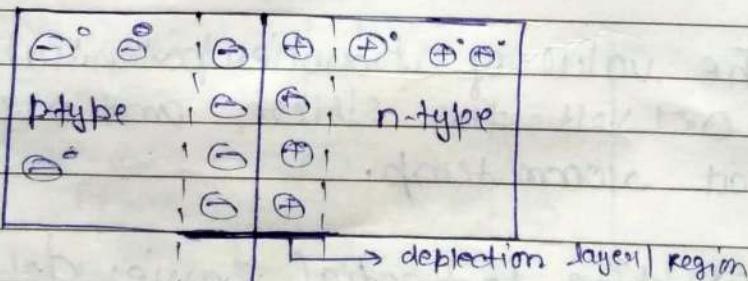
(3) Potential

$$E = -\frac{dV}{dx}$$

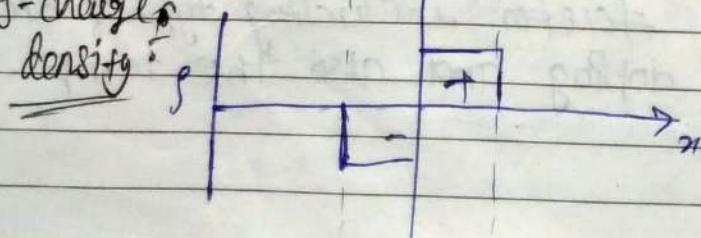
$$V = -$$

* Variation of charge density electric field intensity and potential with in depletion layer:

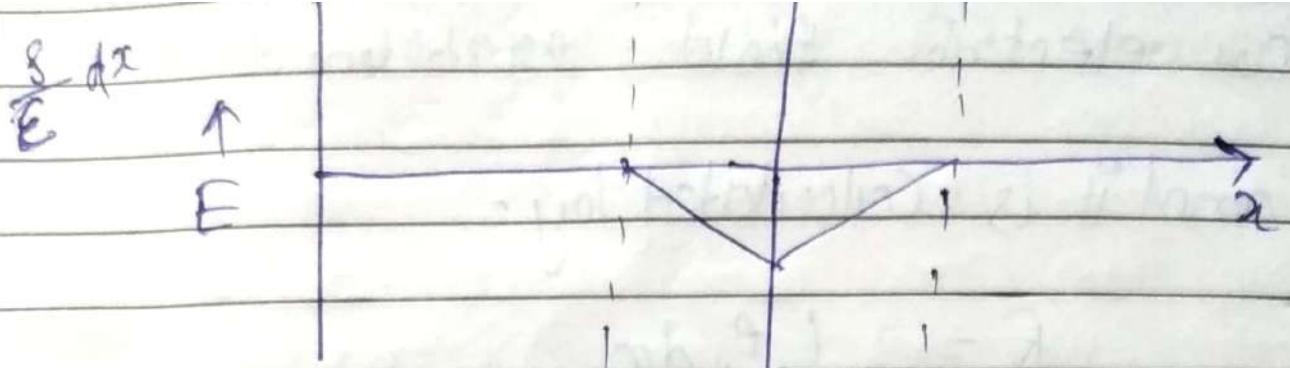
1. space in between depletion layer and



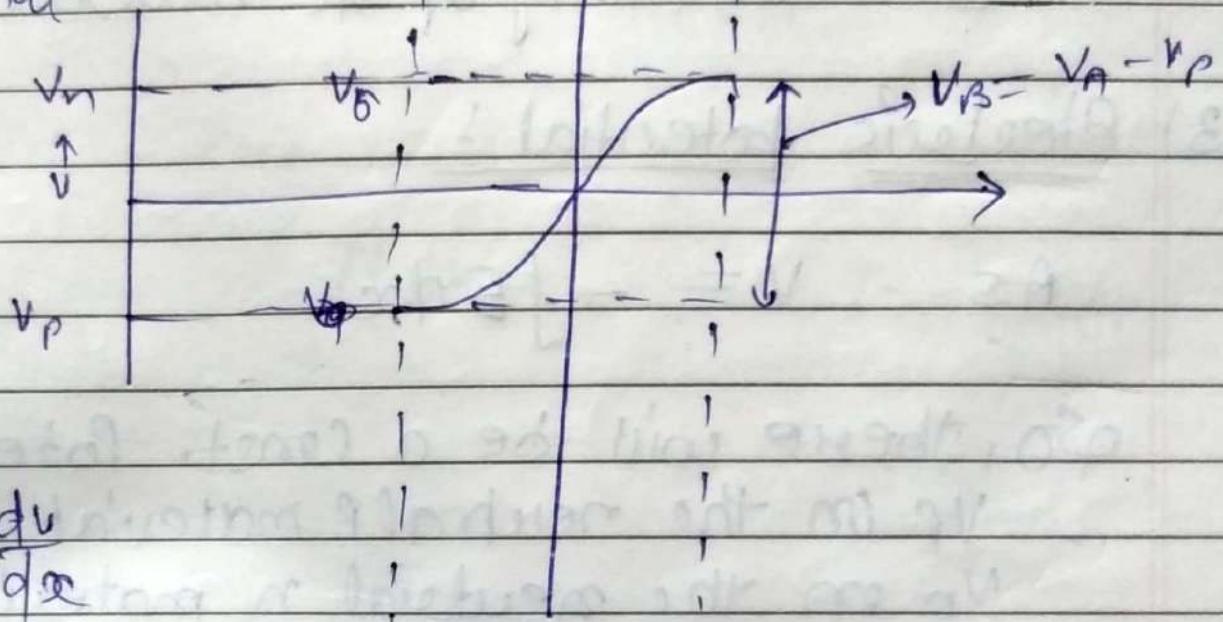
(1) f-charges density: s



2. Electric field intensity in the depletion layer



Potential



$$E = -\frac{dv}{dx}$$

$$V = - \int E dx$$

Space charge density contains negative in p region and positive in n region because the charge density negative in depletion region in p side

and $S=0$ at the junction.

layer. In this case there will be electric flux lines from right to left and electric field established.

and it is calculated by -

$$E = \frac{F}{\epsilon}$$

ϵ = Permittivity of SiC material.

(3) Electric potential :

$$\text{As } V = - \int E dx$$

so, there will be a const. Potential V_p on the neutral P material and V_n on the neutral n material

$$\text{then } V_B = V_n - V_p$$

i.e known as contact potential.

and it is given by

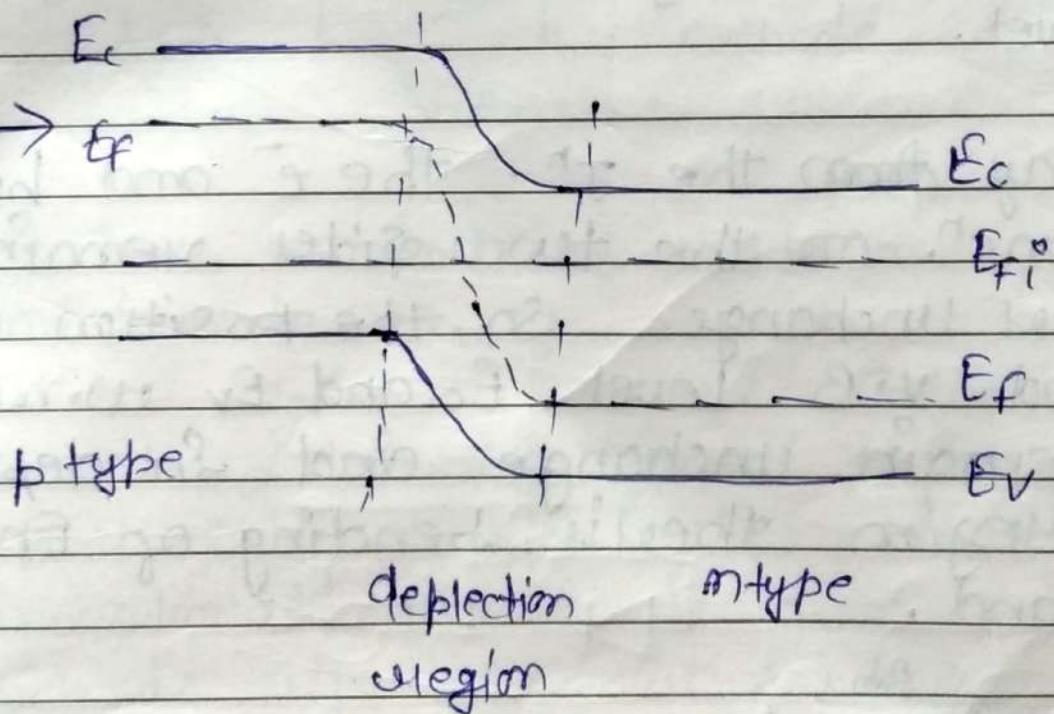
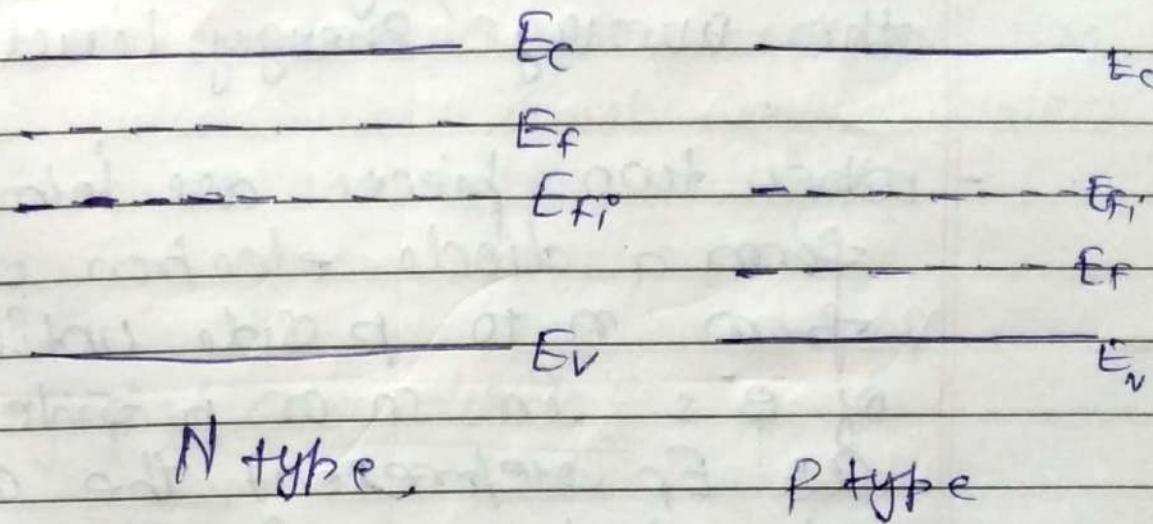
$$V_B = V_n - V_p$$

due to influence of strong electric field set up by the barrier potential when external electric field is equal to zero then no mobile charge carriers cross the junction or we can say

$$J_{\text{diffuse}} + J_{\text{drift}} = 0$$

$$J_{\text{diffuse}} + J_{\text{injection}} = 0$$

Energy band diagram of P-N Junction



P-N Jⁿ under thermal equilibrium

As in n-type SiC E_F is close or near the E_C so, that electrons are occupying the higher energy level whereas falls of E_F shows the decrease the Energy content of electron or we can say that E_F indicates the average energy level

When two pieces are join together to form a diode electron will transform from n to p side until avg. energy of e⁻s in n or p side is same as E_F represent the avg. Energy of electrons. So, they are trying to align together at the same Level.

Away from the J. the e⁻ and holes concn. on the two sides remain same or unchange. So, the position of C.B and V.B Level E_C and E_V w.r.t E_F remain unchange and in depletion region there is bending of Energy band.

Bias

Biasing of

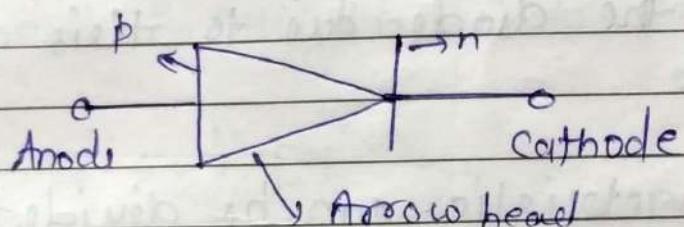
1) What is Biasing, type,

* P-N Junction Diode:

A P-N junction is known as P-N Junction diode or SIC diode. This is also known as crystal diode. Because ~~this~~ it is found in a crystal (Si or Ge).

A P-N junction diode is a ~~uni~~ directional two terminal SIC device which conducts current only in one dirn and offers a higher resistance in other direction.

* Crystal symbol of a diode:



The two terminals of diode are called anode and cathode. The P region is called anode and n-region is called cathode. Arrowhead in the symbol points from P to n side which shows that dirn of conventional current is from P to n side which is also the dirn of hole current or flow of holes.

* V-I characteristic of p-n junction diode!

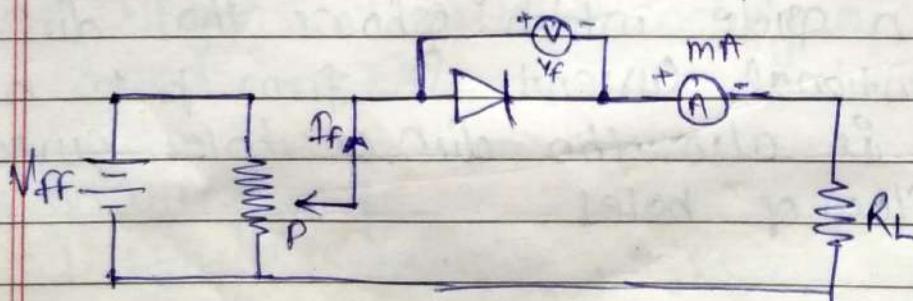
If diode is used in an electrical circuit it is imp. to know that how it response or behave in elect'n's circuit this type of information may be known obtained by a curve known as volt amperie or V-I characteristic of a particular diode.

V-I characteristic of a diode is simple a curve. Shows Voltage applied across its terminal or current that flow through the diode due to this applied voltage.

V-I characteristic can be divided into two parts

- (i) forward characteristic
- (ii) reverse "

(i) forward characteristics:



- The diode in the circuit is forward bias because battery N_{ff} is pushing

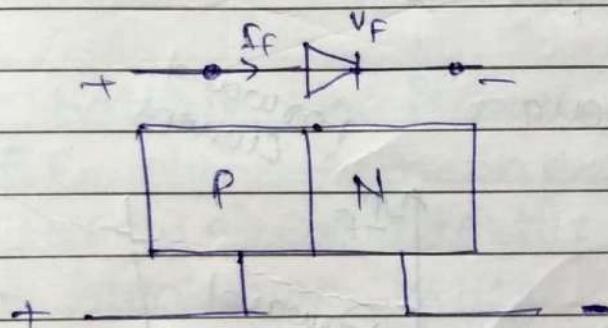
the current in direction of arrow head.

Battery V_F is connected to the diode through the potentiometer (P). Potentiometer (P) helps in varying the voltage across the diode.

Load Resistance (R_L) is used in the circuit to limit current through the diode.

A voltmeter is connected across the diode to measure the voltage.

A ~~red~~ ammeter is connected to measure current in the circuit.



Forward characteristics

The voltage across the diode increases gradually and corresponding increase in current is noted. The graph is plotted by taking voltage along the x-axis and current along the y-axis.

from the graph, it is seen that upto a point current is very small and this is due to the applied voltage has to over come the potential barrier. So, In this region diode conduct poorly.

- once applied voltage is increased then it overcome the potential barrier and current increases steeply thus voltage at which current increase suddenly is known as knee voltage and it is denoted by V_0

$$V_0 = 0.3 \text{ for Ge}$$

$$= 0.7 \text{ for Si}$$

* Reverse chara forward current

I_F

forward
bias
region

- Th

V_R

a

b

c

$-V_R$
Reverse
bias

point

knee

cutting
voltage

forward
bias

R

0

J-SF Reverse
current

The battery V_{RR} is pushing the current in
dpr opposite to the arrow head
the reverse characteristic shows that below
breakdown voltage diode current is
very small and almost cons. this
current is known as reverse saturation
current and denoted by I_0

So I_R of the order of $10^{-12} A$ for Ge
and $10^{-10} A$ for silicon diode.

Reverse saturation current is due to the
movement of minority charge carriers which
are thermally generated so ~~so~~ ~~not~~
dep is depend on temp.

and does not depend on Reverse bias voltage.

* Breakdown voltage:

V_B is the minimum reverse voltage at which P-N junction breakdown with sudden increase in current in reverse dir.

* Breakdown voltage: In forward bias to P-N J^N a very small current flows until the forward voltage exceeds the junction potential. This forward voltage at which current through the junction increases rapidly is known as break down voltage or cut off voltage.

* P-Reverse voltage:

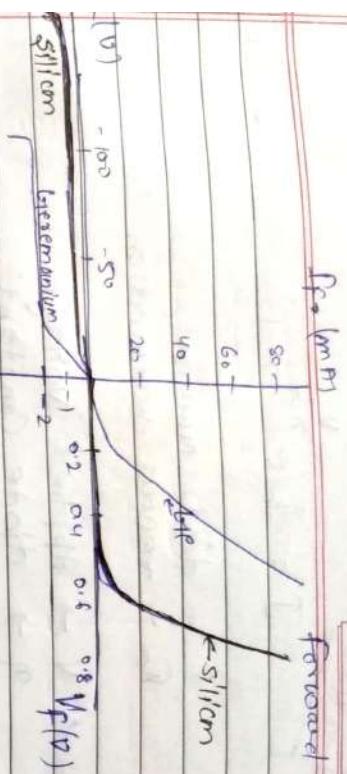
If the max. reverse voltage that can be applied to p-n junction diode without damage the junction.

If reverse voltage exceeds the it's peak reverse voltage it may get destroyed due to over heating.

* V-I characteristic for one and si.:

$I_f = \text{current}$

forward bias



$I_f (mA)$

knee volt.

Cut off voltage for Si is 0.6 volt
and for Ge is 0.2 volt.

The breakdown voltage for Si is higher than that of Ge. because Si can withstand a higher reverse voltage.

Increase saturation current for Ge is 10 μA and for Si nearly 20 μA at room temp.

Diode current eqn.:

In solid state phys. diode current eqn.
relating voltage and current for forward bias and increased bias can be given by

I = diode current
 I_0 = reverse saturation current

V → Applied Voltage

$\eta \rightarrow$ diode Constant
 $n=1$ for I_0 , $n=2$ for I .

$$V_T = \frac{k_B T}{e} = \frac{1.38 \times 10^{-23} T}{1.6 \times 10^{-19}}$$

$$V_T = \frac{T}{11,600}$$

at Room temp $T = 300K$.

$$V_T = 26mV$$

$$I = I_0 [e^{40V/n} - 1]$$

for I_0 $n=1$

$$I = I_0 [e^{40V} - 1]$$

for I_0 : $n=2$

$$I = I_0 [e^{20V} - 1]$$

$$V_f = 0.7 \text{ (1)}$$

Find V_f , V_e and T

30/10/18

* Rectifiers

A rectifier is a circuit which is used to convert AC voltage into pulsating DC voltage.

There are two types of rectifiers used:

- (i) half wave rectifier [HWR]
- (ii) full wave rectifier [FWR]

(i) Half wave rectifier : [HWR]

- (i) In HWR rectifier conducts current only during the positive half cycle of AC supply.

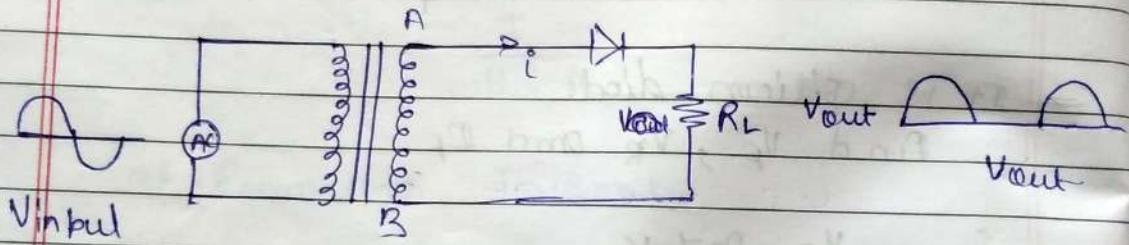


Fig - (a)

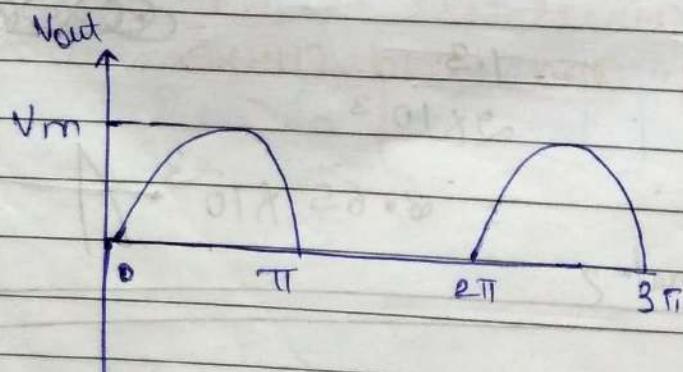
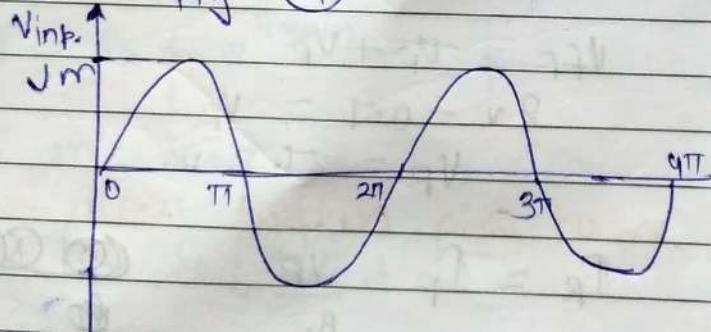


Fig - (b)

iii) The negative half of AC supply are suppressed as there is no current conduct and hence no voltage appears across the load.

* Circuit details:

- circuit has a single crystal diode which acts as a half wave rectifier
- The AC supply to be rectified is applied in series with the diode and load resistance R_L .
- AC supply generally going through a transformer as there are two advantages of transformer
 - (i) it allows to step up or step down the AC input voltage as the situation demands
 - (ii) Transformer isolates the rectified circuit from power line and thus reduce the risk electric shock.
- The input and output waveform of rectifier
(Fig-3)

- To calculate the DC value of output voltage and Load current for HWR?

$$v_o = v_m \sin \omega t \quad \text{for } 0 \leq \omega t \leq \pi$$

$$v_o = 0 \quad \text{for } \pi \leq \omega t \leq 2\pi$$

A

e-1

DATE:	1 / 20
PAGE No	

Dc value or avg. value of o/p voltage
is expressed as

Vag. = Vdc = Area under the curve over full cycle
Rate.

$$\begin{aligned} \text{Area} &= \int_{0}^{2\pi} v_o d(\omega t) = \int_{0}^{\pi} v_o d(\omega t) + \int_{\pi}^{2\pi} v_o d(\omega t) \\ &= \int_{0}^{\pi} v_o \sin \omega t d(\omega t) + \int_{\pi}^{2\pi} 0 d(\omega t) \end{aligned}$$

$$\text{Area} = V_m \left[-\cos \omega t \right]_0^{\pi} = 0$$

$$\text{Area} = V_m [-\cos \pi - (-\cos 0)]$$

$$= 2V_m$$

$$Vdc = \frac{2V_m}{2\pi} = \frac{V_m}{\pi}$$

$$\boxed{Vdc = 0.318 V_m}$$

Similarly

$$I_{dc} = \frac{Vdc}{R_L} = \frac{V_m}{\pi R_L} = \frac{0.318 V_m}{\pi R_L}$$

$$\boxed{I_{dc} = 0.318 \frac{V_m}{R_L}}$$

The above calculation is considered by assuming that diode resistance in forward biased is zero.

then if forward resistance R_f is taken

$$V_{dc} = \frac{V_m}{\pi} - f_{dc} R_f$$

$$f_{dc} = \frac{V_m}{\pi [R_L + R_f]}$$

* Peak inverse value of voltage of half wave rectifier.

During negative cycle diode is reverse bias and does not conduct the current so, the current in the circuit is zero and voltage across R_1 is also zero and hence whatever is the supply input voltage it will appear across reverse bias and max. value of this reverse voltage occurs at peak of next negative cycle of input voltage i.e. V_{m2} . This voltage is called peak reverse voltage and it depends on

$$P.T.V = V_m$$

* Drawback (i) The pulsating current in the load contains alternating components whose basic freq. is equal to supply freq. so, an elaborate filtering is required to produce steady direct current.

- (ii) AC supply delivers only power only during the half time, so output is low.
- (iii) circuit has low transformer utilization factor. which means transformer is not completely utilized.
- (iv) Efficiency of rectification is also low (which is equal to 40% theoretically but actual practice value is less than 40%)

* Repell factor (γ) :-

It is given by ratio value of AC comp. of O/P

$$\gamma = \frac{\text{rms value of ac component of O/P}}{\text{dc component of O/P}}$$

V_{rms} = rms value of ac component

N_{dc} = avg. or dc component

I_{rms} = rms value of ac component

I_{dc} = dc value of load current

Q) Output voltage or load current of a rectifier contains two components mainly dc component and ac component. ac comp. present in output is called a ripple. This ripple accounts for pulsations in the output of rectifier and are undesirable. So, effectiveness of a rectifier depend on magnitude of ripple. In output is smaller in ripple more effectively is the rectifier.

Mathematically ripple factor is calculated by

$$\gamma = \frac{V_{rms}}{V_{dc}} = \frac{I_{rms}}{I_{dc}}$$

$$I_{rms} = \sqrt{I_{ac}^2 + I_{dc}^2}$$

$$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

$$\gamma = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

Now the general expression for ripple factor

for Half w.r.t:

$$\gamma = \sqrt{\left(\frac{I_{m/2}}{I_{m/1}}\right)^2 - 1}$$

$$\omega = 100 \text{ rad/s}$$

Ans A

* Rms Load current (I_{rms}) of HWR:

$$I_{rms} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} i_L^2 d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{1}{2\pi} \left[\int_0^{\frac{\pi}{2}} i_m^2 \sin^2 \omega t d(\omega t) + \int_{\frac{\pi}{2}}^{2\pi} 0 d(\omega t) \right]}$$

$$I_{rms} = I_m \sqrt{\frac{1}{2\pi} \int_0^{\pi} \frac{1 - \cos 2\omega t}{2} d(\omega t)}$$

$$I_{rms} = I_m \sqrt{\frac{1}{4\pi} [(\pi - 0) - (0 - 0)]}$$

$$I_{rms} = \frac{I_m}{2} \quad \text{Rms Load current of HWR.}$$

* Efficiency of rectification:

It is defined as the ratio of dc power delivered to load to AC input power from secondary windg of transformer

$$\eta = \frac{\text{Output dc power}}{\text{Input ac power}}$$

$$\eta = \frac{P_{dc}}{P_{ac}}$$

$$\eta = \frac{I_{dc}^2 \times R_L}{V_{rms}^2 (R_L + R_F)}$$

for HWR

$$\eta = \frac{I_m^2 / \pi^2 \times R_L}{\frac{E_m^2}{4} (R_L + R_F)} - \frac{4 R_L}{\pi^2 (R_L + R_F)}$$

$$\boxed{\eta = \frac{0.406}{(1 + \frac{R_F}{R_L})}} \quad (2)$$

η will be max. if $R_L \gg R_F$

$$\eta_{max} = 0.406 = 40.6\%$$

* Transformer utilization factor (TUF) :
It is defined as the ratio of dc Power delivered to the load to total AC rating of transformer.

TUF = dc Power to load
AC Power rating of transformer

$$TUF = \frac{I_{dc}^2 R_L}{V_{rms} \times I_{rms}}$$

$$TUF = \left(\frac{0.318 I_m}{2}\right)^2 \times R_L$$

$$\frac{V_m}{2} \times \frac{I_m}{2}$$

$$0.025 R_L$$

~~$$0.101 I_m^2 \times R_L$$~~

~~$$0.025 R_L$$~~

Q. Find the transformer utilization factor for HWR.

[in DC consider
continuous RF condition]

$$TUF = \frac{\text{DC Power}}{\text{AC Power}} = \frac{V_{dc} \cdot I_{dc}}{V_{ac} \cdot I_{ac}}$$

af

$$TUF = \frac{I_m}{\pi} \cdot \frac{V_m}{\pi} = \frac{V_m}{2} \cdot \frac{I_m}{\pi^2}$$

$$TUF = 0.406 = 40\%$$

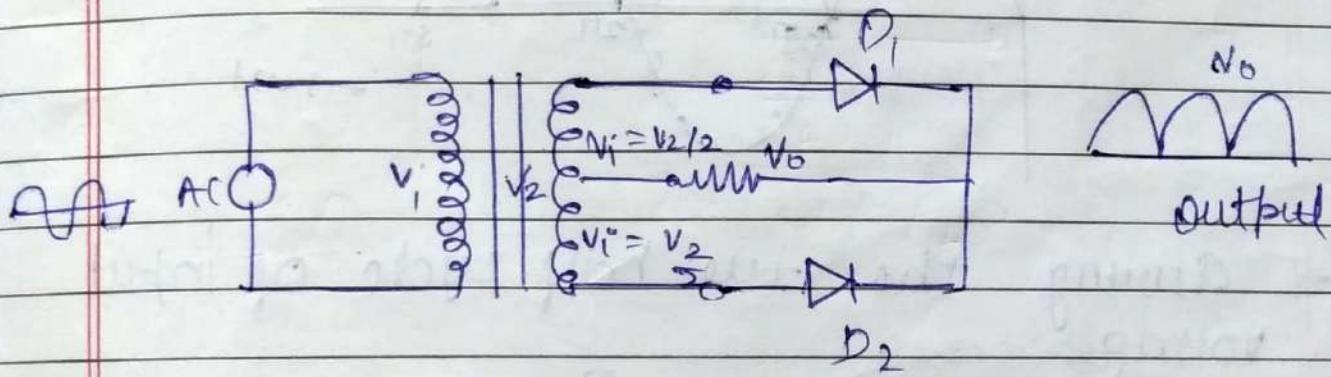
* full wave rectifier:

In full wave rectification current flows through the load in same dirⁿ for both cycles of AC input voltage. This can be achieved by using two diodes in coacting conditions or alternately there are two types of full wave rectifier

- (i) centre tap full wave rectifier
- (ii) bridge full wave rectifier

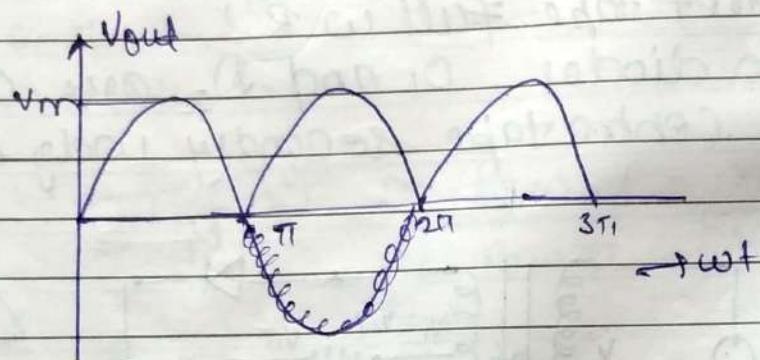
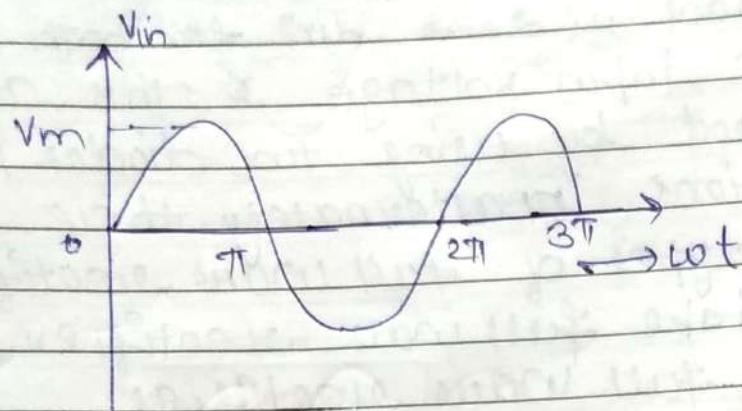
(i) centre tap full wave:

Two diodes D_1 and D_2 are connected to centre tap secondary wdg of transformer



Input voltage is applied to the primary of transformer. The voltage b/w one end of secondary and centre tap is equal to ~~center~~ half of secondary voltage. It means if applied voltage across primary is V , and across secondary is

Working :



- during the first half cycle of input voltage

let v_i be the instantaneous value of voltage across secondary then v_i is equal to $V_m \sin \omega t$

$$v_i = V_m \sin \omega t$$

- for the cycle diode D_1 is forward biased and D_2 is reverse biased. Hence D_1 conducts and D_2 is in cutoff position. A current I_L flows through R_L producing output voltage V_o .

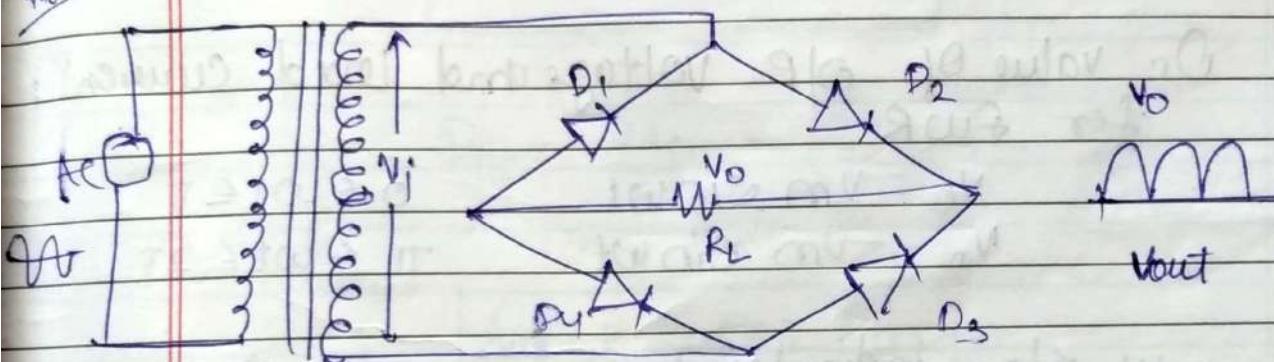
- during negative half cycle D_1 is reverse bias and D_2 is forward bias hence D_1 is in cut off position and D_2 is forward bias.

flow through R_L Producing output voltage V_o

* full wave Bridge Rectifier

Bridge Rectifier uses four diodes which are connected across secondary of transformer

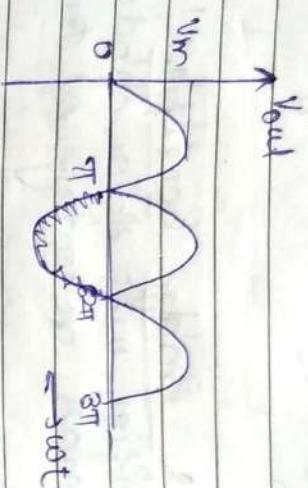
Low power loss
high efficiency



- During +ve half cycle D_2 and D_4 are in F.B cond'n and they conduct and output voltage develop across the resistor R_L

- During -ve half cycle D_1 and D_3 are F.B and conducts. D_2 and D_4 are reverse bias and in cut off position. So and output voltage obtain $\frac{V_o}{R_L}$

ωt



* DC value of output voltage and load current

for full R

$$V_o = V_m \sin \omega t$$

$$V_o = -V_m \sin \omega t \quad \pi < \omega t < 2\pi$$

- w sign indicates during second half cycle, sine wave is inverted.

$$V_{avg} = V_{dc} = \text{Area under the curve over full length}$$

Base

$$\begin{aligned} \text{Area} &= \int_0^{\pi} V_o d(\omega t) + \int_{\pi}^{2\pi} V_o d(\omega t) \\ &= \int_0^{\pi} V_m \sin \omega t d(\omega t) + \int_{\pi}^{2\pi} -V_m \sin \omega t d(\omega t) \end{aligned}$$

$$= [V_m \cos \omega t]_0 + [V_m \cos \omega t]_{\pi}$$

$$= V_m [-\cos \pi - \cos 0] + V_m [\cos 2\pi - \cos \pi]$$

$$= V_m [-1+1] + V_m [1+1]$$

$$\text{Area} = 4V_m$$

$$V_{dc} = \frac{4V_m}{2\pi} = \frac{2V_m}{\pi}$$

$$V_{dc} = 0.636 V_m$$

$$P_{dc} = \frac{V_{dc}}{R_L} = \frac{2V_m}{\pi R_L} = \frac{2P_m}{\pi}$$

$$V_{dc} = 0.636 P_m$$

Peak inverse voltage (PIV):

concrete take PIV: During the true half cycle
diode D_1 conducts and D_2 cut off if

$$V_t = V_m \sin \omega t$$

where V_m is the max. or peak value
across half secondary wdg

D_1 is $\frac{1}{2}B$ and offers almost zero resistance
 \therefore across voltage V_m appears across R_L

- D_2 in reverse bias and total voltage across D_2 is sum of voltage drop across lower half of secondary and V_m across R_L . So,

$$P_1 V = V_m$$

viii) for Bridge Rectifier!

Diodes D_1 and D_3 are not conducting whenever as D_2 and D_4 are conducting the voltage drop across D_2 and D_4 may be assumed zero bcz they are in fig conditions

The reverse voltage across non conducting D_1 and D_3 is equal to V_m

$$\text{so, } P_1 V = V_m$$

* RMS value of Load Current of FWR ($I_{L\text{av}}$) *

$$I_{L\text{av}} = \sqrt{\frac{1}{2\pi} \int_{0}^{2\pi} I_L^2 d(\omega t)}$$

$$I_{L\text{av}} = \sqrt{\frac{2}{2\pi} \int_{0}^{\pi} I_L^2 d(\omega t)}$$

$$I_{rms} = \sqrt{\frac{1}{\pi}} \int_0^{\pi} I_m^2 \sin^2 \omega t d(\omega t)$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} \left[\frac{1}{\pi} \int_0^{\pi} 1 - \cos \omega t - \sin^2 \omega t \right]^{\frac{1}{2}}$$

$$I_{rms} = I_m \sqrt{\frac{1}{\pi} \int_0^{\pi} \left[\frac{\omega t}{2} - \sin^2 \omega t \right]^2}$$

2-

$$I_{rms} = I_m \sqrt{\frac{1}{2\pi} \int_0^{2\pi} [\pi - \theta]^2}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

This is rms load current of FWR.

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

* Ripple factor of FWR:

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}} \right)^2 - 1}$$

$$I_{dc} = \frac{2I_m}{\pi} \quad I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$\gamma = \sqrt{\left(\frac{I_m \sqrt{2}}{\frac{2I_m}{\pi}} \right)^2 - 1}$$

$$\gamma = \sqrt{\frac{\pi^2}{8}} \approx 0.48$$

$$\gamma = 0.482 \text{ (FWR)}$$

$$\gamma = 1.21 \text{ (HWR)}$$

Hence we seeipple factor of FWFR is much smaller than HWR. due to this reason it is widely used.

* Efficiency of rectification in FWFR:

$$\eta = \frac{\text{Output dc Power}}{\text{Input ac Power}}$$

$$\eta = \frac{P_{dc}}{P_{ac}} \quad P_{dc} = I_{dc}^2 \times R_L$$

$$P_{ac} = I_{rms}^2 \times (R_L + R_F)$$

$$\eta = \frac{I_{dc}^2 \times R_L}{I_{rms}^2 (R_L + R_F)}$$

$$\eta = \frac{\frac{4I_{rms}^2}{\pi^2} \times R_L}{\left(\frac{I_{rms}}{\pi}\right)^2 \times (R_L + R_F)}$$

$$\eta = \frac{8}{\pi^2} \frac{R_L}{(R_L + R_F)}$$

$$\eta = \frac{8}{\pi^2} \cdot \frac{R_L}{(R_L + R_F)}$$

$$\eta = \frac{0.812}{1 + \frac{R_F}{R_L}}$$

η will be max. if $R_L \gg R_F$

$$\eta_{max} = 0.812 = 81.2\%$$

η for FWR = 2 HWR.

* TUF of FWR :

TUF of a centre tapped is calculated for secondary & primary coils separately and then avg. TUF is calculated

$$TUF(\text{secondary}) = \frac{\left(\frac{2fm}{\pi}\right)^2 R_L}{\frac{V_m}{\sqrt{2}} \times \frac{fm}{R_2}}$$

$$\text{As } V_m = fm R_L$$

$$TUF = 0.812 = 81.2\%$$

As we know that FWR consist of 2HWR

$$\begin{aligned} TUF(\text{Primary}) &= 2 \times TUF \text{ of HWR} \\ &= 2 \times 0.287 \\ &= 0.574. \end{aligned}$$

$$\text{Total TUF of FWR} = \frac{\text{Primary TUF}}{2} + \frac{\text{Secondary TUF}}{2}$$

$$\text{Total TUF for FWR} = \frac{0.574}{2} + \frac{0.814}{2} = 0.693$$

- * Breakdown mechanism: In a P-N junction there are two types Breakdown mechanism
 - (i) Zener breakdown
 - (ii) Avalanche

(i) Zener breakdown:
zener breakdown occurs in zener diodes having $V_Z < 5$ volt or also 5 to 8 volt.

(ii) When a reverse voltage of 5 volt applied to a zener diode it caused a very intense electric field to appear across a narrow depletion region field intensity is typically of the order of 3×10^5 volt/cm. Such an intense electric field is strong enough to pull some of the valence electron into C.B by breaking covalent bond these electrons become free and available for conduction.

(iii) Large no. of these free electrons constitute a large reverse current through zener diode and breakdown occurs due to zener effect

(iv) A current source to pass excess

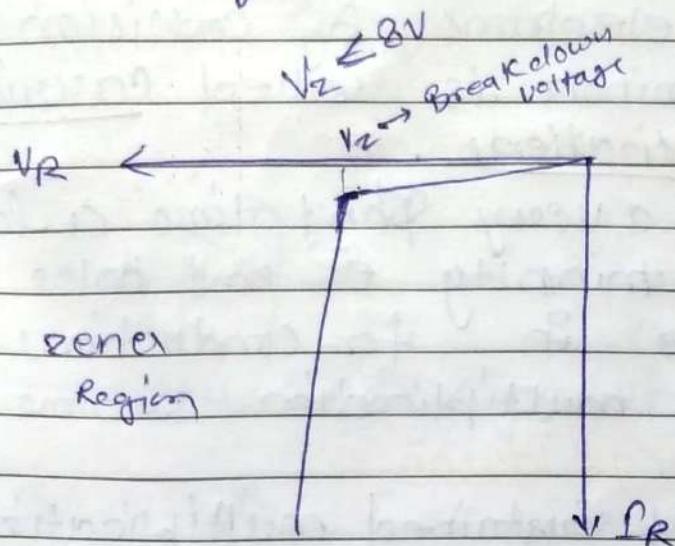
(iii) Avalanche
A.V.B

- In Re only due the diode acce

- These cell imba elect

- Due these cond

(iii) A current limiting resistance should be connected in series with the zener diode to protect it against damage due to excess heating

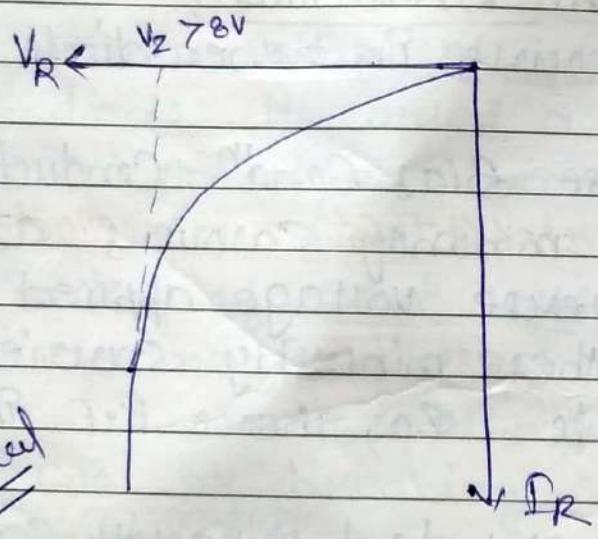


(ii) Avalanche Breakdown:

- A.B occurs in zener diode with $V_Z > 8V$
- In Reverse Bias Cond'n. conduction take place only due to minority carriers as we increase the reverse voltage applied to zener diode these minority carriers tend to accelerate So, their K.E increases
- These accelerated minority carriers will collide with stationary atom and impart some of the K.E to valence electron Present in covalent bond
- Due to this additional Aquant Energy these valence electron will break their Covalent bond and jump to C.B.

carrier multiplication become self sustained

this self sustained multiplication is called avalanche effect



~~QMP~~ P
Numerical

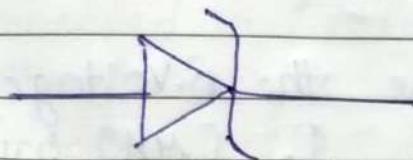
* Zener diode :

- (i) It is a reverse biased heavily doped p-n junction diode which operate in breakdown region.
- (ii) Reverse breakdown of a p-n junction may occurs either due to zener effect or avalanche effect

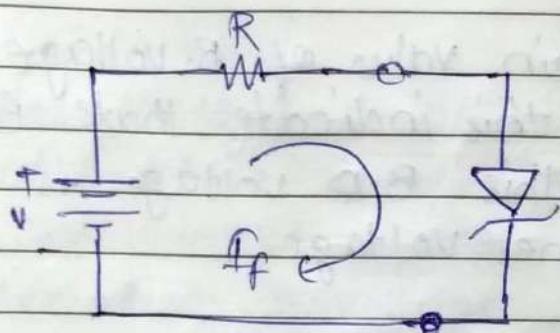
~~V.K Mottey~~

viii) Zener effect dominant at reverse voltage $\leq 6V$ where A-Effet dominant above $6V$

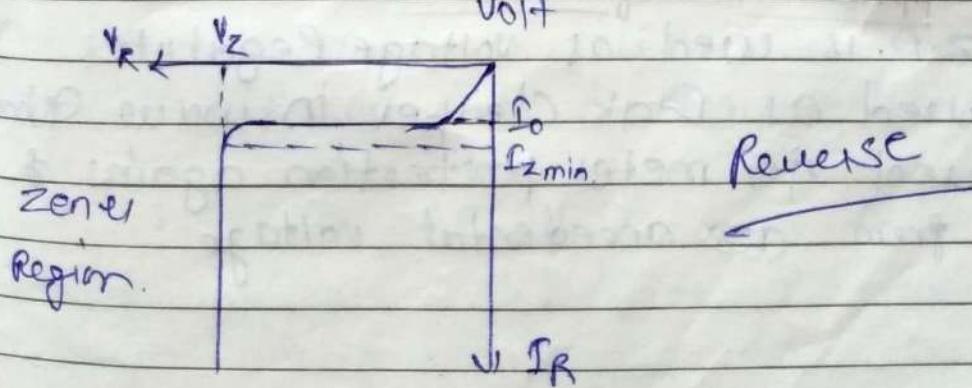
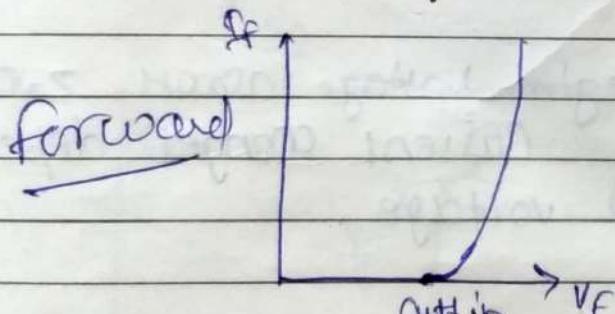
iv) Breakdown voltage of zener by setting the doping σ



zener diode symbol



* V-I characteristic of zener diode:



V-I characteristic are divided in two

F. char.

- Reverse char.

- * Forward char. is same as the P-N junction diode
- * Saturation current I_0 (mA) is same
- * As we increase the R.Voltage initially a small current I_0 (mA) will flow due to minority carriers
- * At a certain value of R.Voltage if increase suddenly this indicate that Breakdown occurs this B.D voltage is known as breakdown voltage
- * After B.D a zenerdiode operates in a region called a zener Region.

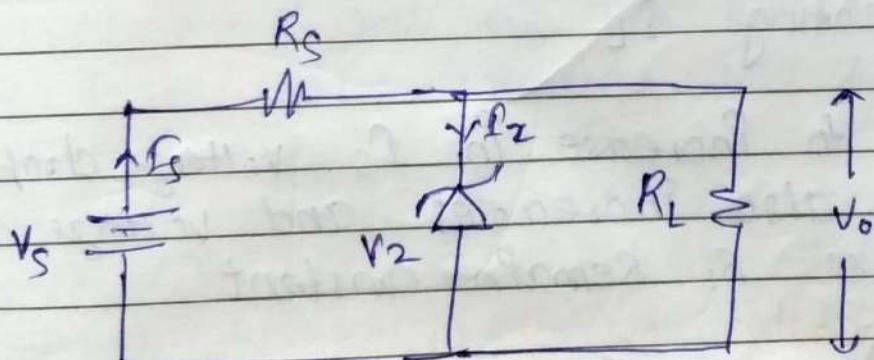
On this region Voltage across Z.D remain const. but Current changes depending on supply voltage.

* Application of Z.D

- * Z.D is used as voltage Regulator
- * used as Peak Clipping in wave Shaping
- * used for meter protection against damage from over accidental voltage

A) Zener diode as Voltage Regulator!

- voltage Regulator is a circuit whose job is to maintain a const. output DC voltage inspite of the AC input voltage fluctuating or changes in load resistance
- So this is called shunt Regulator bcz the Z.D is connected in parallel or shunt with the load resistance
- R_s is connected to limit the current in the circuit
- Regulated Voltage is obtained across the load resistance R_L for the operation of the ckt. Input voltage V_s should be greater than z-voltage V_z only then diode operate in Breakdown region



Op current is calculated

$$I_s = I_2 + I_L$$

$$I_S = I_Z + I_L$$

$$V_S = I_S R_S + V_Z$$

$$I_S = \frac{V_S - V_Z}{R_S}$$

$$V_O = V_Z$$

$$I_Z = I_S - I_L$$

* Working!

(i) Case i: Regulation when input voltage is variable!

* In this case R_L is fixed V_S is varying when P/P voltage is I_{ES} current is also I_{ES}

* It means $I_S = I_Z + I_L$ increases without

affecting I_L

* Due to increase in I_S voltage drop across R also increases and voltage drop across R_L remains constant

Case ii when R_L is variable

* In this case V_S is fixed

* When R_L decreases I_L increases which causes I_Z to decrease due to this voltage drop across R_S remains constant.

and V_L is also remain constant.

* Drawbacks:

- * O/P voltages varies slightly due to zener resistance (R_S)
- * efficiency is low for heavy Load current bcz there is considerable lossing R_S .

13/11/18

* LED (Light Emitting Diode):

LED is a special type of P-N PN Jⁿ that under F.B Condⁿ can emit external spontaneous radiation (this radiation is UV, visible and infrared region) they are widely used as visual indicator as well as moving light display.

* Constructions:

Direct Band gap s/c (ex-GaAs, GaP, AlAsP) used as light emission and Tim Light emitted by three Process

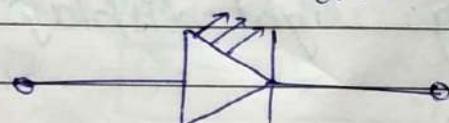
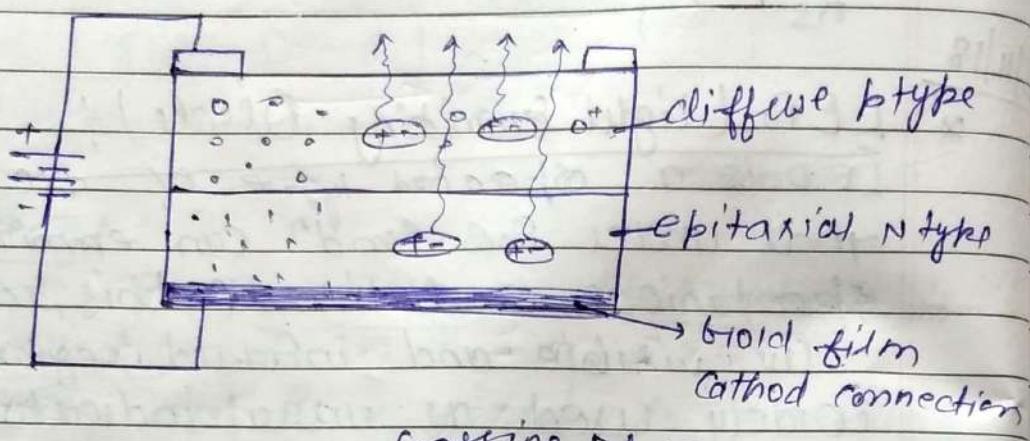
- (i) Generation of e^- holes pair by excitation
- (ii) Recombination of electron holes pair
- (iii) photon emits as a result of recombination.

- Only f.B Photon generated by recombination of e^- ejected from N to holes in P side and holes ejected from P to electron of N side

- Efficiency of light production can be improved if current passes crossing the J_h is predominantly due to e^- and it can be done by increasing the mobility of e^- or res the density of donors

$$M_e > M_h$$

$$N_d >> N_a$$



Symbol

HAI \Rightarrow gives visible infrared

HAASP \Rightarrow Red or yellow

HAP \Rightarrow Red or orange or green

- N-type - layer is grown upon a substrate on P region deposited on it by diffusion

- Gvoid film at the bottom of the substrate used to provide cathode as well as

to reflect light as much as possible

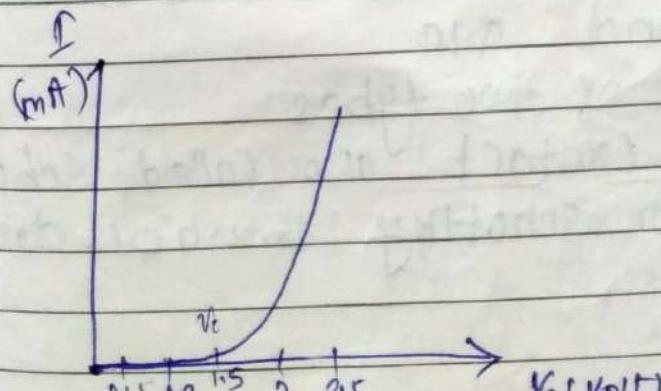
- Working Principle:

It is based on the fact the called injection electroluminescence which is emission of light from a solid with the excitation provided by an electrostatic field.

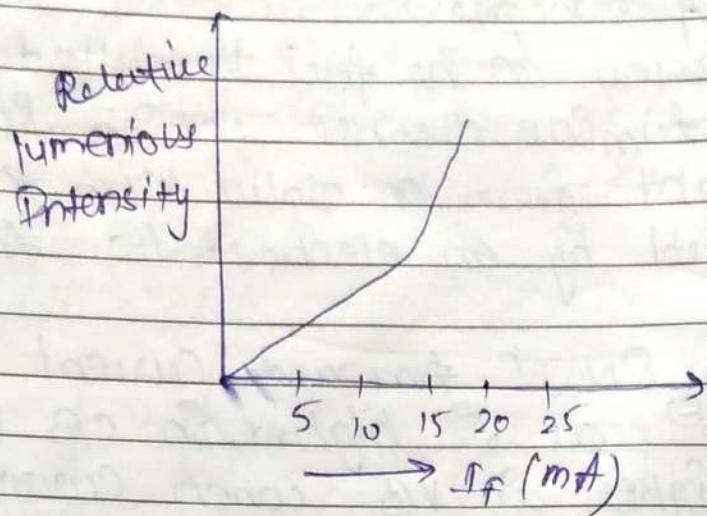
In FB PN junction forward current flows due to free e^- as e^- higher in CB and holes are higher in VB when current passes through PN junction recombination of e^- holes takes place

- When e^- recombine with h^+ holes its falls from higher energy to lower energy state by releasing a photon of wavelength corresponding to energy diff. of transition
 - Energy difference given off either in form of heat or in form of light.
- \Rightarrow Efficiency of LED is given by

$$\text{efficiency} = \frac{\text{lumen generated}}{\text{Applied electric power}}$$



The Cut off voltage is nearly equal to 1.5 which is greater than the ordinary diode.



* Advantages of LED:

- It has smaller size and light weight
- Low working voltage (1 or 2 volt)
- Current (5 to 20 mA)
- Very fast response time (≈ 10 ns)
- Long Life
- High reliability

* Uses:

- As display devices
- In optical communication system.

* Metal \varnothing /c Junction:

are those J 's which are formed b/w a metal and \varnothing /c

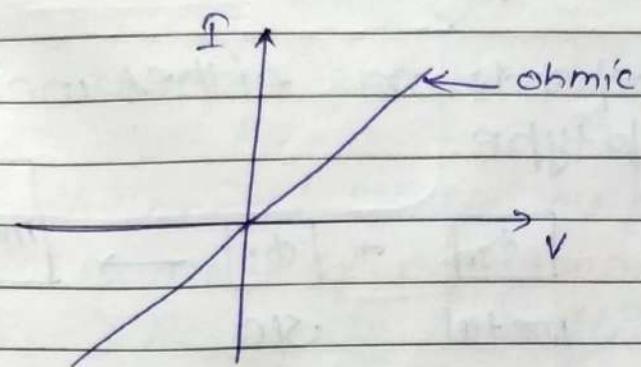
these are of two types

(i) Rectifying Contact: also called Schottky diode or Schottky barrier diode

Rect^o

- Non Rectifying Contact / Ohmic contact
- It is formed by heavily doped n-type SiC
- in compact region

- metal-SiC junction refers to a contact which allows a current to flow in one direction and block in other diode like Normal diode



(ii) Schottky diode or Schottky barrier diode:

It work on the principle of Schottky effect
"when the negative charges are brought near a metal surface the free charges induced in the metal it causes reduction of charge forces when metal is subjected to an electric field the charge forces combine with it and reduce the effective work function (ϕ_{eff}) to some extent such reduction in work function is known as Schottky effect.

This mech' can be explained by two specific cases

- (i) When SiC is of n type
- (ii) " " " " p type.

when $\phi_m < \phi_s$ is n type!

$e\phi_m \Rightarrow$ work fn of metal

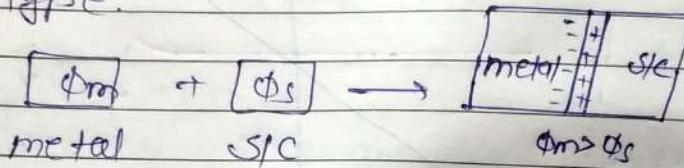
$e\phi_{SIC} = " " " \phi_{SIC}$

• $E_{Fm} =$ Fermi level of metal

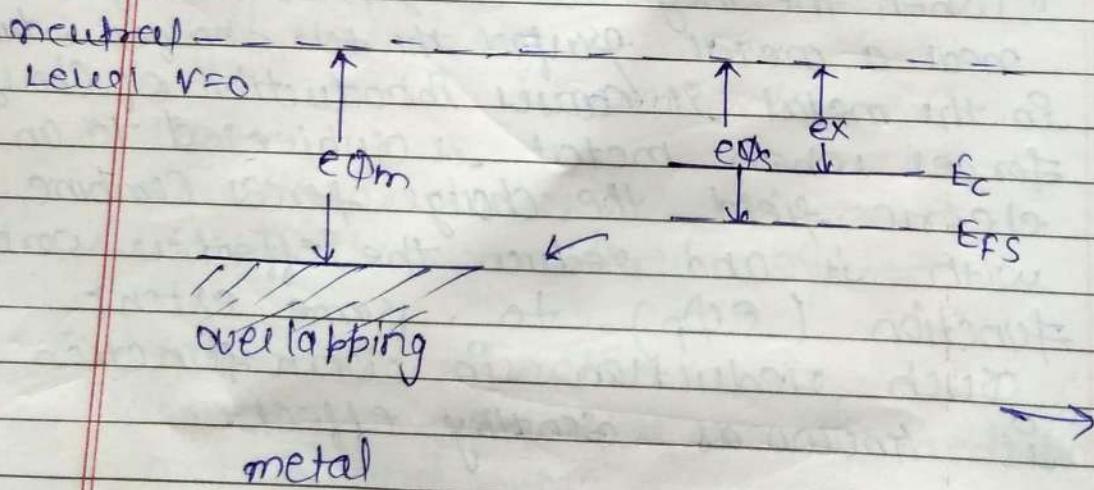
$E_{FS} = " " " \phi_{SIC}$

for n type $\phi_m > \phi_s$

ϕ_s depends on either we use n-type or p-type.

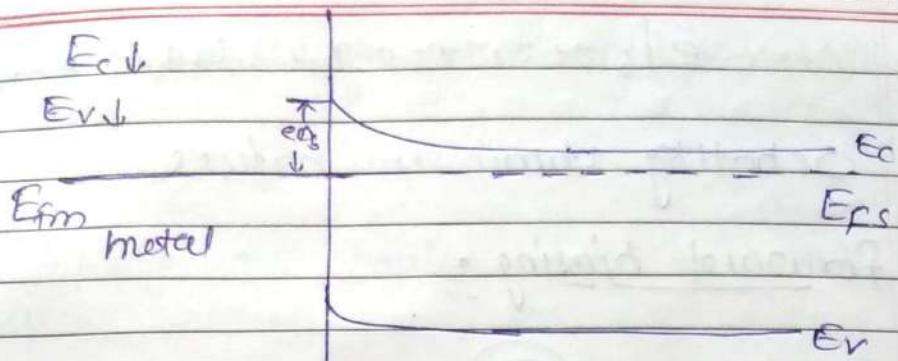


Book: Energy band diagram of Schottky diode



before joining n-type SiC

$$x = e^{\phi_{affinity}}$$



After joining

$e\phi_b$ = Schottky barrier or Schottky potential

When both metal & SiC are brought in contact transfer of charge take place as $E_Fs > E_{Fm}$ so, to align Fermi level at same level at $e\phi_b$ ϵ^\ominus potential of SiC has to be raised or ϵ^\ominus energy must be lowered w.r.t to the metal at $e\phi_b$ diffusion of electron from C.B to metal is stop due to ϵ^\ominus potential known as Schottky potential and barrier

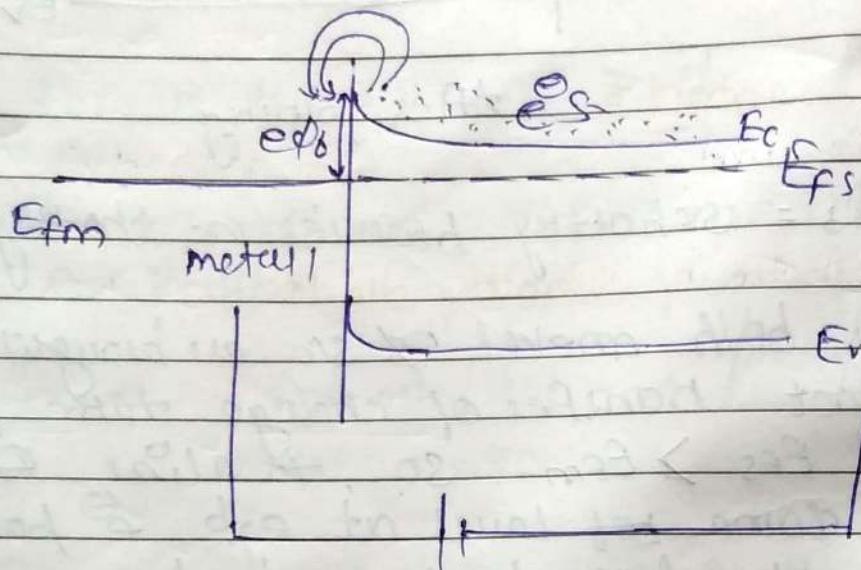
and its value is given by $e\phi_b = e[\phi_m - \chi]$

In general $\chi < \phi_m$

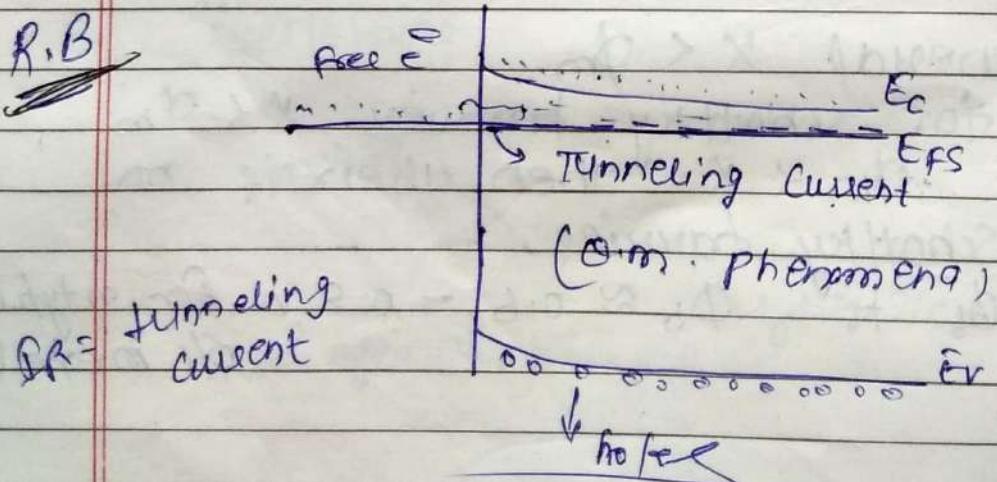
$$e\phi_b \approx 0.7 \sim 0.9 \text{ V} \cdot \text{Grat + metal}$$

Schottky ohmic in nature.

forward biasing:



- Current is produced due to thermionic emission
- $I_f = \text{thermionic effi}^{\circ} \text{t} \cdot \text{emission current}$
- as energy is goes up e^- moves across the barrier and produce thermionic emission



DATE: / 20
PAGE No

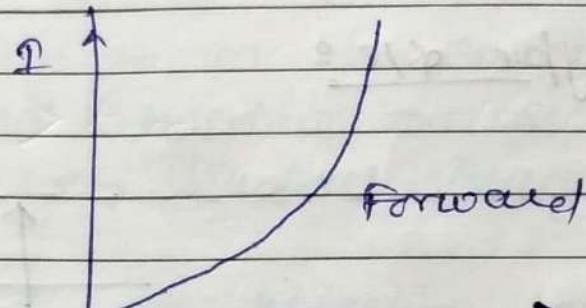
tunneling probability is directly proportional to
width of barrier

by doping p/i/c heavily barrier width can be
reduced

* ohmic Contact:

ohmic contact means resistance i.e. $R \propto V$

* characteristic of Schottky diode:



In ohmic V-I characteristics the scale on X and Y axis should be same

- Mech' of ohmic contact can be explain by two process

- (i) For N type SiC
- (ii) P type SiC

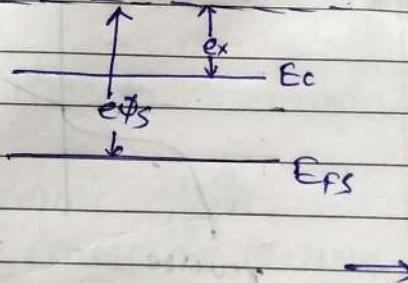
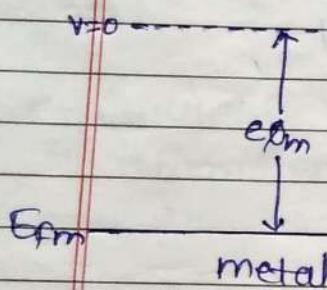
N type SiC

$$\phi_m < \phi_s$$

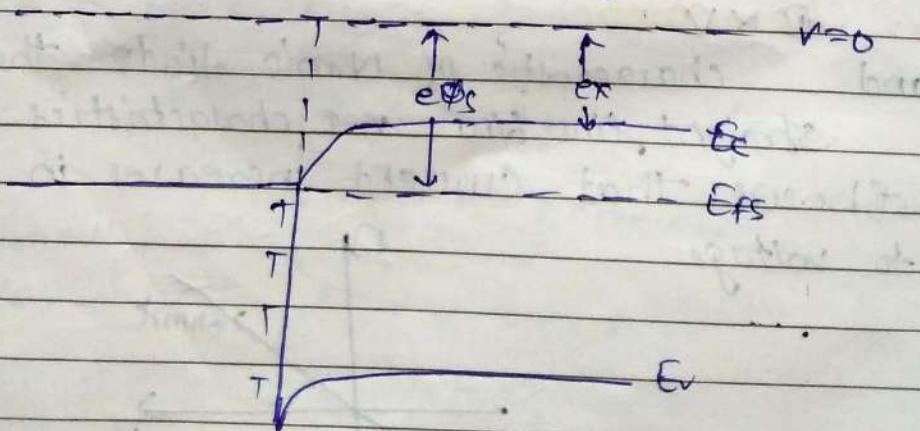
Ptype SiC

$$\phi_m > \phi_s$$

(i) For N type SiC:

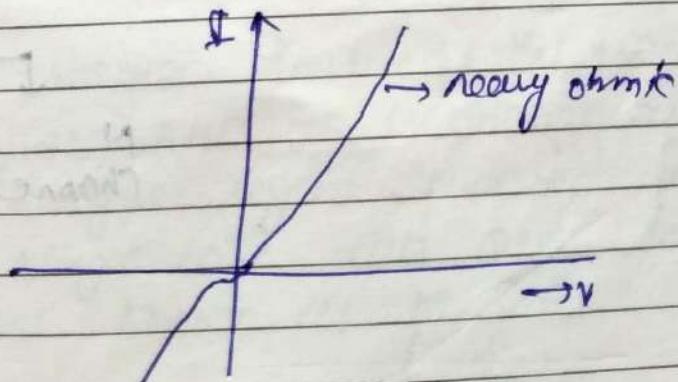


N type SiC



- Ohmic Contact can not be obtain Practically so to get nearly ohmic contact we use n type SiC of highly doped
- Ef arises at esp by transferring e^- from metal to SiC
- So Potential drop across SiC is given by

$$\text{Potential drop} = e (\phi_s - \phi_m)$$
- Negative charge on SiC surface is surface charge and positive charge on metal charge is also surface charge.
- So there is no depletion layer in SiC
- so, Barrier to flow e^- from metal to SiC or SiC to metal is small.
- It shows nm rectifying action on ohmic contact.
- * VR characteristic of nearly ohmic contact



* Field Effect Transistor (FET):

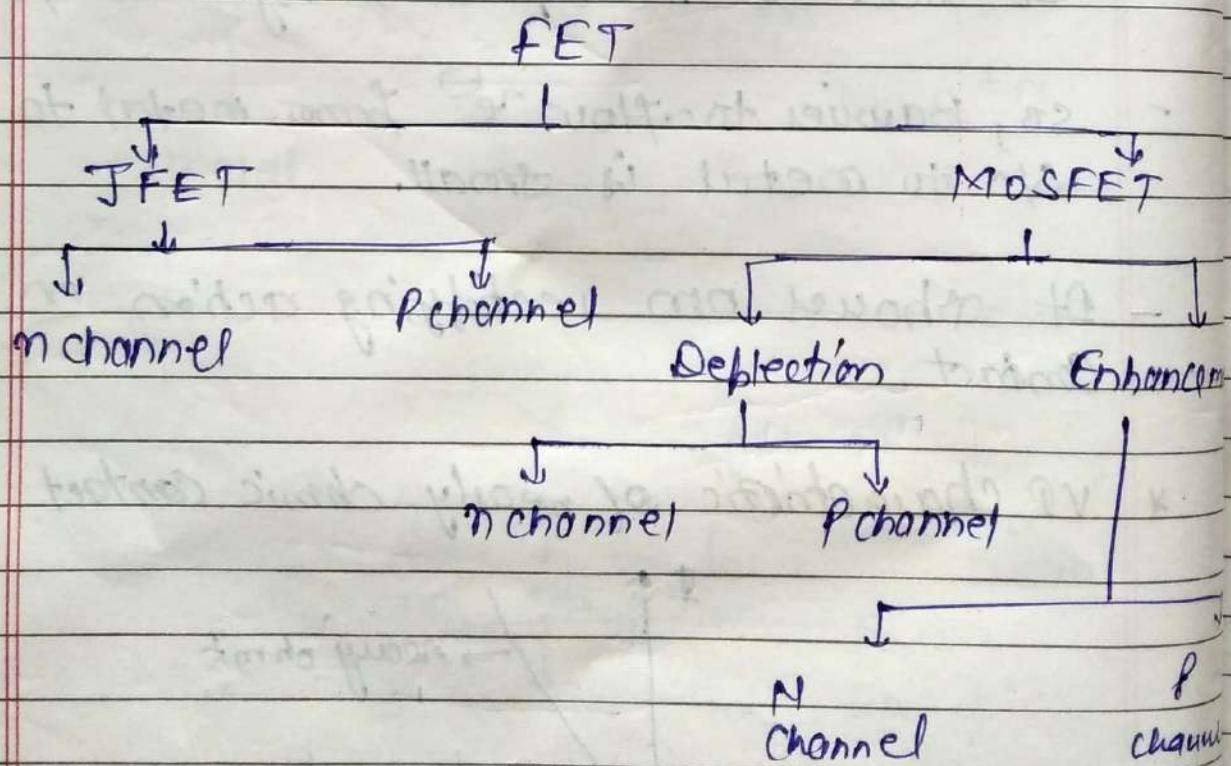
A FET is a three terminal device in which current conduct by one type of carrier either by e^- or holes.

And is controlled by Effect of electric field

- It is another type of transistor which is Voltage controlled unipolar device. O/P characteristic of FET are controlled by applied gate voltage

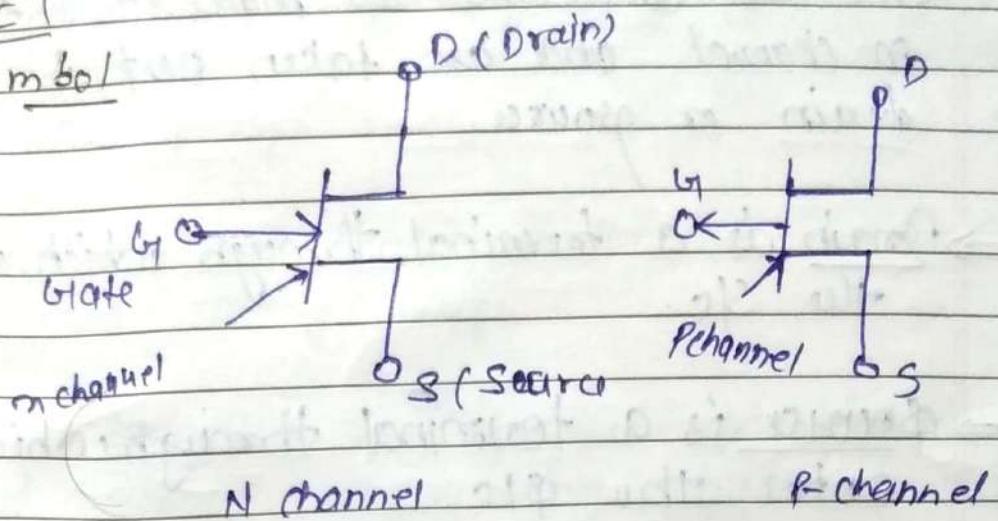
- There are two types of FET

- (i) Junction field effect transistor (JFET)
- (ii) metal oxide sic field effect transistor (MOSFET)



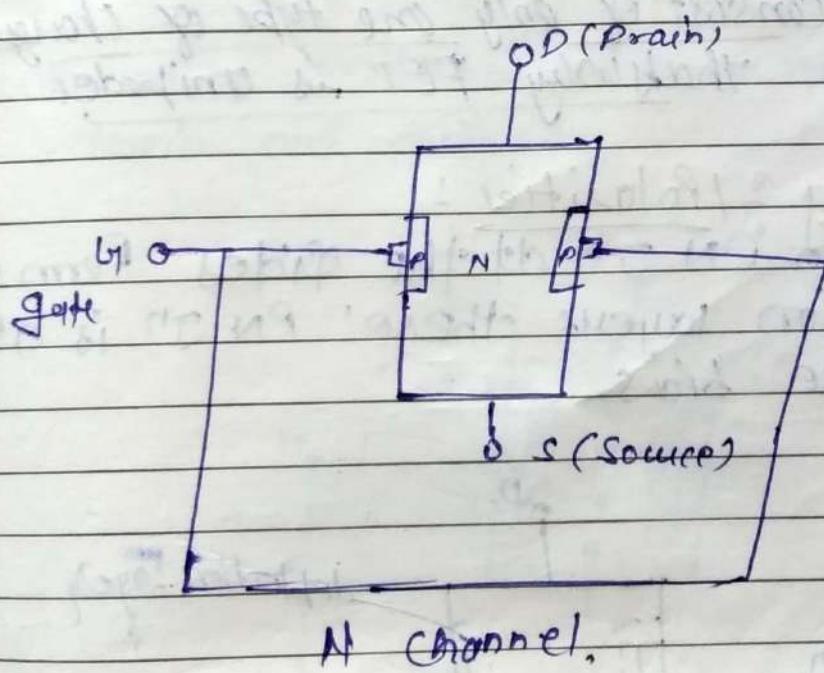
(ii) JFET

Symbol



The construction

In n channel JFET and n type sic bar which two P type sic heavily doped region diffuse on opposite side of middle path



- P type region formed the two PN Jn
- the space b/w J is known as channel
- both the P type region connected internally
- and a single wire take out in front of terminal known as gate.

Electrical connection are made to both ends of n channel and are taken out in form of drain or source.

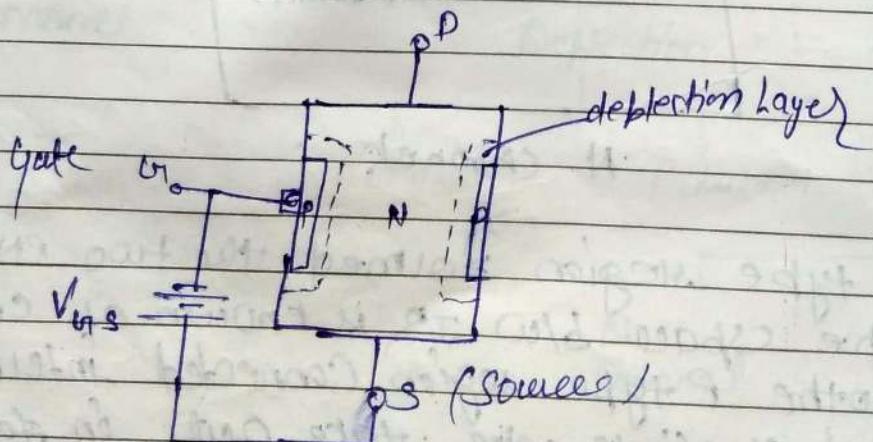
- Drain is a terminal through which e leaves the SIC
- Source is a terminal through which e enter the SIC

when ever a voltage is applied b/w drain and source a current flow through n channel

Ques → Current consist of only one type of charge carriers that's why FET is Unipolar

* Working & Polarities :

The two PN J_N at the sides form two depletion layers these' PN J_N is always reverse bias



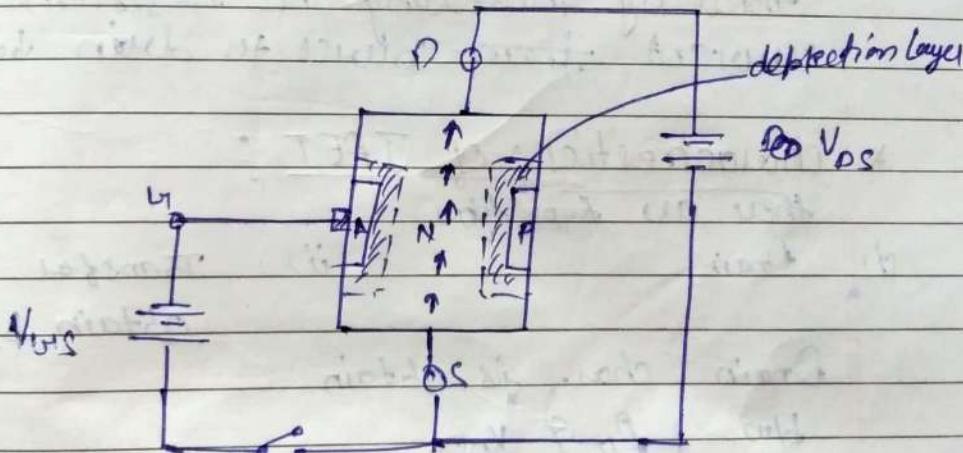
The current conduction by charge carriers through channel b/w two depletion layer and out of the drain

The width and hence resistance can be controlled by the voltage V_{GS}

Greater the V_{GS} wider the depletion layer and more the conducting channel which reduce the source to drain current

~~Int~~ The JFET operates on the principle that width of conducting channel can be varied by changing the value of V_{GS}

When a voltage V_{GS} is applied b/w drain and source

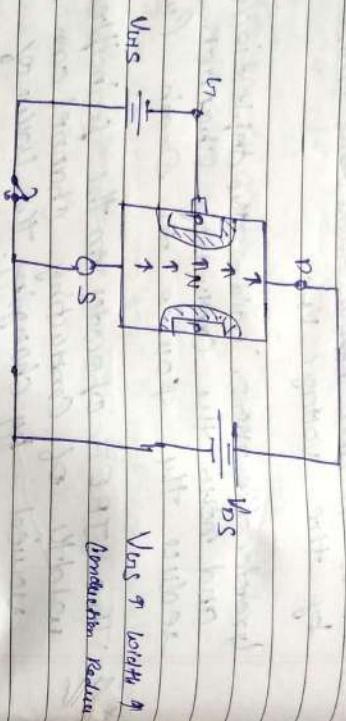


① And $V_{GS} = 0$

the two PN junction at the grid establish depletion layer and size of this layer determines the width of channel

through which current is constricting

(ii) when V_{DS} is applied and V_{GS} increases by



The width of depletion layer increases which reduces the width of channel thereby increasing the Resistance R_D , current flows from source to drain less.

* Characteristics of JFET :

There are two types

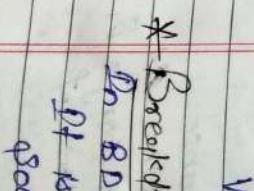
i) Drain Transfer

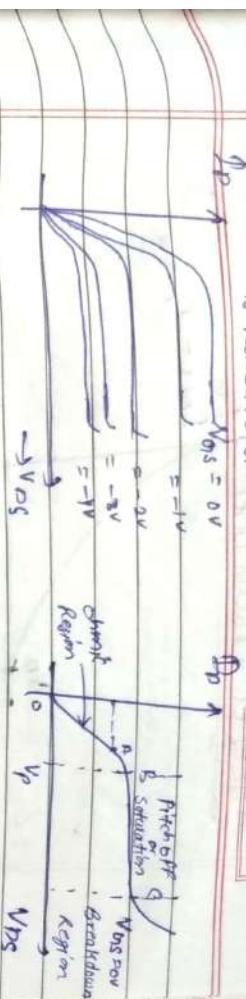
Obtain I_D vs V_{DS}

Drain char. is obtain

I_D vs V_{GS}

Drain char.





- Ohmic region of drain current & I_D linearly with the voltage and obeys the ohm law this is due to the fact in SiC as a simple resistance behave

Curve AB

- So it varies with V_{DS} but not linearly it is due to the ~~strength~~ of depletion layer and reducing width length of channel

- Saturation Region / Pitch off :
Current remains constant as independent to the V_{DS} and its max. value is Loss

$$I_D = LOSS \left[1 - \frac{V_{DS}}{V_p} \right]^2 \text{ Schotthly eq}$$

$V_{DS} \Rightarrow$ max. Drain current

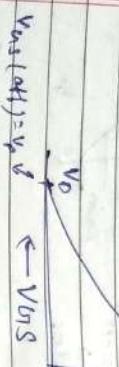
* Breakdown Region!

In BDR I_D increase

It is due to - the Breakdown of gate to source Jn due to avalanche effect

Transfer Characteristics

Loss = Saturation.



It is the curve b/w I_D and V_{DS} for const. value of V_{GS} .

* JFET Parameters:

(i) D.C drain resistance (R_{DS}):

$$R_{DS} = \frac{V_{DS}}{I_D}$$

(ii) A.C drain Resistance (R_{AD}):

$$R_{AD} = \frac{\Delta V_{DS}}{\Delta I_D}$$

This is the output resistance.

Transconductance

It is also known as forward transconductance or forward transmittance. It is given as the ratio of small change in drain current to change in V_{DS} for constant V_{GS} .

$$g_m = \frac{\Delta I_D}{\Delta V_{DS}}$$

for const. V_{GS}

* Amplifying

* Amplification factor (μ) :-

If it is the ratio of small change in V_{ds}
to small change in V_{gs}

$$\mu = \frac{\Delta V_{ds}}{\Delta V_{gs}} = \frac{\Delta I_D}{\Delta V_{gs}}$$

$$M = \alpha_d \times g_m$$

* Output Resistance (R_o) :-

$$R_o = \frac{V_{ds}}{\Delta I_D}$$

* Advantages of JFET :-

It has very high input impedance which permits high degree of insulation between input and output circuits. It has the negative temp. coefficient resistors which avoids the risk of thermal run away.

- It has small size, longer life and high efficiency.
- high power gain
- produce the less noise

* Disadvantages :-

- It can not be used as current amplifier
- voltage gain of JFET amplifier is less than Transistor amplifier

* Difference b/w JFET and transistor :

- JFET is a voltage controlled device as Current I_D is controlled by applied voltage b/w gate and source.
- Transistor is current control device as the output current I_C is controlled by varying the base current.
- JFET is current flow through only due to one type of charge carriers either holes and e^-
- Transistor has a Bipolar device in which current flows by both holes and e^-

* MOSFET : (Metal oxide sic field effect transistor)

Like JFET MOSFET has a source gate and drain however unlike JFET gate of MOSFET is insulated from the channel due to this MOSFET is also known as IGFET (Insulated Gate Field effect transistor)

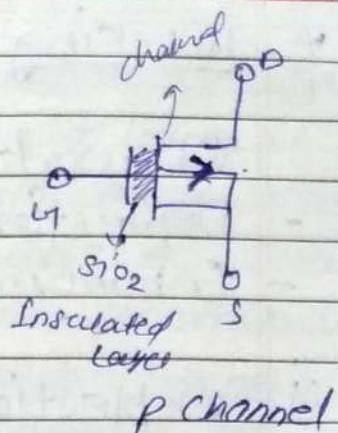
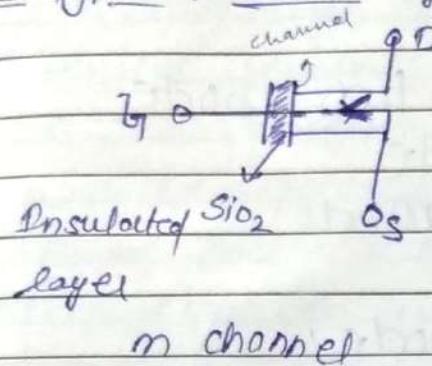
J.
depletion

J.
Enhancement

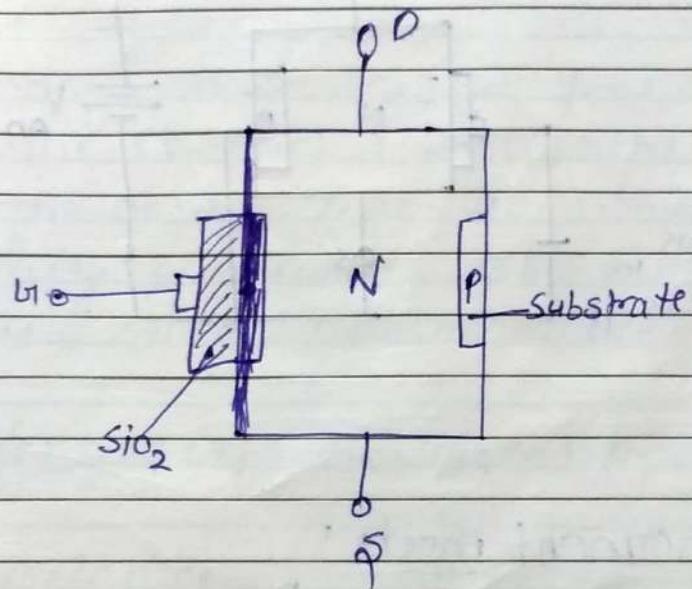
N chan
sting
gate
with
drain
throu
P reg
- the +
chan
ge

① * Deflection type MOSFET :

(1) Symbol



(2) Construction :



N channel depletion type MOSFET consist of a Conducting bar of N type material with an insulating gate on left and P region on right. with an insulating material P from source to drain through S.

P region is called substrate.

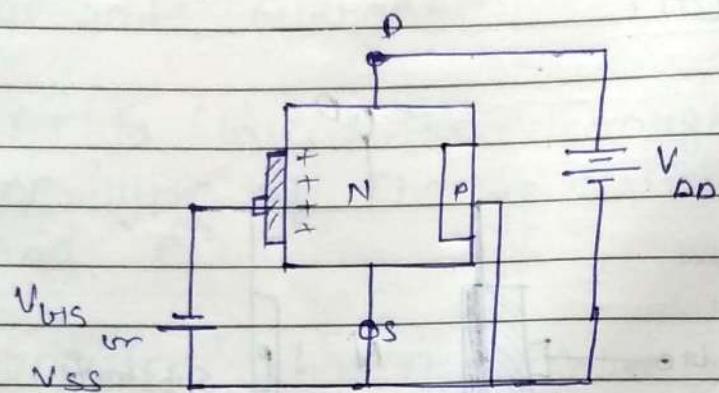
- the thin layer of SiO_2 insulate bar from channel in negligible current flow in gate terminal.

* Working :

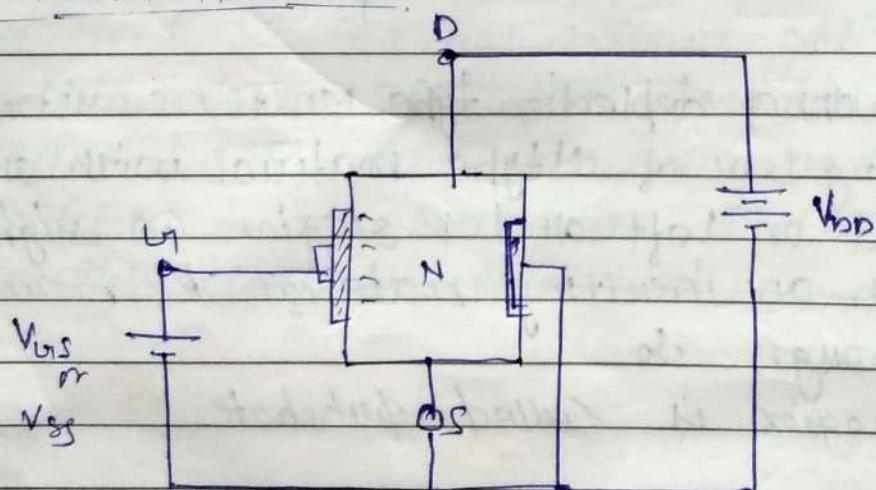
- It works in two mode
- Depletion mode
- Enhancement mode

(i) Depletion mode :

In DM Gate voltage is negative



(ii) Enhancement mode :



QM

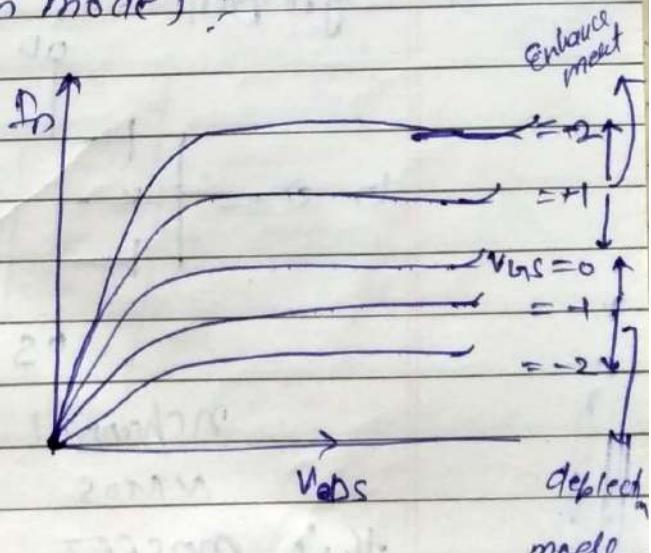
In DM Gate is negative which repel the free e^- in n channel leaving a layer of tail ion on the surface of SiO_2 as a result n channel will be depleted of free e^- . therefore less no. of free e^- available for conduction. This is known as depletion type. Depletion type MOSFET conduct even if $V_{DS} = 0$ bcz of this is commonly known as on MOSFET.

Enhancement type:

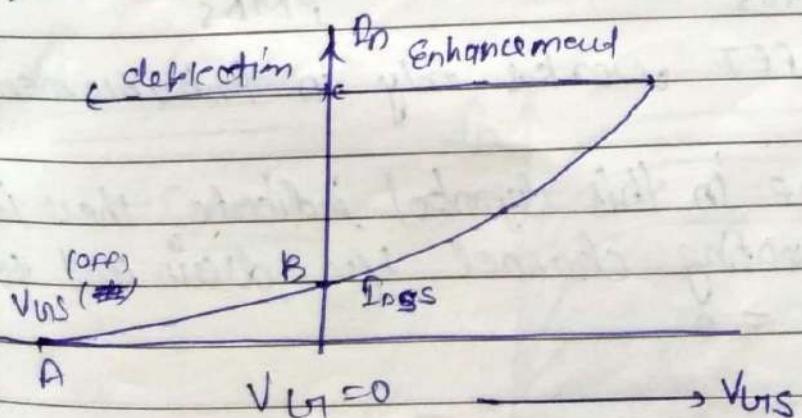
The gate voltage increases the free e^- passing through the channel creates the voltage greater than the no. of free e^- which enhance the conductivity of channel φ_0 , Positive gate operation is called enhancement mode.

Characteristic (Depletion mode):

Output characteristics



Transfer



- The AC region of transfer characteristic is similar to JFET. The difference is that this curve is extent towards the two sides of V_{DS} also.

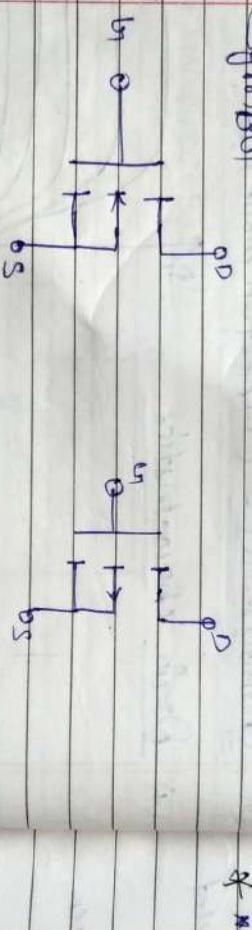
- When $V_{DS} = 0$
then I_{DS} represent the drain current
when drain current is given by

$$I_D = I_{DSS} \left[1 - \frac{V_{DS}}{V_{DS(0.5)}} \right]^2$$

When $V_{DS} = 0$, $I_D = I_{DSS}$ and in this condition it is known as an MOSFET.

(2) Enhancement type MOSFET!

(i) Symbol



n channel
NMOS
PMOS

This MOSFET works only in enhancement mode.

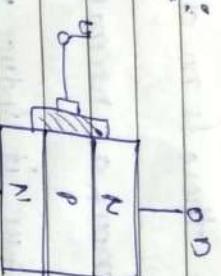
Broken line in this symbol indicate there is no conducting channel b/w drain and source if $V_{GS} = 0$.

This device is also known as NMOS or MOSFET

N-channel Enhancement MOSFET also known as NMOS

" " " " " P-MOS

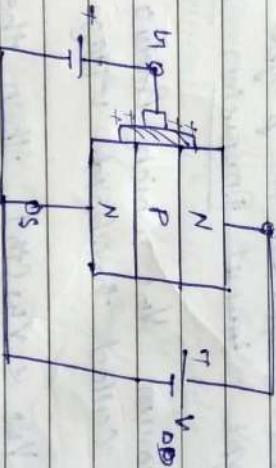
Construction:



The construction is same as depletion type MOSFET

The main difference is there is no physical channel between drain and source.

Working & Polarities:



Characteristics:

① Drain Current:



$$ID = ID(sat)$$

$$ID = V_{DS} = V_{DS}$$

$$V_{DS} = V_{DS}$$

Operating

- It always operate with V_{GS}
- When $V_{GS} = 0$ Von Supply tries to force free e^- from Source to Drain But Presence of P Region does not permit e^- to pass through it thus there is no drain current when $V_{DS} = 0$.

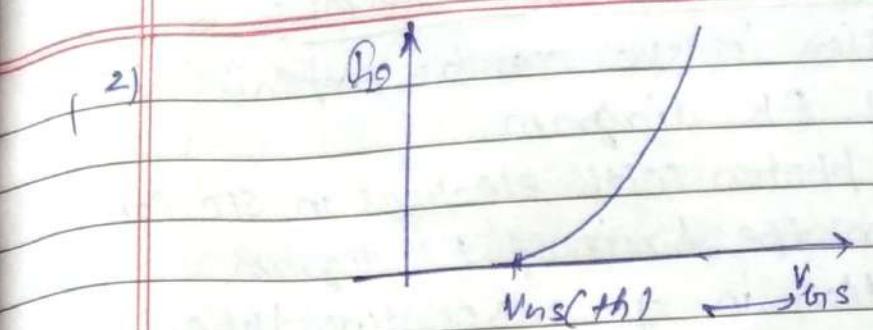
Therefore it is known as normally off MOSFET

- When $V_{GS} = +ve$ it induce Negative Charge in p type substrate just adjacent to SiO_2 layer.
- When Gate is +ve enough it can create a no. of free e^- . This form a thin layer of electrons which stretches from Source to drain due to this a thin layer of n type channel is formed in p type substrate. called N type Inversion Layer.
- minimum V_{GS} which produce inversion layer is called threshold voltage $V_{GS}(th)$
- If $V_{GS} < V_{GS}(th)$ then there is no current when $V_{GS} > V_{GS}(th)$ a significant current flows in the device.

(1) Drain

Draw at Previous Page

DATE : / 20
PAGE No



$$I_D = K [V_{DS} - V_{DS(th)}]^2$$

- The Drain curve shows that when $V_{DS} < V_{DS(th)}$ there is no drain current. But practically a very small drain current flows through it due to release of thermal generated e^- in P substrate.
- When $V_{DS} > V_{DS(th)}$ then I_D can flow

Transfer char.

If V_{DS} increase above threshold $V_{DS(th)}$ then drain current increases rapidly and its value is given by this eq⁴ when K is const depends on data sheet of ~~one~~ MOSFET

$$I_D = K [V_{DS} - V_{DS(th)}]^2$$

Unit - 4

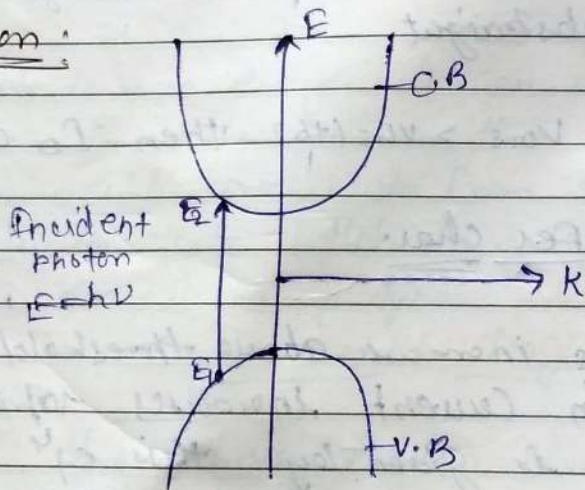
Optical Transition in semiconductor:

- Optical transition in SiC can be explain with the help of EK diagram
- Interaction of photon with electrons in SiC can be explain on the basis of EK diagram.
- Optical transition in SiC are of two types
 1. Absorption
 2. Emission

Emission is again of two type.

- (i) Spontaneous
- (ii) Stimulated

(1) Absorption:



$$E_2 - E_1 = h\nu$$

E_1 = Energy state of e^- in V.B

E_2 = " " " " " in C.B

When a photon of energy $h\nu$ is incident on a SiC then this photon is absorbed by an e^- in V.B. and electrons move to Energy state E_2 in C.B.

Ques 2(a)

No absorption generation of e^- and hole pair take place

Absorption is the basis of photo detection. In photo detector we generally have a reverse bias diode. When an photon is incident on this junction when generation of e^- and hole pair takes place so photo current generate due to the incident photon.

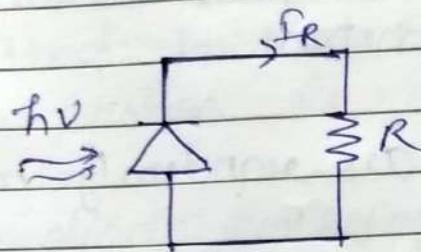


Photo detector

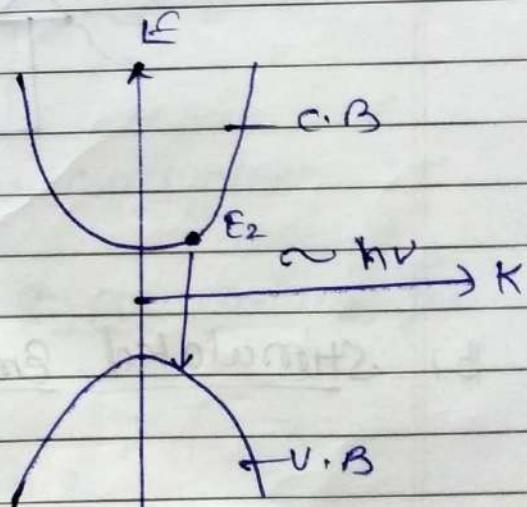
(2) Emission

(a) Spontaneous:

$$E_2 - E_1 = h\nu$$

E_1 = Energy state of e in VB

E_2 = " " " " " C.B



In spontaneous emission e^- from E_2 state of C.B jumps to the E_1 state of V.B without any external help emitting a photon of energy $h\nu$

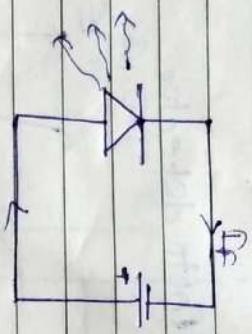
$$h\nu = E_2 - E_1$$

$E_2 - E_1$

Spontaneous emission is the basis of operation of LED.

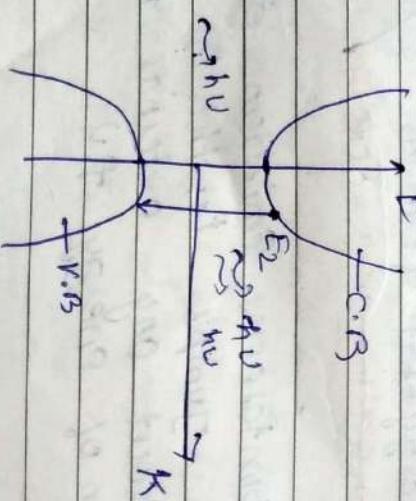
In LED, a forward bias current I_F is flow in the junction and due to this it gives out light in form of photon in this e^- -hole pair recombination produce the photon.

These photon are randomly moving in diff. dirn



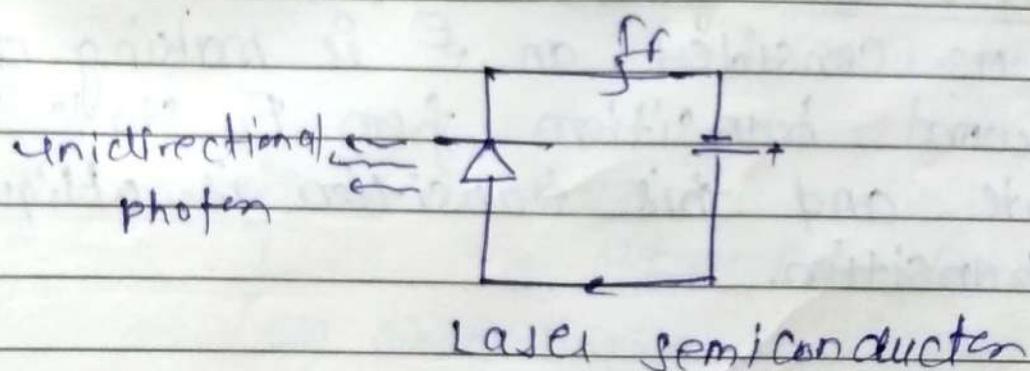
LED

b) Stimulated Emission: \rightarrow Higher and stimulated



the basis of operation of laser diode. In this when a forward current I_f is passed through the junction the emitted photon which are depicted as coherent photon is in phase.

In Laser diode emission is unidirectional



* Conservation of Energy & momentum in optical transition:

1) Conservation of Energy:

Energy is conserved when a photon is either incident or emitted in a direct band gap SC during

During incident of photon absorption - taken place which is given by

$$\hbar\nu = E_2 - E_1$$

- when photon is released the emission take place it may be spontaneous or stimulated and emission is given by

$$E_2 - E_1 = \hbar\nu$$

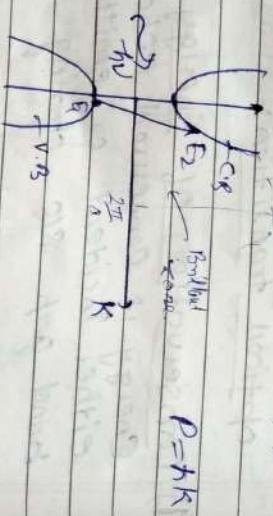
- In both process absorption or emission energy is conserved

2. Conservation of momentum!

let us consider, an e^- is making an upmost transition from E_1 state to E_2 state and this transition is oblique transition.

momentum before absorption should be equal to momentum after absorption

As the



$$P = \hbar k$$

Acc.
final
tran
a

$$\hbar k_{\text{photon}} + \hbar k_1 = \hbar k_2$$

$$\hbar (k_{\text{photon}} + k_1) = \hbar k_2$$

$$[k_{\text{photon}} + k_1 = k_2] \quad - \quad \textcircled{A}$$

$\lambda \approx 1 \mu \text{m}$

$$k_{\text{photon}} = \frac{2\pi}{\lambda} \quad \text{-> wavelength of light}$$

$$k_1 = \frac{2\pi}{\lambda_e} \quad \text{-> de Broglie wavelength}$$

$\alpha_f \in \text{v.B.}$

$$k_2 = \frac{2\pi}{\lambda_e} \quad \lambda_e \rightarrow " " " "$$

$\lambda_e \approx 10 - 100 \text{ Å}$

- $\frac{2\pi}{L} \leq \lambda_e \leq \frac{2\pi}{a} \quad \text{In terms of size or wavelength.}$

As wave length of electron is much "lower" than the wavelength of photon

$\alpha_f \text{ photon} \ll \alpha_e$

$$k_1 = k_2$$

$$\text{or } \boxed{\Delta k = 0}$$

Acc. to Conservation of momentum the allowed transition in EK diagram is only vertical transition and when a photon is interact with a e^- .

* Non Radiative or Radiative transition?

i) Radiative transition:

RT are transitions which involves emission or absorption of a photon

Ex: transition b/w direct band gap SiC

iii) Non-Radiative transition:

does not involves emission or absorption of a photon.

Ex: transition b/w Indirect band gap SiC

In this emission of phonon takes place which have very small energy and momentum. So, in Indirect band gap SiC the presence of phonons can not be neglected.

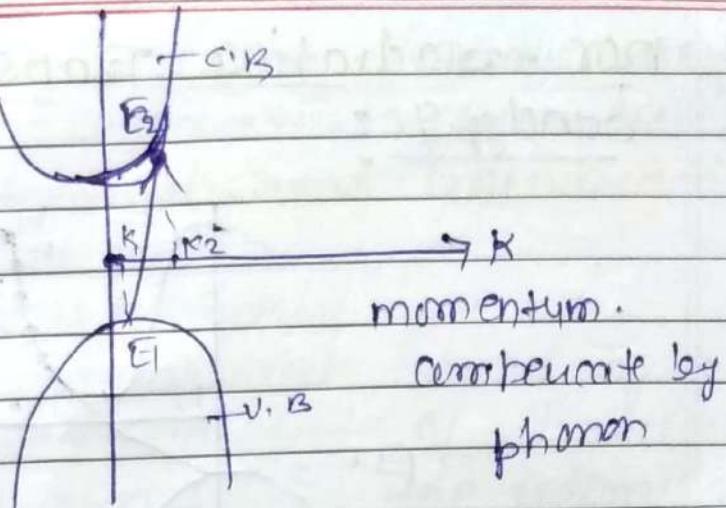
In this phonon emission predominates over the photon emission.

* Radiative Transition in Case of oblique Transition:

as for momentum conservation the allowed ~~for~~ transition is $\Delta K = 0$ which is vertical transition but in actual practice $\Delta K \neq 0$

$$= k_1 - k_2$$

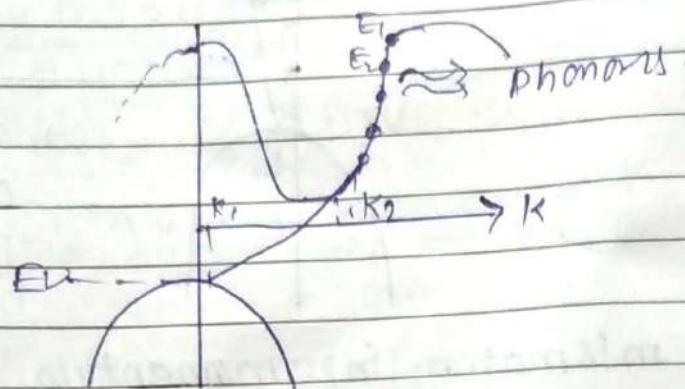
has finite value. In case of oblique transition.



The mismatch in momentum as \vec{K} is compensated if we consider there are phonons which also take part in this radiation as this transition takes place with help of phonons. This is known as phonon assisted radiative transition but as energy difference Eg in case of SiC is 1 or 1.5 eV so, the energy conservation during oblique transitions is taken care by photons as phonons have very small energy whereas in momentum conservation phonon particle take place.

The Probability of occurrence of phonon assisted radiative transition is much lower than the vertical transition. so, in this case vertical transition is dominant over the phonon assisted radiative transition. Indirect Band gap. q/c e^{\pm} holes & phonons takes part in radiation.

* non-radiative Transition in indirect bandgap:



- (1) As $E_1 - E_2$ is very small
or $E_2 - E_3$ is very small
so, Energy released by e^- in the form
of phonons
as phonon is low energy particle

So, Energy conservation taken care by phonons
In energy conservation e^- moves in C.B
from higher to lower Energy State
by process of thermalization

- (2) as $K_1 \neq K_2$ & ΔK has a finite value
which is given by consideration of
phonons

In momentum Conservation of phonons
have K value which is comparable
with K_1 & K_2 of e^- they in this
case phonon momentum not neglected
By this case radiations by the

phonons which have very small energy so, it is no radiative transition. In this, photons do not take place.

x What is phonon?

In a crystal atoms are bound by elastic bond which are in state of vibration due to finite thermal e^- . The atom which vibrate or oscillate in nature has some e^- associated with them. A quanta of these lattice vibrations are phonons.

Phonons are of two types.

- ① Acoustic phonons
- ② Optical phonons

(i) Acoustic phonons:

On acoustic. If one atom is displaced in one direction & another adjacent atom displaced in opp direction then this type of vibration is known as acoustic phonons. Type of vibration is known as acoustic phonons.

ii) The magnitude of both the atom can be different in opposite direction.

iii) The wavelength of acoustic phonon is higher.

(2) optical phonon:

A group of atom move in upward direction whereas the adjacent whereas the adjacent group of atoms moves in downward direction then this type of vibration is known as optical vibration.

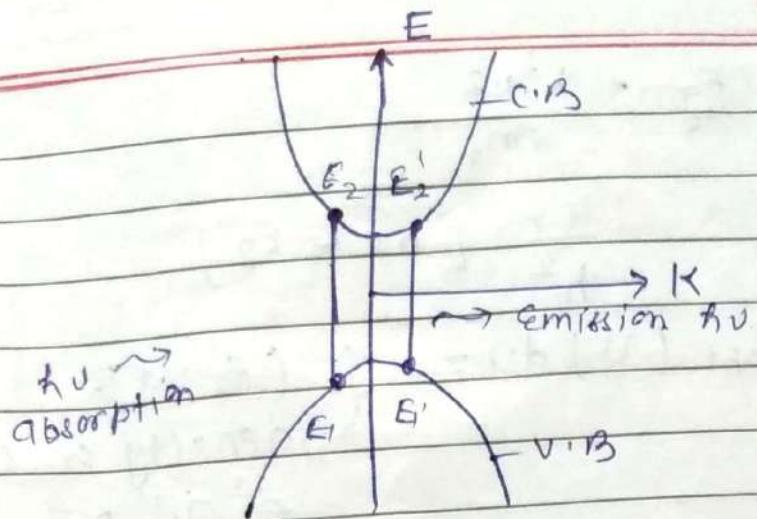
wavelength of optical phonon is lower than the acoustic phonon.

optical joint density of state:

It is generally denoted by J_{opt} . It is the member of state available for photons to interact with simultaneously. It for photons to interact with simultaneously. it take care of state in V.B & C.B

In optical Transition joint density of state is important. whereas in Electron process we always deal with C.B & V.B separately but a photon interact with sic involve a state in VB & a state in CB simultaneously

$$J_{opt} = \text{no. of states/vol. for photons having energy } h\nu \text{ & } h(V+\delta\nu)$$



E_1 & E_2 energy state of e^\ominus in V.B & C.B
for absorption

E_1' & E_2' Energy state of e^\ominus in V.B &
C.B for emission

$$E_2 = E_0 + \frac{\hbar^2 k^2}{2mc}$$

$$E_1 = E_V - \frac{\hbar^2 k^2}{2m_V}$$

$$E_2 - E_1 = (E_C - E_V) + \frac{\hbar^2 k^2}{2} \left[\frac{1}{m_C} + \frac{1}{m_V} \right]$$

$$E_2 - E_1 = (E_C - E_V) + \frac{\hbar^2 k^2}{2m_V}$$

$$\boxed{\frac{1}{m_e} = \frac{1}{m_C} + \frac{1}{m_V}}$$

$$E_2 - E_1 = E_g + \frac{\hbar^2 k^2}{2m_V}$$

$$\hbar v = E_g + \frac{\hbar^2 k^2}{2m_r}$$

$$k^2 = \frac{2m_r}{\hbar^2} [hv - E_g]$$

as $\int_{opt}(v) dv = \int_c (\epsilon_2) dE$
 density or concn of
 e[⊖] in c.b

$$\text{as } f_c(\epsilon_2) = \frac{1}{2\pi^2} \left(\frac{2m_c}{\hbar^2} \right)^{3/2} (\epsilon_2 - \epsilon_c)^{1/2}$$

for $d\epsilon_2$ use eq⁴ ①

$$\epsilon_2 = E_c + \frac{\hbar^2 k^2}{2m_c}$$

$$k^2 = \frac{2m_r}{\hbar^2} [hv - E_g]$$

$$\epsilon_2 = E_c + \frac{\hbar^2}{2m_c} \cdot \frac{2m_r}{\hbar^2} [hv - E_g]$$

$$\epsilon_2 = E_c + \left(\frac{m_r}{m_c} \right) (hv - E_g)$$

$$\frac{d\epsilon_2}{dv} = \frac{m_r h}{m_c}$$

$$\int_{opt}(v) = \frac{1}{2\pi^2} \left(\frac{2m_c}{\hbar^2} \right)^{3/2} (\epsilon_2 - \epsilon_1)^{1/2} \frac{m_r h}{m_c}$$

$$= \frac{1}{\pi \hbar^2} \left(\frac{2m_r}{m_c} \right)^{3/2} (\epsilon_2 - \epsilon_c)^{1/2} \frac{m_r}{m_c}$$

$$= \frac{1}{\pi \hbar^2} (2m_c)^{3/2} \left(\frac{m_r}{m_c}\right)^{1/2} (\hbar v - \epsilon_g)^{1/2} \frac{m_r}{m_c}$$

$$\boxed{f_{opt}(v) = \frac{1}{\pi \hbar^2} (2m_r)^{3/2} (\hbar v - \epsilon_g)^{1/2}}$$

It is the final optical Joint density of state which tells us about how many energy spaces are available for phonon transition.

Dated : _____

Page : _____

24/11/18

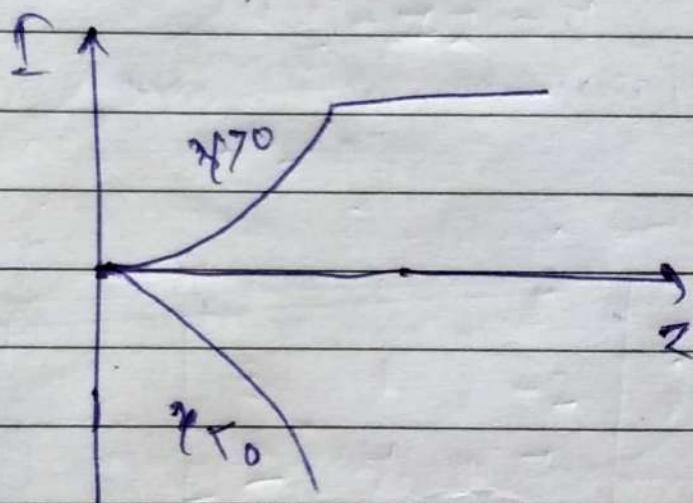
* Absorption spectrum / loss coefficient of absorption :

$$I_{\text{out}}(z) = I_{\text{in}}(z) e^{\gamma z} \quad z \rightarrow \text{length of s.c. material}$$

γ = gain constant / coefficient

$\gamma > 0$ @ there is amplification

$\gamma < 0$ there is attenuation



$$\gamma = \frac{v^2}{8\pi v^2} \cdot \frac{1}{T_r} \cdot (2m)^{3/2} \cdot \frac{1}{\pi \hbar^2} \cdot (h\nu - Eg)^{1/2} \cdot (P_e - P_a)$$

Dated : _____

23/02/2022

Page : _____

* If $f_g(v)$ is negative ($f_g(v) < 0$)

$$\gamma = -\nu e^{-\gamma z}$$

$$I_{out} = I_{in} e^{-\gamma z}$$

$$Y = -\frac{V^2}{8\pi V^2} \frac{1}{T_r} (2m_r)^{3/2} \frac{1}{\pi h^2} (h\nu - Eg)^{1/2} f_0(v)$$

$$f_0(v) = |f_g(v)|$$

$$\gamma = -\alpha_a$$

α_a = attenuation constant / coefficient

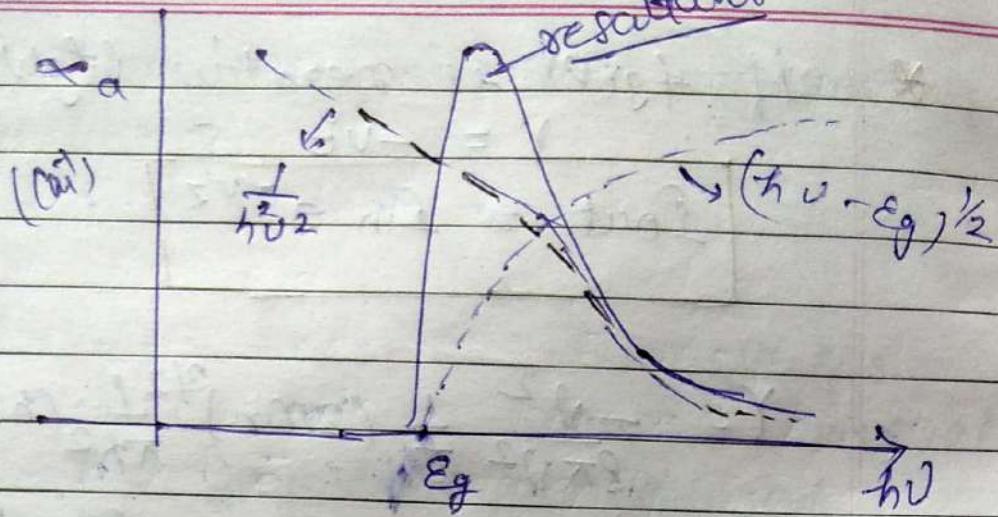
$$\alpha_a = \frac{V^2}{8\pi V^2} \frac{1}{T_r} (2m_r)^{3/2} \frac{1}{\pi h^2} (h\nu - Eg)^{1/2} f_0(v)$$

$$V = \frac{C}{n}$$

where n = refractive index of material

$$\alpha_a = \frac{(C/n)^2}{8\pi V^2} \cdot \frac{1}{T_r} (2m_r)^{3/2} \frac{1}{\pi h^2} (h\nu - Eg)^{1/2} f_0(v)$$

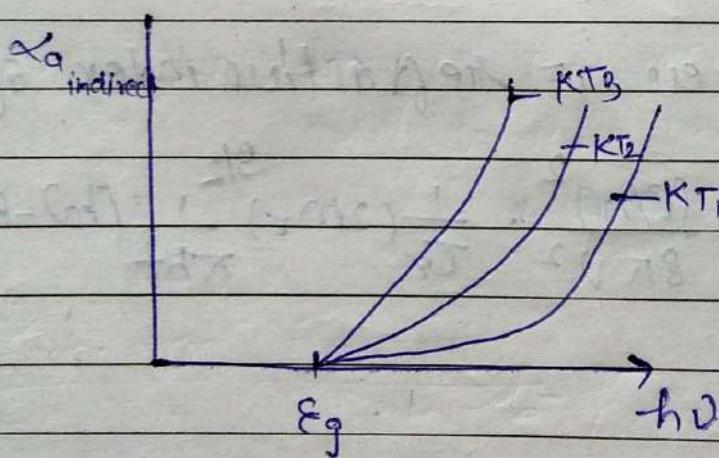
Dated: _____
 Page: _____



- This Graph shows the variation of α_a only for direct band gap s/c
- the α_a for indirect band gap s/c is given by *

$$\alpha_a \approx [K_0 + K_1 (T + T_f)] / (h\nu - \epsilon_g)^2$$

Where K_0 and K_1 is constant dependent.



$$T_3 > T_2 > T_1$$

In this

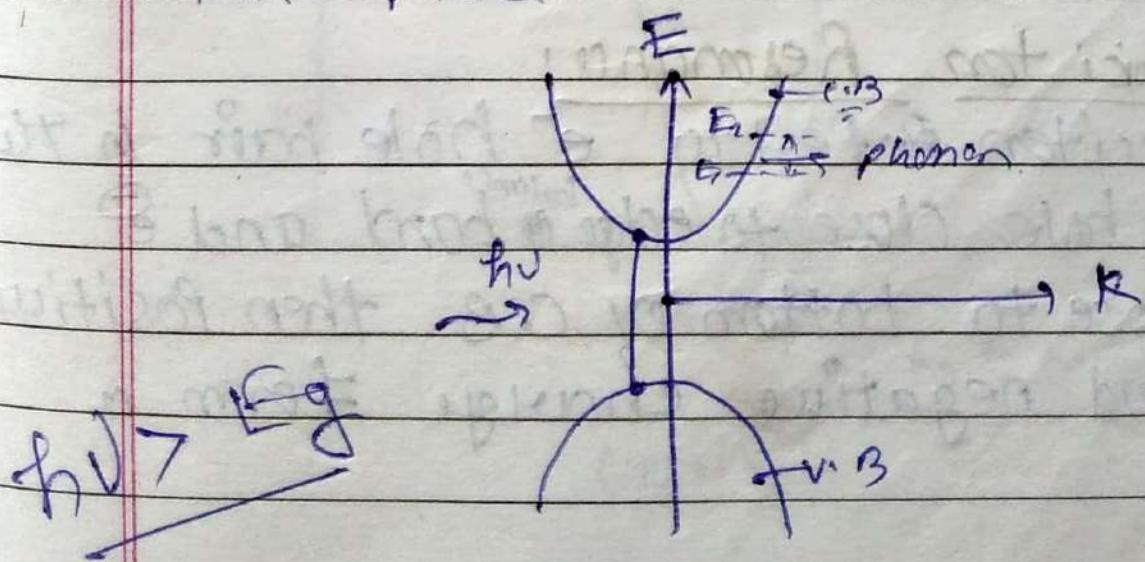
$h\nu$

* Types of Transition in absorption Process of SIC:

There are four type of transition possible

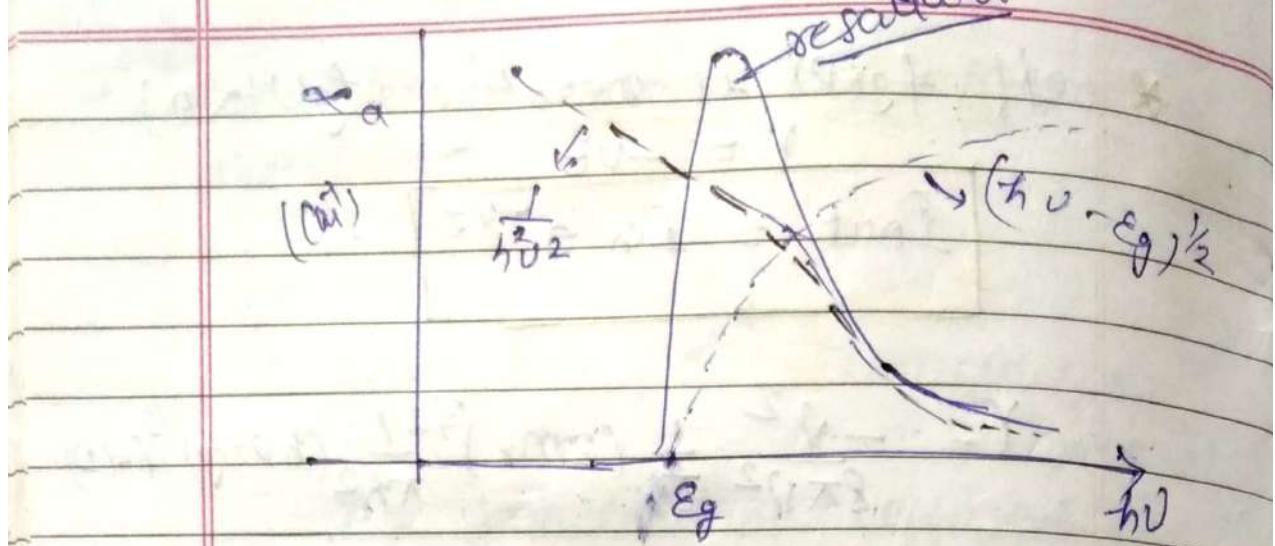
- (i) Inter band transition. [$C.B \rightarrow V.B$ & $V.B \rightarrow C.B$]
- (ii) Intra band " [from inside the same band either in $C.B$ & $V.B$]

In this low energy or low freq. transition take place.



Dated: _____

Page: _____

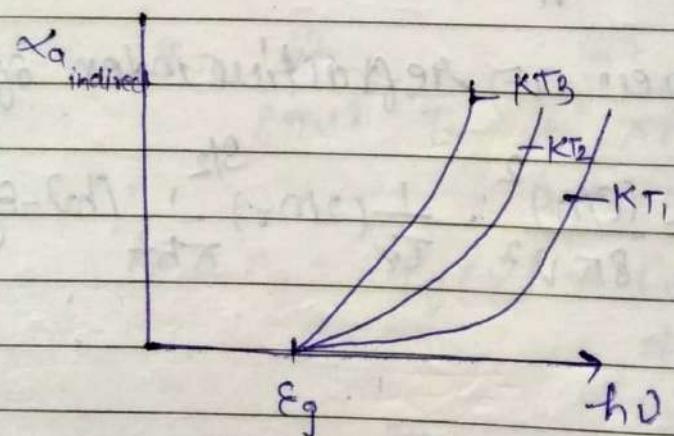


This Graph shows the variation of α_a only for direct band gap s/c

the α_a for indirect band gap s/c
is given by

$$\alpha_a \approx [K_0 + K_1 (\text{temp})] / (\hbar\omega - E_g)^2$$

Where K_0 and K_1 is constant dependent.



$$T_3 > T_2 > T_1$$

So the net absorption =

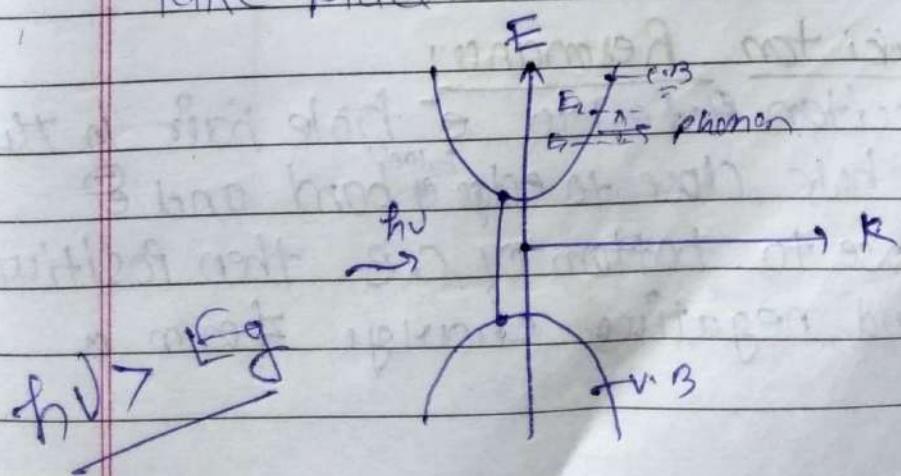
= radiation absorption + non-radiation absorption

- The Probability of radiation absorption is very high in direct band gap sic whereas in indirect band gap sic probability is very low (because of phonon assisted transition or violation of momentum conservation).

* Types of Transition in absorption Process of sic:

- There are four type of transition Possible
 - (i) Inter band transition [C.B \rightarrow V.B & V.B \rightarrow C.B]
 - (ii) Intra band " [from inside the same band either in C.B & V.B]

In this Low energy or low freq. transition take place.



position (state) is known as hot \bar{e} .
these hot \bar{e} subsequently comes down
due to thermalization.

3. Phonon transition :

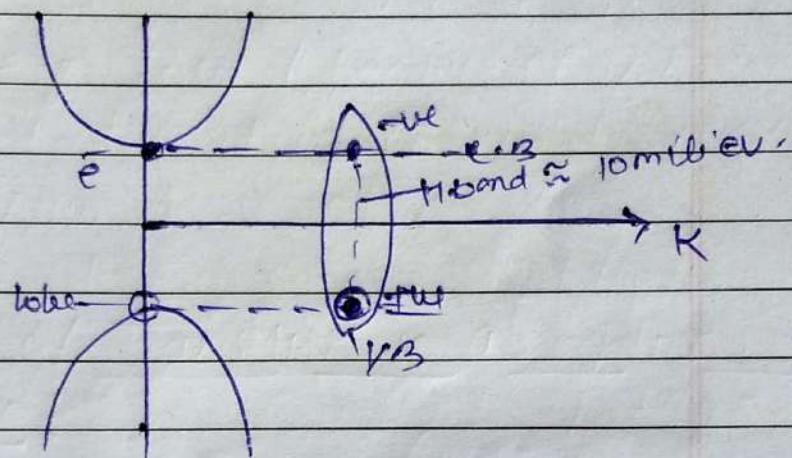
when \bar{e} in c.b at higher energy state comes to the lower energy state it release energy in terms of phonon energy which has very small value

$$E \approx 0.01 \text{ eV} - 0.1 \text{ eV}$$

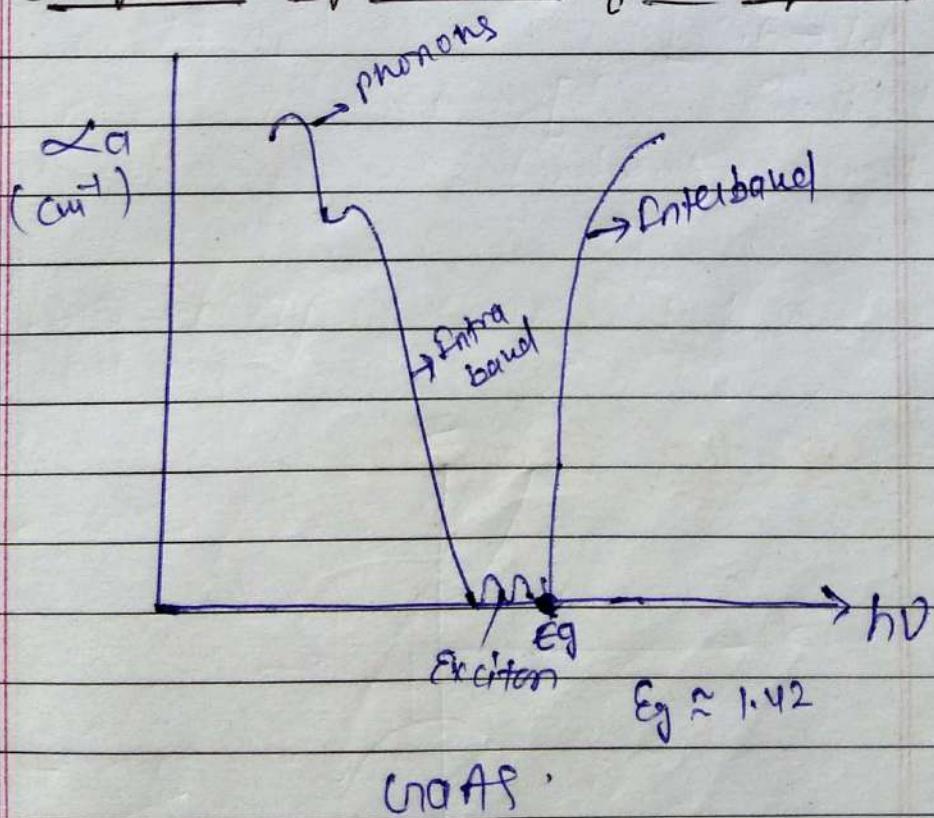
this transition is known as phonon transition and in this low energy photons generated the phonons

Hydrogen bond due to Cohesive attraction. So e^- and hole are localised thus localised entity called exciton

Binding energy of exciton is nearly equal to 10 milliev.



* Complete Spectrum of absorption in SiC:



Dated: _____
Page: _____

Unit - 5

Heterojunction is associated
band diagram
on the basis of structure P-N
J_n can be divided into three
Categories

Homojunction: The J_n b/w same type of
semiconducting material.
ex: n or p types of Si.

The the J_n is called homojunction

Schottky J_n:
the J_n b/w semiconducting
material and metal

Heterojunction:

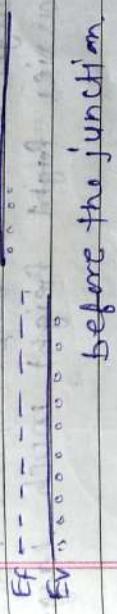
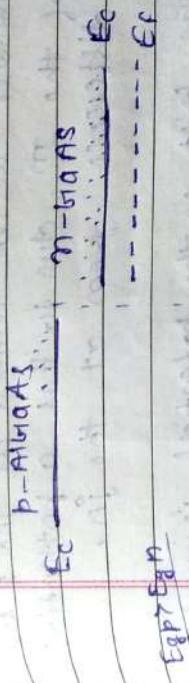
The J_n b/w two dissimilar
material usually diff. band gap.
It can be P-N J_n, P-P J_n and N-N J_n.
When two semiconducting material
have the same type of conductivity
then it is known as iso type hetero J_n.

when the conductivity of two
semiconducting material are diff. like
P-N J_n. then it is called
an isotropic hetero J_n.

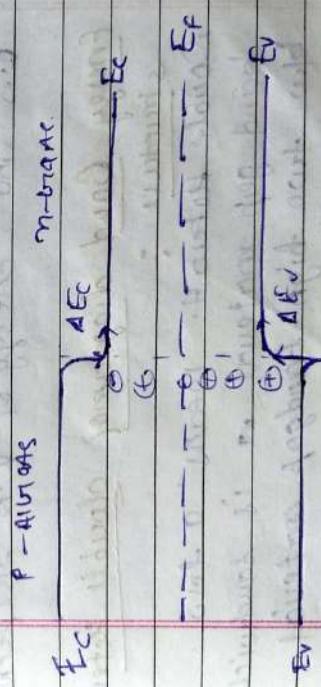
Dated: _____
Page: _____

4. Energy band diagram of p-n junction.

5. Single heterostructure / Junction.



before the junction.



After the junction

Dated : _____

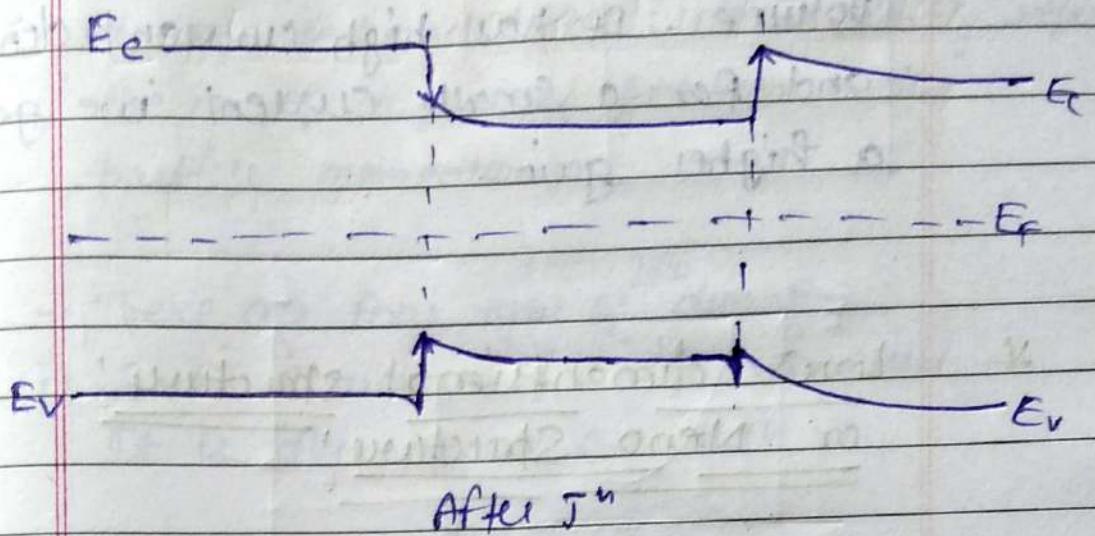
Page : _____

Concⁿ of electrons are higher in n-type n-Al_{0.5}As whereas concⁿ of holes are higher in p-Al_{0.5}As. So, diffusion take place and a mobile immobile - no ion formed at the p side of the J^m. due to this a potential difference form at the jn.

The built in potential is much larger then the simple PN J^m. because barrier height height much larger

ΔE_C & ΔE_V are known as the differencing known as Energy of C.B and Energy of V.B respectively

$$n_p > n_p^+ > n_p^-$$



In Double Heterostructure the intermediate layer has a potential well under non bias Condition . or we can say that a large no. of e and holes presence in Intermediate Region and e and hole recombine due to this a current flow in external circuit .

- The width of depletion region in case of heterostructure is $1 \text{ } \mu\text{m}$ which can be controlled . but in case of P-N Junction width of PN junction depends depletion region depends on doping level . which is not our controlled

Dated : _____
Page : _____

- In Heterostructure for the same current we have large no. of carriers in small volume. It has high current density and for a small current we get a higher gain.

* One dimensional structure or Nano Structure

When the one or more dimensions of a solid reduce significantly (below 100 nm) its physicochemical characteristic changes. (magnetic Properties changes, chemical properties, electrical, mechanical Properties changes) Resulting new structure low dimensional structure or nano structure

- Nanostructure can be explain with the help of quantum mechanics
- In nano st at least one dim. in the range of ^{few} nanometer.

* Classification
Low dim.
no. of size
the no. of
particle

- There are

(i) 3-D str
It is all

(ii) 2-D str
(quantum)

(iii) 1-D str
(quantum)

(iv) zero dim
quantum

1. 3 D (Three
No quan
occur if
holes in
in all 3 d)

Dated : _____

Page : _____

* Classification of low dimensional st. :

low dim. st. are usually classified acc. to no. of reduced dim. (dimensionally refer the no. of degree of freedom in the particle momentum).

- There are four type of ^{low} dim st.

(i) 3-D structure / 3-dim. structure

It is also known as bulk st.

(ii) 2-D structure / 2-dim. structure.

(quantum well.)

(iii) 1-D structure / 1-dim structure

(quantum wire)

(iv) zero dim. structure / 0-D st. i.e.

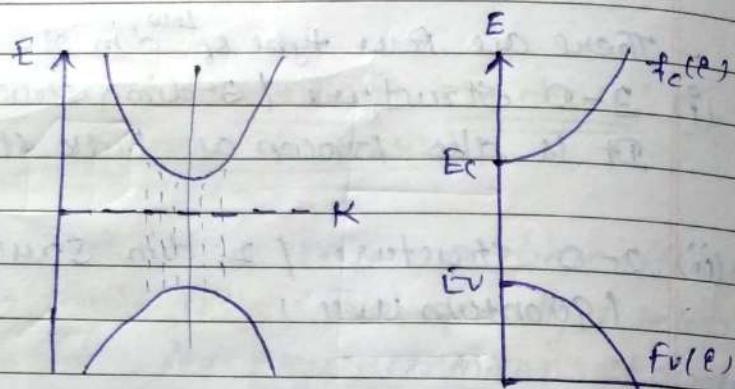
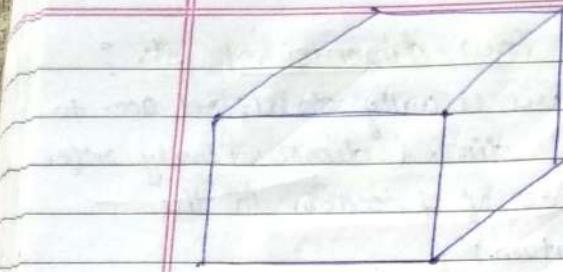
quantum Dot

1. 3-D (Three Dimensional) / bulk structure:

No quantisation of particle motion

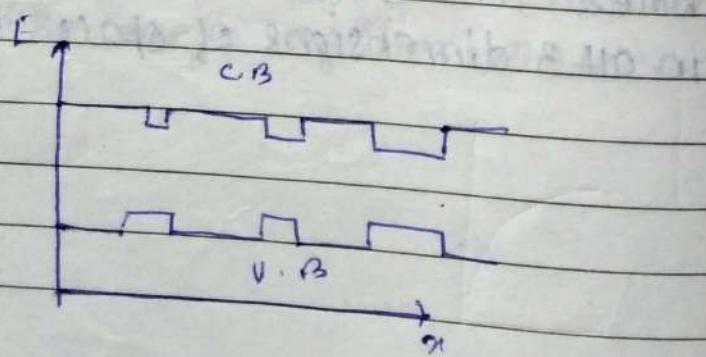
occurs i.e. particle is free. e.g. in c.b.s & holes in v.b. are free to move in all 3 dimensions of space i.e. cube

Dated: _____
 Page: _____

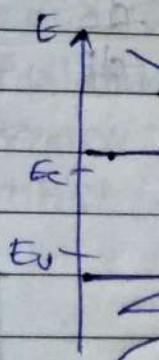


2. 2D (Two dimensional) structure / quantum well:

quantization of particle occurs in one direction, while particle is free to move in the other two directions (one dimensional is confined and reduced to nm range's while other 2 dim. remain large). ex. Thin film & quantum well

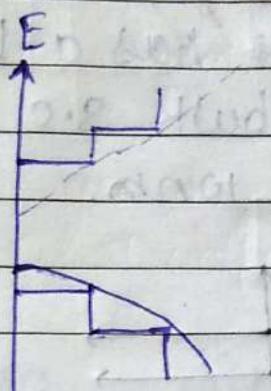
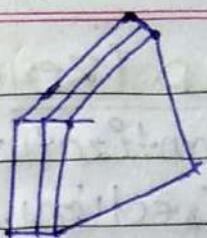
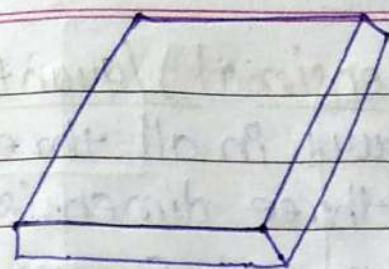


3. 1D (one dimensional) quantum structure / quantum particle confinement in to large nano size



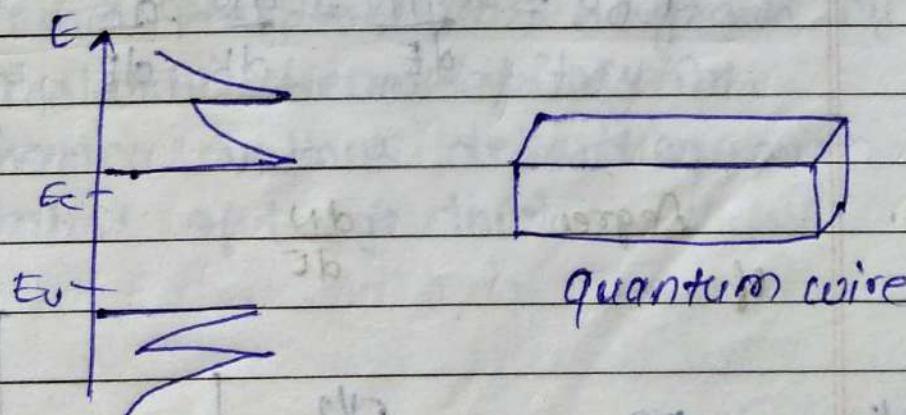
Dated : _____

Page : _____



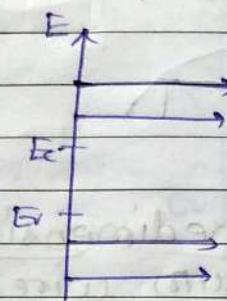
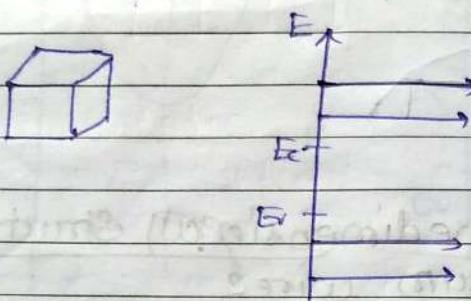
3. 1D (one-dimensional) structure :-
quantum wire

quantization occurs in 2 directions,
particle is free to move in one
direction (2 dimension are reduced
in to nm range & one remain
large). Ex quantum wire, nanowire
nanopillar



Dated: _____
Page: _____

14) 0D (Zero Dimensional) / quantum dot:
quantization occurs in all three directions; (all three dimensions reduced to nanometer range). Ex. nanodot
No quantum dots has a larger band gap like bulk S.C.
dimension = 1-10nm.



* Density of states (DOS):

no. of states / interval of Energy of each energy thru three available occupied states.

$$DOS = \frac{dN}{dE} = \frac{dN}{dk} \cdot \frac{dk}{dE}$$

at:

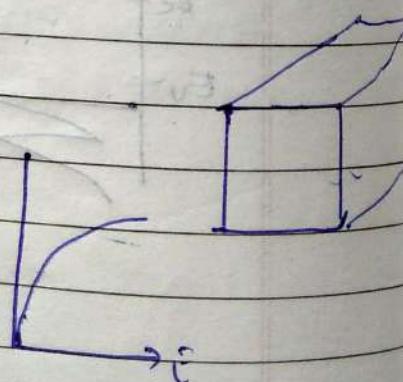
Degree
of

$$\frac{dN}{dk}$$

bulk

0D

$$E^{1/2}$$



Quantum
well

Quantum
wire

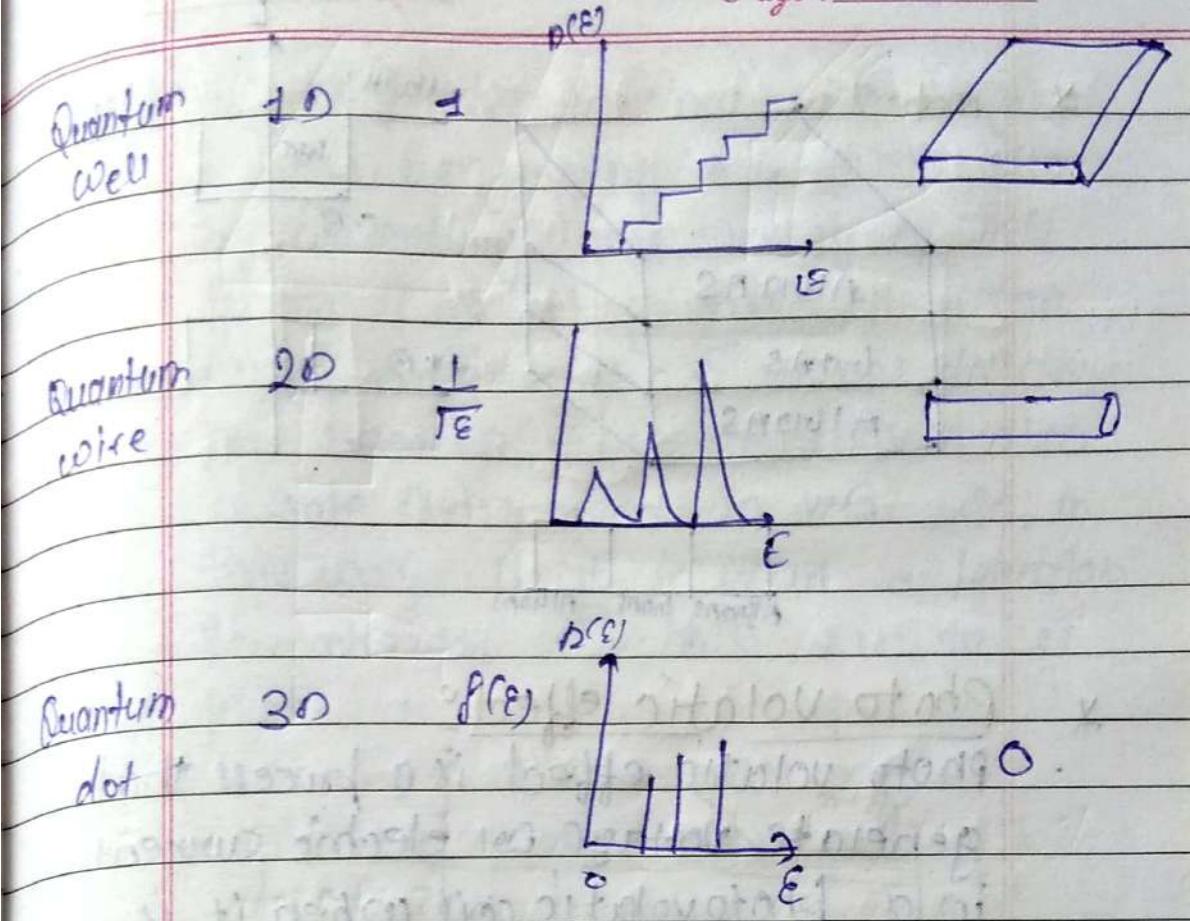
Quantum
dot

* Construction
D.W. of
material
2 large
i.e. AlG
Ex: Pa

* These
molecule
chemical
Control

Dated: _____

Page: _____



* Construction of quantum well:

It is formed in S.E by having a material like GaAs sandwiched b/w 2 layers of material with large band gap i.e AlGaAs i.e heterojunction structure

Ex: Particle in a box

- These structures can be grown by molecular beam epitaxy or chemical vapour deposition with control of large thickness.

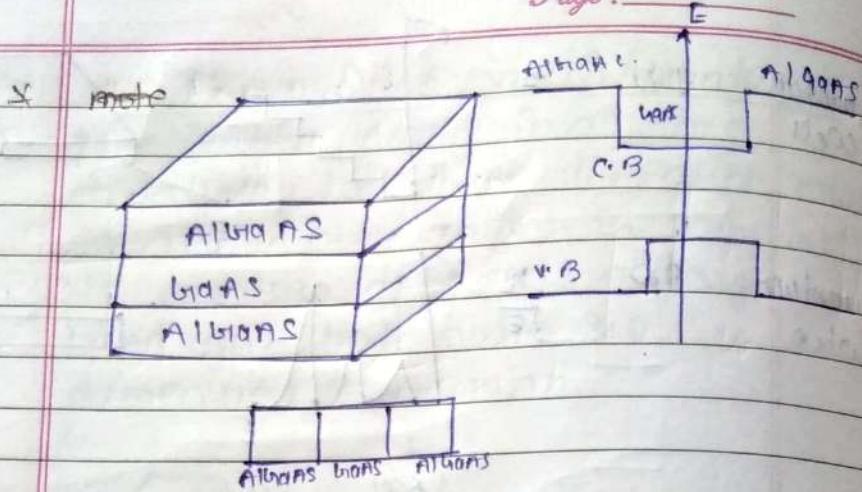
Dated: _____
Page: _____X Photo voltaic effect

photo voltaic effect is a process that generate voltage or electric current in a photovoltaic cell when it is exposed to sunlight. It is this that makes solar panels useful as it is the cells within the panel convert sunlight to electric energy.

The photo voltaic effect occurs in solar cell. These solar cells are composed of two different types of SiC a p-type and a n-type formed together to create a p-n junction.

when photo voltaic effect be by absorption of photon energy band gap becomes smaller this way formation place

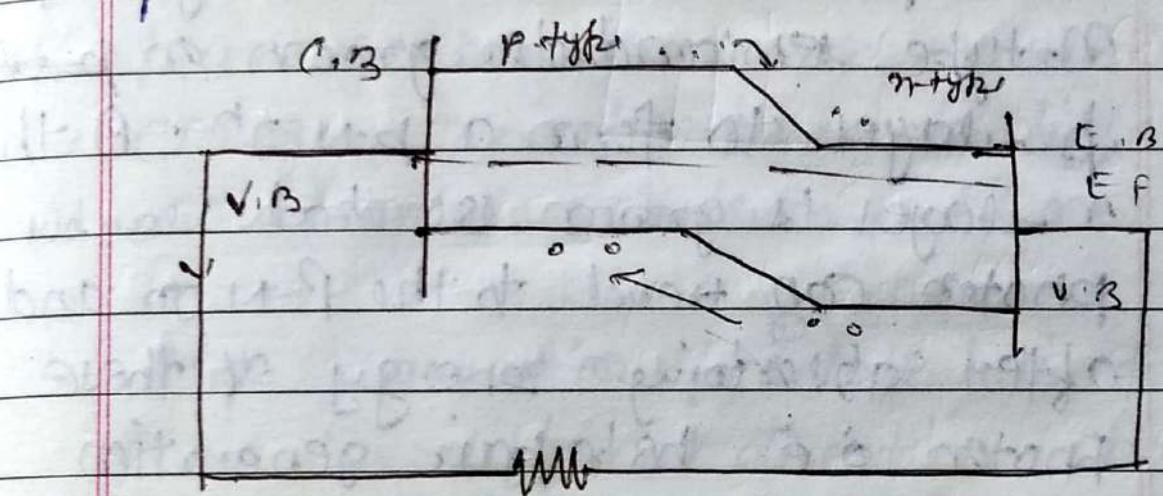
C.B

V.B

V

In a the ten
will am
to buh
in this
much
hole
change
Conne
a cur

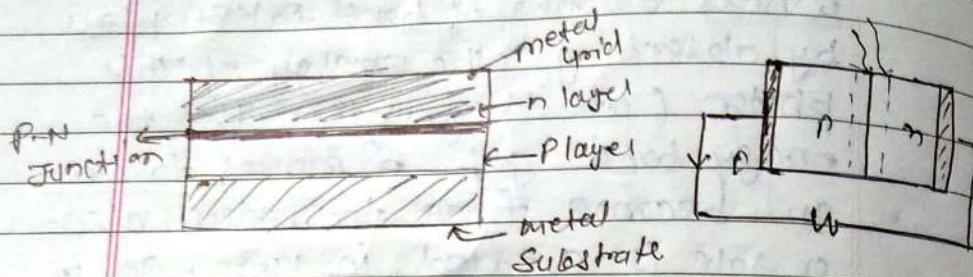
by absorbing the energy of this photon (at its greater than the energy band gap) ϵ moves to C.B. and become free to move, also a hole is created in V.B. So, in this way with incident a photon formation of e^- hole pair takes place.



In a p-n junction electrons have the tendency to move down the hill and holes have the tendency to bubble up (up the fall). So in this way, there will be a large drift of electrons one side and holes other side. If we put a charge collectors both side. And connected through a resistor then a current start flowing.

Dated: _____
Page: _____

1 Construction of a Solar Cell



on a metal substrate a p-layer is deposited and a thin layer of n-type semiconductor grown on ~~p-~~ p-layer to form a P-N J_n. A thin n+ layer is grown so that incident photon can reach to the P-N J_n and after absorbing energy of these photons e⁻ hole pair generation takes place and the charge carriers get collected on without charge.

To form a solar cell a single crystal SiC is used. Efficiency of a single crystal solar cell is about 10-30%.

A poly crystalline or amorphous Si-semiconductor can also be used to

make & will work

- single Cr
- Poly "
- Amorphous

Efficiency because Spectra pair generation works

- Also more reflection again cell compensates to deform acts

Dated : _____

Page : _____

make solar cell but the efficiency will very low

- single crystal solar cell $20 - 30\%$.
- Poly " " " $10 - 15\%$.
- Amorphous " silicon " $3 - 5\%$.

Efficiency of solar cell is very low, because all wavelength of solar spectrum not used their e^- hole pair generation. and remaining energy corresponding to different wavelength wasted as heat.

- Also generation of e^- hole pair they move in different direction change collector, e^- holes get recombination again. In polycrystalline solar cell this recombination is large is compare to single cell this recombination is large is compare to single crystal because any deformity in crystal structure acts as recombination center.

Dated: _____
Page: _____

- * Lattice matched heterostructure:
If $a_s \rightarrow$ lattice constant of a structure
 $a_L \rightarrow$ lattice constant of a layer grown epitaxially

- If $a_L = a_s$ then it is known as lattice matched structure. [heterostructure]

if $a_L \neq a_s$ then there will be some atoms which will not participate in bonding and this is called dangling bonds and which work as a defect in the crystal which increase the non-radiative recombination which decrease the performance of an electronic device.

Qn P - if $a_s \neq a_L$ even then we can grow the defect free layer when the thickness of growing layer is below a critical thickness and this is called strained layer epitaxy. bcz there is a bit in strain in the layer.

- * Strained layer epitaxy? If a_s and a_L is not matched this may lead to dangling bonds

these atoms constant. If stuck

- there will be which compress and also a due to this

$$d_L \{ F \}$$

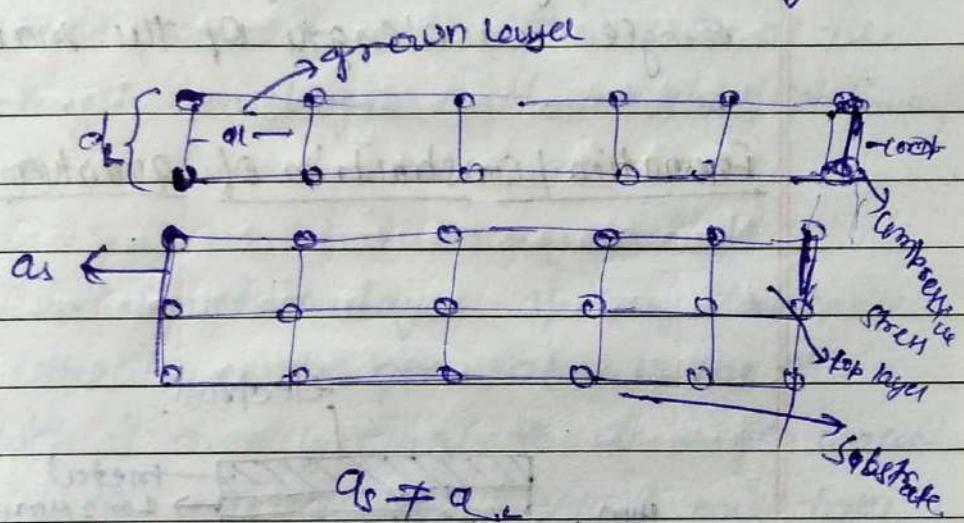
$$a_s \leftarrow \boxed{F}$$

$$d_L < d_c$$
$$d_c =$$

d_c = critical thickness.

these atoms will adjust their lattice constant. If the layer grown is very thick

- there will be a compressive strain which compress the lattice atoms of layer and also a tensile strain ^{with} develops due to this atoms will be elongated.



$$d_L < d_S$$

$$d_C = \frac{a_S}{\sqrt{1 + \epsilon}}$$

$\epsilon \approx$ mismatch

Parameter

$d_C \Rightarrow$ critical

thickness.

$$\epsilon = \frac{a_L - a_S}{a_L}$$

will be load with

stress with

Dated : _____

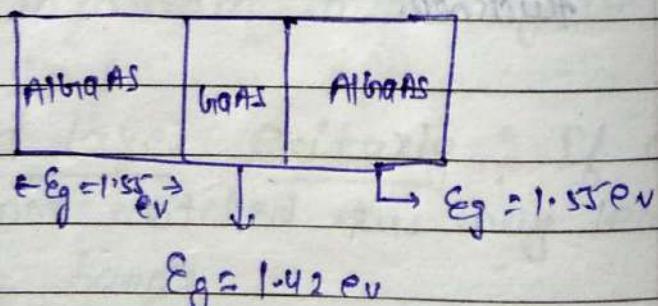
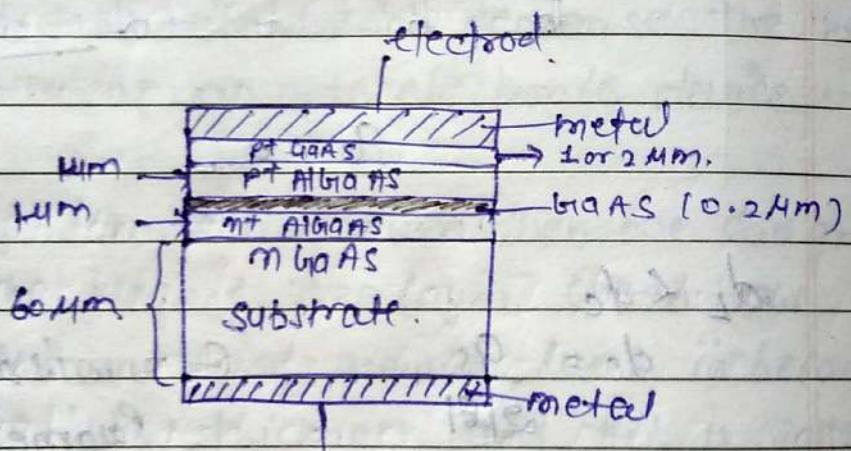
Page : _____

* Quantum well structure :

Quantum well is a double heterostructure which where thickness of active layer is near about 100 \AA .

Quantum well is a semiconductor double heterostructure where the thickness of active layer is always less than the de-Broglie wavelength of the material.

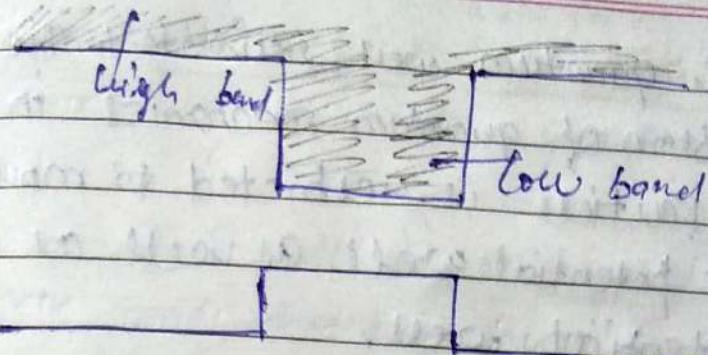
Formation / construction of quantum well structure



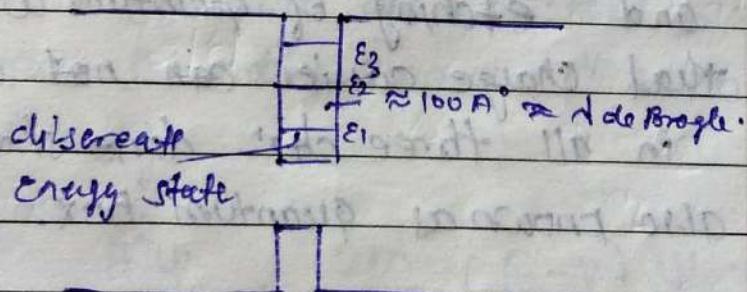
Active band structure

Active region II

Dated : _____
Page : _____



- This is a double barrier heterostructure. It will not be a quantum well, bcs the size of well is not of the order of the de-Broglie wavelength and CoS has continuous energy states.
- If in structure layer arbitrary thickness of the layer is near about 100 \AA which is nearly equal to de-Broglie wavelength then the quantum effect will take place and the formation of discrete energy levels formed in the CoS



Quantum well.

11/2/18 *

This quantum well resembles to the ~~bott~~ well problem of quantum mechanics in which the particle is restricted to move in a ~~finite~~ potential well as well as infinite potential well.

A Quantum wire structure / 1D structure: quantum wire formed from the quantum well in which a layer pattern with photolithography or e^\ominus beam lithography and then etched from the quantum well. Now charge carriers are confined along the two axes one as in quantum well and other dim depending on the size of lithography.

* quantum dot structure: quantum dot formed if the lithography and etching of quantum wire such that charge carrier can not confined in all three dim. dimensions. it is also known as quantum box.

\Rightarrow that particle (e^-) motion is restricted along x dir or dimension of size along x dir in nm range.

as now quantum effect take place
then the Schrodinger wave eq^u in 1D for e^-
is given by

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

$$a) \quad V(n)$$

$$\psi(n).$$

Dated : _____

Page : _____

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

$$\frac{2mE}{\hbar^2} = k^2$$

* K by solving the Schrödinger eqn.

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

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

$$E_n = \frac{n^2\pi^2\hbar^2}{8m^*l^2} \quad \text{or}$$

$$\psi = \frac{1}{l} \left(\frac{n\pi}{l} \right) x$$

$$E_n = \text{or} \quad \frac{n^2\hbar^2}{8m^*l^2}$$

m^* = effective mass of electron.

n = Principle quantum no

n = 1, 2, 3, ...

* Energy state of e^- in a SC in 1D
or in quantum wire

Dated: _____

Page: _____

$$V = 0 \quad 0 < n < L, \quad 0 < y < L$$
$$V = \infty \quad \text{elsewhere}$$

$$V(x, y) = \psi(x, y)$$

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} + \frac{2m}{\hbar^2} [E - V] \psi = 0$$

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

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

$$\frac{\partial^2 \psi}{\partial y^2} + \frac{2m}{\hbar^2} E_y \psi = 0$$

then the eigen value or energy
value of e^ψ

$$E = E_x + E_y$$

$$E = \frac{n_x^2 \hbar^2}{8m l_x^2} + \frac{n_y^2 \hbar^2}{8m l_y^2}$$

$$= \frac{\hbar^2}{8m} \left[\frac{n_x^2}{l_x^2} + \frac{n_y^2}{l_y^2} \right]$$

+ two quantum no. n_x and n_y

Dated: _____
 Page: _____

$$\Psi(m, y) = \Psi(m) \cdot \Psi(y)$$

$$\Psi = \sqrt{\frac{2}{l_m}} \sin\left(\frac{n_m \pi}{l_m} m\right) \cdot \sqrt{\frac{2}{l_y}} \sin\left(\frac{n_y \pi}{l_y} y\right)$$

* Energy state of e^\ominus in a sic in 00
 or quantum dot.

$$V=0 \quad 0 < n < l_x, 0 < y < l_y, 0 < z < l_z \\ V = \infty \quad \text{elsewhere}$$

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{2m}{\hbar^2} [E - V] \Psi = 0$$

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{\partial^2 \Psi}{\partial y^2} + \frac{\partial^2 \Psi}{\partial z^2} + \frac{2m}{\hbar^2} E \Psi = 0$$

$$\frac{\partial^2 \Psi}{\partial x^2} + \frac{2m}{\hbar^2} E_x \Psi = 0$$

$$\frac{\partial^2 \Psi}{\partial y^2} + \frac{2m}{\hbar^2} E_y \Psi = 0$$

$$\frac{\partial^2 \Psi}{\partial z^2} + \frac{2m}{\hbar^2} E_z \Psi = 0$$

$$E = E_x + E_y + E_z$$

$$\Psi = \Psi(m) \cdot \Psi(y) \cdot \Psi(z)$$

Dated : _____
 Page : _____

$$E = E_x + E_y + E_z$$

$$= \frac{n_x^2 h^2}{8m l_x^2} + \frac{n_y^2 h^2}{8m l_y^2} + \frac{n_z^2 h^2}{8m l_z^2}$$

$$E = \frac{h^2}{8m} \left[\frac{n_x^2}{l_x^2} + \frac{n_y^2}{l_y^2} + \frac{n_z^2}{l_z^2} \right]$$

~~two~~ quantum three quantum no. n_x, n_y, n_z

$$\Psi(x, y, z) = \psi(x) \cdot \psi(y) \cdot \psi(z)$$

$$\Psi(x, y, z) = \sqrt{\frac{2}{l_x}} \sqrt{\frac{2}{l_y}} \sqrt{\frac{2}{l_z}} \sin\left(\frac{n_x \pi}{l_x}\right) x$$

$$\cdot \sin\left(\frac{n_y \pi}{l_y}\right) y \sin\left(\frac{n_z \pi}{l_z}\right) z$$

* Density of states in 3D (σ)
 Density of state (σ) in 3D

$DOS_{3D} = \text{no. of State per unit Energy}$
 Per unit volume

$$= \frac{1}{V} \frac{dN}{dE}$$

$$= \frac{1}{V} \cdot \frac{dN}{dk} \cdot \frac{dk}{dE} \quad \text{--- (1)}$$

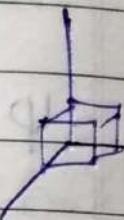
Dated: _____
Page: _____

or $N = \text{no. of states in a given } k \text{ space.}$

between energy state E & $E + dE$

$$N = \frac{2 \times \frac{1}{8} \times \frac{4}{3} \times \pi \times 3^3}{(\pi/a)^3}$$

$$= \frac{k^3 a^3}{3 \pi^2}$$



$$= \frac{k^3 a^3}{3 \pi^2}$$

$$N = \frac{k^3 a^3}{3 \pi^2}$$

$$\frac{dN}{dk} = \frac{a^3 k^2}{\pi^2}$$

2

$$k^2 = \frac{2m\beta}{\hbar^2}$$

$$\propto k dk = \frac{2m dE}{\hbar^2}$$

$$dE = \frac{m}{\hbar^2} \frac{dk}{k}$$

Dated : _____

Page : _____

$$\frac{d^k}{dE} = \frac{m}{\hbar^2} \cdot \frac{1}{k} - \textcircled{3}$$

$$DOS_{SO} = \frac{1}{V} \frac{a^3 k_B}{\pi^2} \times \frac{m}{\hbar^2} \cdot \frac{1}{k}$$

Volume is taken physical volume

$$V = a^3$$

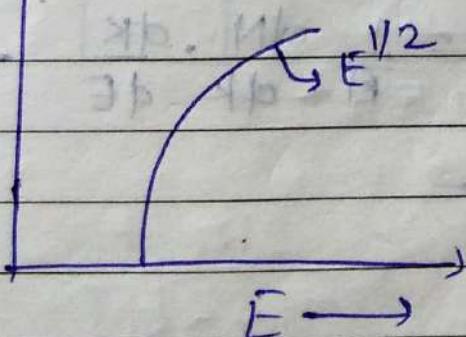
$$DOS_{SO} = \frac{1}{a^3} \cdot \frac{a^3 k_B}{\pi^2} \times \frac{m}{\hbar^2} \cdot \textcircled{3}$$

$$= \frac{k_B m}{\pi^2 \hbar^2}$$

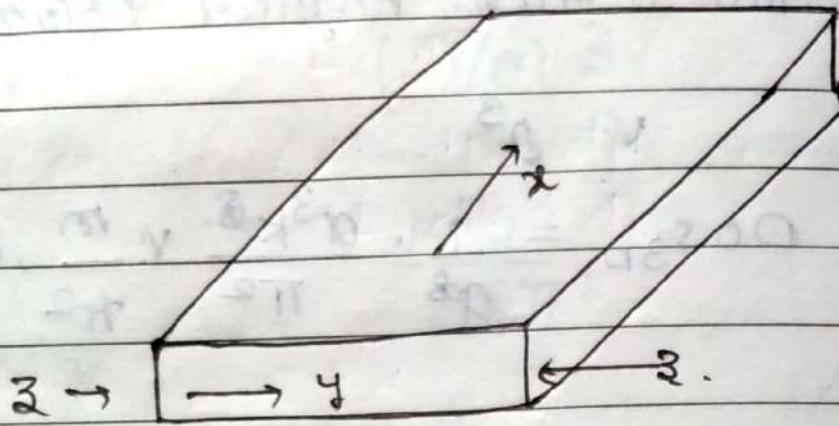
$$DOS_{SO} = \frac{m^{3/2} g^{1/2} E^{1/2}}{\pi^2 \hbar^3}$$

$$DOS \propto E^{1/2}$$
$$\propto m^{3/2}$$

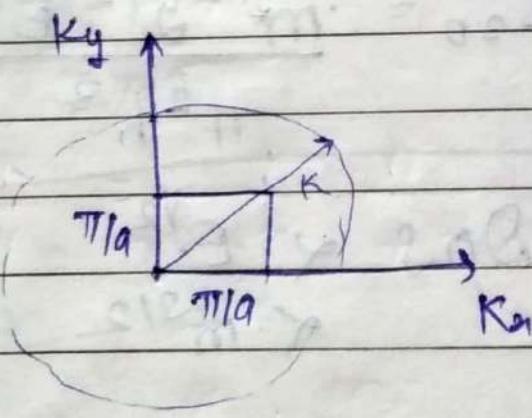
$f(E)$



+ the one with p & z dirn) and moves freely along x and y axis
 (quadrant wave)



moving of e^{\pm} $\rightarrow x, y$
 confined along $\rightarrow z$.



$$\begin{aligned}
 \text{DOS}_{2D} &\Rightarrow \frac{1}{A} \frac{dN}{dE} \\
 &= \frac{1}{A} \frac{dN}{dk} \cdot \frac{dk}{dE} \quad \text{--- (1)}
 \end{aligned}$$

Dated : _____
Page : _____

$$N = \frac{2 \times \pi k^2}{4} = \frac{a^2 k^2}{2\pi}$$

$$\frac{dN}{dk} = \frac{a^2 k}{\pi} \rightarrow \textcircled{2}$$

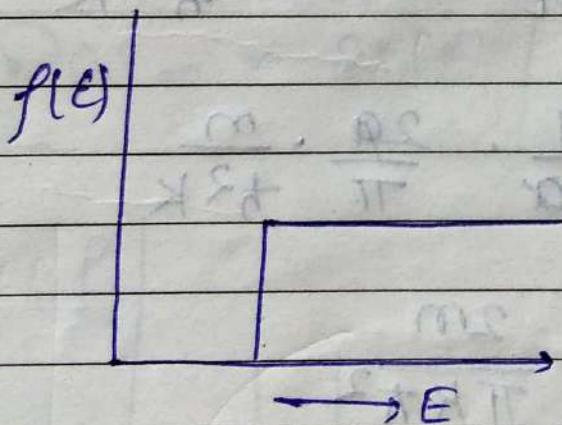
$$\frac{dk}{dE} = \frac{m}{\hbar^2 k} \rightarrow \textcircled{3}$$

$$A = a^2$$

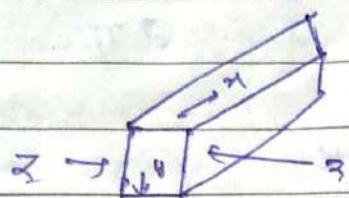
$$\text{DOS}_{2D} = \frac{1}{a^2} \cdot \frac{a^2 k}{\pi} \cdot \frac{m}{\hbar^2 k}$$

$$\boxed{\text{DOS}_{2D} = \frac{m^*}{\pi \hbar^2}}$$

DOS_{2D} is independent of energy.

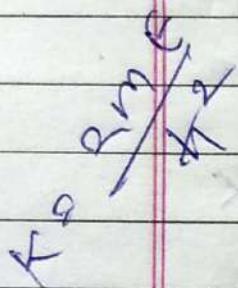


* Density of state in 1D quantum wire



$$DOS_{1D} = \frac{1}{L} \frac{dN}{dE}$$

$$= \frac{1}{L} \frac{dN}{dK} \cdot \frac{dK}{dE}$$



$$N = \frac{2\pi K}{\pi/a}$$

$$N = \frac{2Ka}{\pi}$$

$$\frac{dN}{dK} = \frac{2a}{\pi}$$

$$\frac{dK}{dE} = \frac{m}{\hbar^2 K}$$

$$= \frac{1}{a} \cdot \frac{2a}{\pi} \cdot \frac{m}{\hbar^2 K}$$

$$DOS_{1D} = \frac{2m}{\pi K \hbar^2}$$

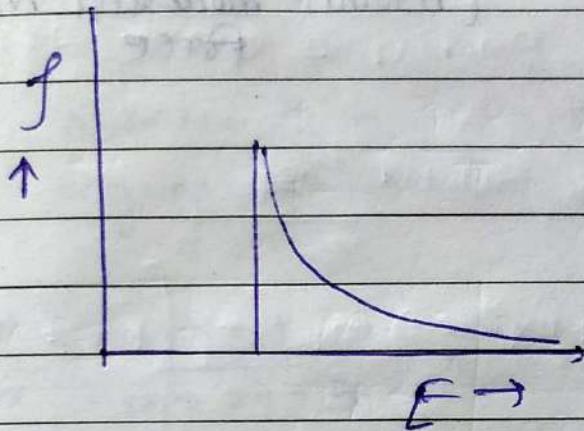
$$DOS_{1D} = \frac{2m}{\pi \hbar^2 \sqrt{mE}}$$

factorization of
DOS Dated: _____
Page: _____

$$DOS_{1D} = \frac{2m^*}{\pi \hbar^2} \sqrt{2mE}$$

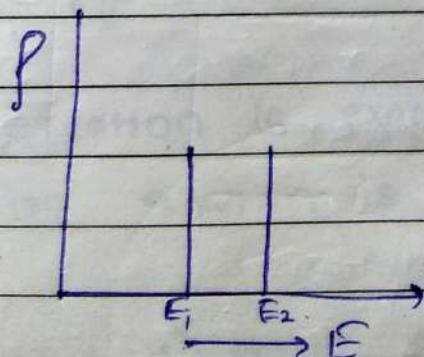
$$DOS_{1D} = \frac{(2m^*)^{1/2}}{\pi \hbar} E^{-1/2}$$

$$DOS \propto E^{-1/2}$$



* Density of state in 0D)

$$DOS_{0D} = 2 \times \delta E$$



* Characterisation of nanostructure or low dimension material can be done by following instruments or techniques.

- ① XRD (X-ray diffractometer)
- ② SEM (Scanning electron microscopy)
- ③ TEM (Tunneling effect microscopy)
- ④ AFM (Atomic molecular microscopy force.)