Unit → I

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Introduction to Semiconductor Physics

★ Classification of Semiconductors

Classification of Semiconductors

- Elemental Semiconductor (example → Si & Ge)
- Compound Semiconductors
  - → Binary : e.g. * GaP } usually used in LEDs
    - * GaAs
    - * ZnS } usually used in Television screens & Fluorascent materials
  - → Ternary : e.g. → GaAsP, AlGaAs
  - → Quaternary : e.g. → InGaAsP

★ Solid Materials

Three types of crystal structures :

1. Crystalline : materials in which atoms are arranged or placed in a periodic fashion. e.g. → Si, Ge.
2. Non-Crystalline or Amorphous
3. Poly Crystalline : materials are composed of many small regions of single crystal material. These material consist of small crystalline regions with random orientation called grains.

$\boxed{\text{Crystal Structure} = \text{Lattice} + \text{Basis}}$

The periodic arrangement of atoms in a crystal is called a lattice.

Most crystals have a combination of atoms associated with each lattice point. This combination of atoms is called basis.

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★ **Packing Density or Atomic Packing Density**

It is defined as fraction of space occupied by atoms in unit cell.

$$\text{Packing Density} = \frac{\text{Volume of the atoms per unit cell } (v)}{\text{Volume of unit cell } (V)}$$

$$\boxed{\text{Volume of atoms} = \frac{4}{3}\pi r^3} \qquad \boxed{v = \frac{4}{3}\pi r^3 \times N}$$

$$\frac{v}{V} = \frac{\frac{4}{3}\pi r^3 \times N}{V}$$

N ⟶ No. of effective atoms

for example: Find the fraction of FCC [redacted], volume filled with hard spheres.

Sol^n ⟹ $N = 4$ side $= a$ FCC ⟹ $r = \frac{\sqrt{2}}{4}a$

$$v = \frac{4}{3}\pi r^3 \times N \Rightarrow v = \frac{4}{3}\pi\left(\frac{\sqrt{2}}{4}\right)^3 a^3 \times 4$$

$$V = a^3$$

$$\text{Packing density} = \frac{v}{V} = \frac{\frac{4\pi}{3}\left(\frac{\sqrt{2}}{4}\right)^3 \times a^3 \times 4}{a^3}$$

$$= 0.7404 = 74.04\%$$

	Packing Density
FCC ⟶	74%
SC ⟶	52%
BCC ⟶	68%

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★ Calculation of Lattice Constant

The dimension 'a' of ρ density

- Volume of unit cell = a^3
- Mass of each unit cell = density X volume = ρa^3

→ Let there be n molecules (lattice point) per unit cell
M be the molecular weight and N be Avogadro Number

Mass of each molecule = $\frac{M}{N}$

mass in each unit cell = $n \times \frac{M}{N}$

$$\Rightarrow \rho a^3 = \frac{nM}{N} \Rightarrow a^3 = \frac{nM}{\rho N} \Rightarrow \boxed{a = \left(\frac{nM}{\rho N}\right)^{1/3}}$$

Q- Find the number of atoms per unit cell in iron cube lattice having lattice parameter 2.9 Å & density 7.87 gm/cc. Given atomic weight of metal 55.85

Sol^n)

$a = 2.9$ Å $= 2.9 \times 10^{-8}$ cm, $N = 6.022 \times 10^{23}$
$\rho = 7.87$ gm/cc $\quad M = 55.85 \quad n = ?$

$$a = \left(\frac{nM}{\rho N}\right)^{1/3} \Rightarrow n = \frac{a^3 \rho N}{M}$$

$$\Rightarrow n = \frac{(2.9 \times 10^{-8})^3 \times 7.87 \times 6.022 \times 10^{23}}{55.85}$$

$$\Rightarrow n = 2.069 \approx 2 \text{ Ans}$$

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★ Principle of Quantum mechanics

1. Principle of energy quanta
2. The wave particle duality principle
3. The uncertainty principle

→ Postulates of Quantum mechanics

★ Bonding Forces in Solids

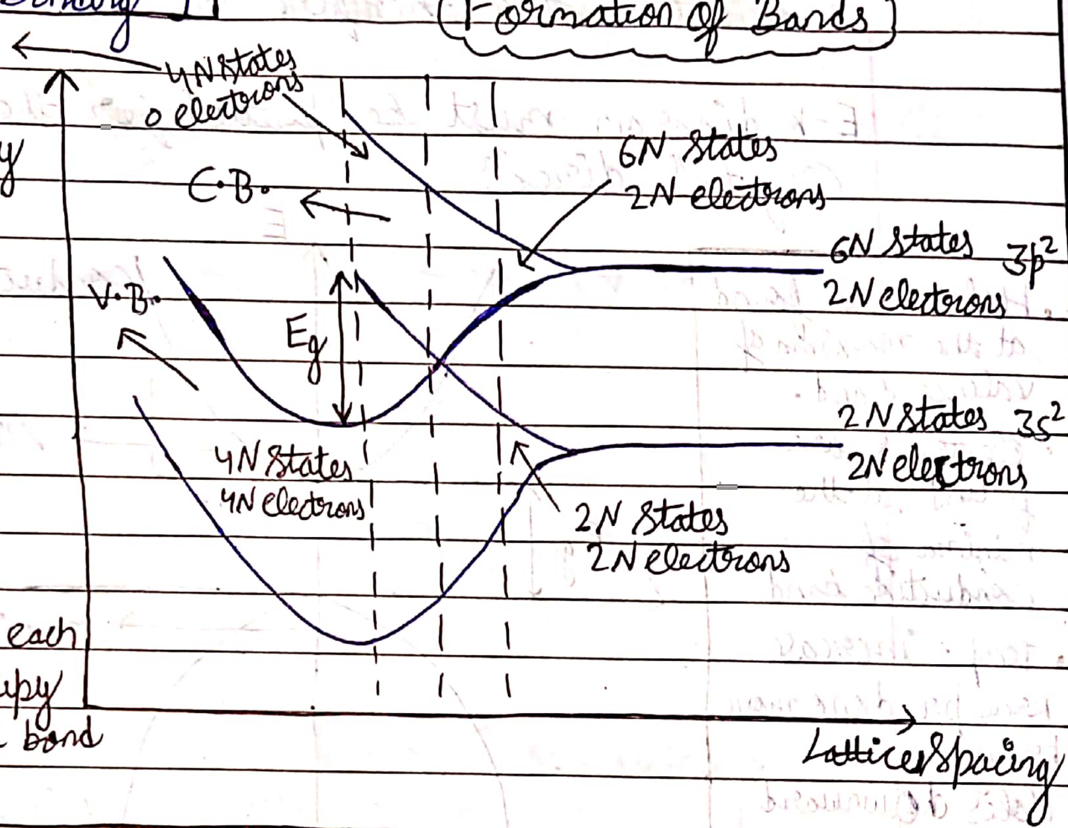
① Ionic Bonding
② Covalent Bonding
③ Metallic Bonding

} Primary Bonding (or Bonds)

Formation of Bands

Higher band remains empty

V.B. → Valence Band
C.B. → Conduc^n Band



4e⁻s of each atom occupy the lower band

$$\boxed{E_g(\text{for Si}) = 1.12 \text{ to } 1.5\,eV \; ; \; E_g(\text{for Ge}) = 0.67\,eV \text{ to } 0.73\,eV}$$

- electrons & holes are generated in pairs.
  - They are generated due to temp. that's why it is called "Thermally generated EHP"

EHP → pair generation (electron hole pair generation)

★ Direct and Indirect Semiconductors

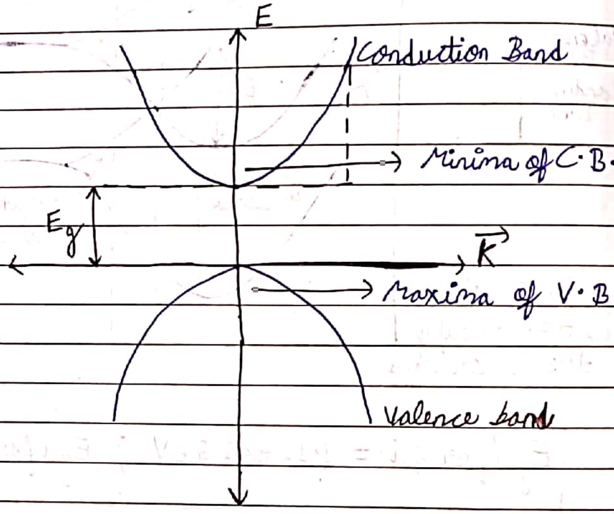
* E-K Diagram

E represents energy
K is wave vector

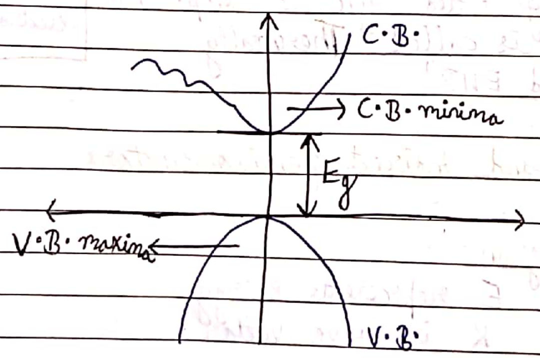
The E-K diagram is the plot of total electron energy (potential as well kinetic) as a function of the crystal direc^n dependent electron wave vector at some point in space. This electron wave vector is proportional to the momentum and therefore the velocity of the electron.

E-K diagram must be plotted for the various crystal direc^n.

- Holes are found at the maxima of valence band.
- electrons are found at the minima of conduction band.
- Temp. increase krne pr dono move krenge. Holes downward e^-s upward

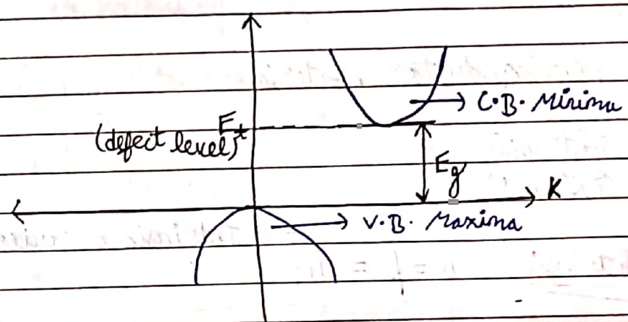


→ Direct Semiconductor → (e.g. Compound Semiconductor)



In the direct semiconductor, C.B. minima & V.B. maxima are located at same momentum value.
In this type of semiconductor, an e^- can make a transition from V.B. maxima to C.B. minima without change in the value of momentum.

→ Indirect Semiconductor → (e.g. elemental semiconductor)



In this type of semiconductor, C.B. minima & V.B. maxima are located at different momentum value.
In this type of semiconductor, an e^- makes a transition from V.B. maxima to C.B. minima with a change in the value of momentum.

★ Effective Mass [redacted] (m^*)

$p = mv = \hbar K$ (K → wave vector) where $\hbar = \frac{h}{2\pi}$

$E = \frac{1}{2}mv^2 = \frac{1}{2}\frac{p^2}{m} \Rightarrow E = \frac{\hbar^2 K^2}{2m}$

$$\Rightarrow \boxed{\frac{d^2E}{dK^2} = \frac{\hbar^2}{m^*}}$$

The effective mass of $e^- \rightarrow m_e^*$
The effective mass of hole $\rightarrow m_h^*$

	m_e^*	m_h^*
Ge	$0.55m_0$	$0.37m_0$
Si	$1.1m_0$	$0.59m_0$

$m_0 \rightarrow$ rest mass of charge carrier in vacuum

★ Semiconductor material

① Intrinsic
② Extrinsic

for Intrinsic $n = p = n_i$ → Intrinsic carrier concentration

at room temp. $n_i = 2\times10^6/cm^3$ for GaAs
$1.5\times10^{10}/cm^3$ for Si
$2.5\times10^{10}/cm^3$ for Ge

$\boxed{r_i = g_i}$ (recombination rate; generation rate)

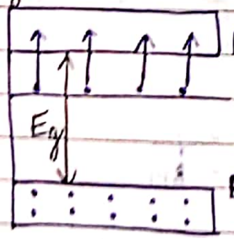
$\boxed{r_i \propto n_0 p_0}$ (equilibrium concentration of holes & electrons)

$\boxed{r_i = \alpha_r n_0 p_0 = g_i}$
$= \alpha_r n_i^2$

α_r is constant of proportionality

for extrinsic • n-type

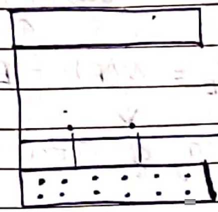
$(n_0 >> n_i, p_0)$



E_c
E_D Donor energy level
E_g
E_v

At $0°K \rightarrow 50°K$

• p-type $(p_0 >> n_i, n_0)$



E_c
E_A Acceptor level
E_v
at 50°K

★ Carrier Concentration

→ Fermi Dirac Statistics

• Assume we are taking two energy levels E_1 & E_2 $(E_1 > E_2)$

• The number of n_2 atoms at E_2 } at thermal equilibrium
• The number of n_1 atoms at E_1 }

$$\boxed{\begin{aligned} n_2 &= N_2 e^{-E_2/KT} \\ n_1 &= N_1 e^{-E_1/KT} \end{aligned}}$$

$$\boxed{\frac{n_2}{n_1} = \frac{N_2 e^{-E_2/KT}}{N_1 e^{-E_1/KT}}}$$

N_1 & N_2 → No. of states (energy level occupied by a electron)

$$\boxed{\frac{n_2}{n_1} = \frac{N_2}{N_1} e^{-(E_2-E_1)/KT}} \quad (1)$$

• The no. of free e^-s$/m^3$ of a metal whose energy is lies between E & $E+dE$ is given by

$$\boxed{dn_E = \rho_E \cdot dE} \quad (2)$$

ρ_E represent the density of e^-s in this interval (no. of e^-s per eV per m^3)

$$\boxed{\rho_E = N(E)\cdot f(E)} \quad (3)$$

$/m^3$

$N(E)$ → density of states per eV per m^3
$f(E)$ → Fermi Dirac Distribution func^n

$f(E) \rightarrow$ It gives the probability that an available ~~[illegible]~~ energy ~~[illegible]~~ state at E will be occupied by an e^-

★ Fermi Dirac Distribution Function

$$\rho_E = N(E)\cdot f(E) \quad \text{— (3)}$$

Density of states $N(E)$

$N(E) \propto E^{1/2} \longrightarrow$ half power energy

$$\Rightarrow \boxed{N(E) = \gamma E^{1/2}} \quad \text{— (4)}$$

$\gamma \rightarrow$ proportionality constant

$$\gamma = \frac{4\pi}{h^3}\left[2m_e^* e\right]^{3/2} \quad \text{— (5)}$$

$$\gamma = 6.83\times10^{27} \text{ per eV per } m^3$$

also known as occupation probability $\leftarrow$ $\boxed{f(E) = \dfrac{1}{1+e^{(E-E_F)/KT}}}$ — (6)

$E \rightarrow$ energy
$E_F \rightarrow$ Fermi level energy
$T \rightarrow$ temp.
$K \rightarrow$ Boltzmann's constant

If $E = E_F$

$$f(E) = \frac{1}{1+e^{(E_F-E_F)/KT}} = \frac{1}{1+e^0} = \frac{1}{1+1} = \frac{1}{2}$$

$$\rho(E) = N(E)\cdot f(E)$$

$$= \gamma E^{1/2}\cdot\frac{1}{1+e^{E-E_F/KT}} \quad \text{— (7)}$$

$$n_E = \rho_E\cdot dE$$

$$\Rightarrow \boxed{n_E = \frac{\gamma E^{1/2}}{1+e^{E-E_F/KT}}\cdot dE} \quad \text{— (8)}$$

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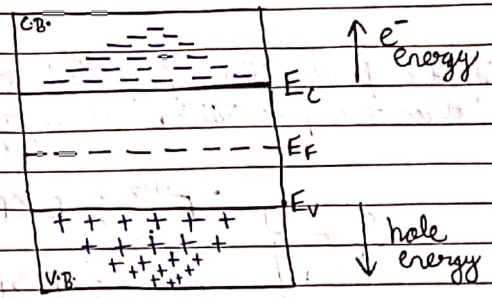
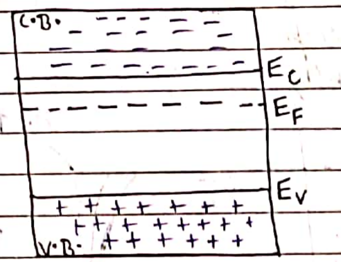
★ Fermi Level

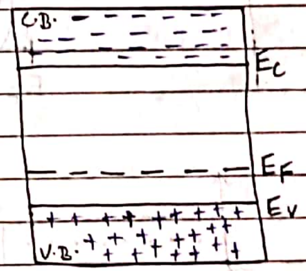
Intrinsic



N-type



P-type



Fermi Distribution funcⁿ at absolute 0 $\quad T = 0\,K$

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

① $E < E_F$ (exponent value −ve) $\quad f(E) = \dfrac{1}{1+0} = 1$

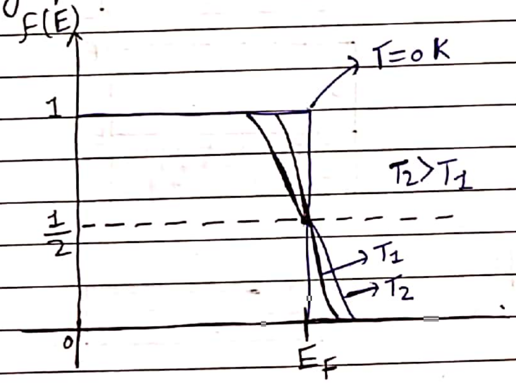
(ii) $E > E_F \Rightarrow$ exponent +ve

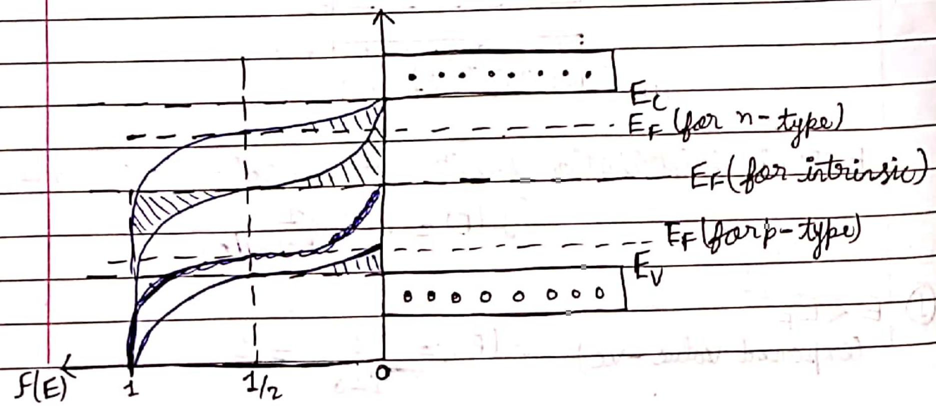
$$\Rightarrow f(E) = \frac{1}{1-\infty} = 0$$

If the probability of filled state is $\boxed{f(E)}$ then the probability of empty state is $\boxed{1-f(E)}$

$$\rho_E = \begin{cases} YE^{1/2} ; & E < E_F \\ 0 ; & E > E_F \end{cases}$$

* E V/s f(E) graph





- Band structure
- Fermi dirac distribution f(E)
  - Density of state N(E)
  - concentration n_E

→ Fermi Level

$$dn_E = \rho_E \cdot dE$$

$$\Rightarrow dn_E = YE^{1/2} \cdot dE$$

$$\int dn_E = Y\int_0^{E_F} E^{1/2} dE$$

$$\Rightarrow n_E = Y\left[E^{3/2}\right]_0^{E_F} \cdot \frac{2}{3}$$

$$= \frac{2}{3}Y(E_F)^{3/2}$$

$$\boxed{E_F^{3/2} = \frac{3n_E}{2Y}} \quad \text{or} \quad E_F = \left(\frac{3}{2Y}\right)^{2/3} \cdot (n_E)^{2/3}$$

★ Carrier concentration in intrinsic semiconductor

(i) Concentration of e^-s in C.B.

(a) Let no. of e^- dn/m^3 whose energies lies b/w E & E+dE

$$dn = N(E) \cdot f(E) \cdot dE \quad \text{—(1)}$$

(b) Density of states, $N(E) = YE^{1/2} = Y(E-E_c)^{1/2}$ —(2)

(c) $f(E) = \dfrac{1}{1+e^{E-E_F/KT}} = \dfrac{1}{e^{E-E_F/KT}} = e^{-(E-E_F/KT)}$ —(3)

(Yeh term 1 se bda ho gya becoz $E-E_F >>$)

$$dn = N(E) \cdot f(E) \cdot dE$$

$$\Rightarrow \int dn = \int_{E_c}^{\infty} N(E) \cdot f(E) \cdot dE$$

$$\Rightarrow n = \int_{E_c}^{\infty} \gamma (E-E_c)^{1/2} \cdot e^{-(E-E_F)/KT} \, dE$$

$$= \gamma (KT)^{1/2} \int_{E_c}^{\infty} \left(\frac{E-E_c}{KT}\right)^{1/2} \cdot e^{-[E-E_F+E_c-E_c]/KT} \cdot dE$$

$$= \gamma (KT)^{1/2} \int_{E_c}^{\infty} \left(\frac{E-E_c}{KT}\right)^{1/2} \cdot e^{-(E-E_c)/KT} \cdot e^{-(E_c-E_F)/KT} \cdot dE$$

$$= \gamma (KT)^{1/2} e^{-(E_c-E_F)/KT} \int_{E_c}^{\infty} \left(\frac{E-E_c}{KT}\right)^{1/2} e^{-(E-E_c)/KT} \cdot dE$$

- put $\frac{E-E_c}{KT} = x$, $dE = dx \cdot KT$

- when $E = E_c$, $x = 0$

  $E = \infty$, $x = \infty$

$$= \gamma (KT)^{1/2} \, e^{-(E_c-E_F)/KT} \int_0^{\infty} x^{1/2} e^{-x} \cdot KT \cdot dx$$

$$= \gamma (KT)^{3/2} \, e^{-(E_c-E_F)/KT} \int_0^{\infty} x^{1/2} e^{-x} \cdot dx$$

$$\Rightarrow n = \gamma (KT)^{3/2} e^{-(E_c-E_F)/KT} \cdot \frac{\sqrt{\pi}}{2}$$

$$\boxed{n = N_c \cdot e^{-(E_c-E_F)/KT}}$$

$$\gamma = \frac{4\pi}{h^3} [2me^*]^{3/2} \cdot (1.6 \times 10^{-19})^{3/2}$$

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& at equilibrium, $n_0 = N_c \, e^{-(E_c-E_F)/KT}$

where $N_c = \gamma (KT)^{3/2} \cdot \frac{\sqrt{\pi}}{2}$

$$= \frac{4\pi}{h^3} (2me^*)^{3/2} \cdot (KT)^{3/2} \cdot \frac{\pi^{1/2}}{2} \cdot (1.6 \times 10^{-19})^{3/2}$$

$$= 2 \left[\frac{2\pi m_e^* q KT}{h^2}\right]^{3/2}$$

(K in eV/°K)
(K in joules/°K)

$$\Rightarrow \boxed{N_c = 2 \left[\frac{2\pi m_e^* KT}{h^2}\right]^{3/2}}$$

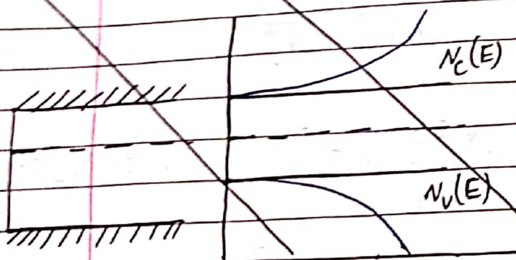
$$\boxed{n = 2 \left[\frac{2\pi m_e^* KT}{h^2}\right]^{3/2} \cdot e^{-(E_c-E_F)/KT}}$$

$p = N_v \cdot e^{(E_v-E_F)/KT}$; $N_v = 2\left[\frac{2\pi m_p^* KT}{h^2}\right]^{3/2}$

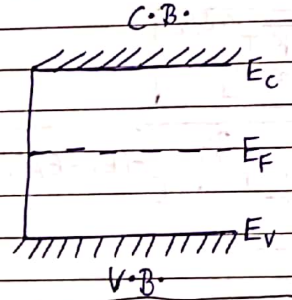
$$p = 2\left[\frac{2\pi m_p^* KT}{h^2}\right]^{3/2} \cdot e^{(E_v-E_F)/KT}$$

Shu

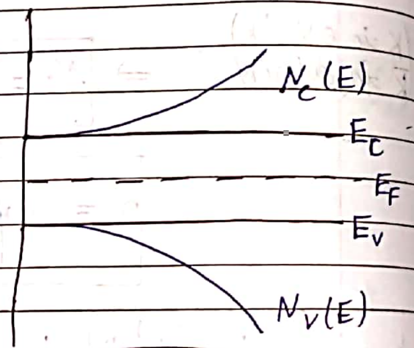
→ Intrinsic



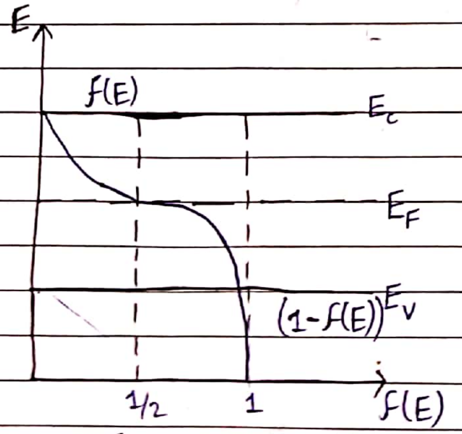
→ For Intrinsic



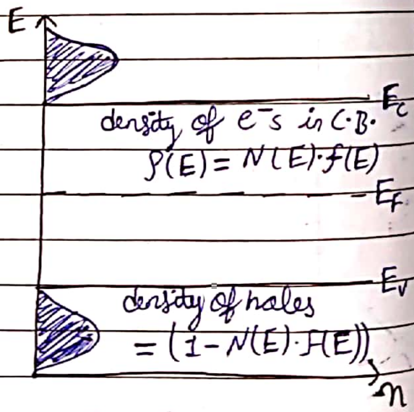
Band Structure



Density of States



Fermi Dirac distribution func^n



Carrier Concentration

Fermi Level in Intrinsic Semiconductor

$$\longrightarrow n = N_c e^{-(E_c - E_F)/KT}$$

$$\longrightarrow p = N_v e^{(E_v - E_F)/KT}$$

for intrinsic S.C. $n = p$

$$\Rightarrow N_c e^{-(E_c - E_F)/KT} = N_v e^{(E_v - E_F)/KT}$$

$$\Rightarrow \frac{N_c}{N_v} = \frac{e^{E_v - E_F/KT}}{e^{-(E_c - E_F)/KT}}$$

$$\Rightarrow \frac{N_c}{N_v} = e^{E_v - E_F + E_c - E_F/KT}$$

$$\Rightarrow \frac{N_c}{N_v} = e^{E_v + E_c - 2E_F/KT}$$

Taking log on both sides

$$\log_e \frac{N_c}{N_v} = \frac{E_v + E_c - 2E_F}{KT}$$

$$\Rightarrow E_v + E_c - 2E_F = KT \log_e \frac{N_c}{N_v}$$

$$\Rightarrow 2E_F = E_v + E_c - KT \log_e \frac{N_c}{N_v}$$

Effective mass of $\boxed{m_e^* = m_p^*} \Rightarrow \therefore \boxed{N_c = N_v}$

$$\boxed{E_F = \frac{E_c + E_v}{2}}$$

Intrinsic Concentration

$$n = N_c e^{-(E_c - E_F)/KT} \quad \text{—— (1)}$$

$$p = N_v e^{(E_v - E_F)/KT} \quad \text{—— (2)}$$

On multiplying both the eqn's, we get

$$\Rightarrow np = N_c N_v e^{-E_c + \cancel{E_F} + E_v - \cancel{E_F}/KT}$$

$$\Rightarrow np = N_c N_v e^{-(E_c - E_v)/KT}$$

$(E_c - E_v = E_G)$

$$\Rightarrow np = N_c N_v e^{-E_G/KT}$$

$$\Rightarrow \boxed{np = n_i^2 = N_c N_v e^{-E_G/KT}} \quad \text{—— (3)}$$

On adding

$$E_c - E_v = E_G$$
$$E_c + E_v = 2E_F$$
$$2E_c = 2E_F + E_G$$

$$\Rightarrow 2E_F = 2E_c - E_G$$

$$\Rightarrow \boxed{E_F = E_c - \frac{E_G}{2}}$$

$$n = N_c e^{-(E_c - E_F)/KT} = N_c e^{-(\cancel{E_c} - \cancel{E_c} + \frac{E_G}{2})/KT}$$

$$\Rightarrow \boxed{n = N_c e^{-E_G/2KT}}$$

On subtract

$$E_c - E_v = E_G$$
$$E_c + E_v = 2E_F$$
$$-2E_v = E_G - 2E_F$$

$$\Rightarrow 2E_F = 2E_v + E_G$$

$$\Rightarrow \boxed{E_F = E_v + \frac{E_G}{2}}$$

$$p = N_v e^{E_v - E_F/KT} = N_v e^{E_v - E_v - \frac{E_G}{2}/KT}$$

$$\Rightarrow \boxed{p = N_v e^{-E_G/2KT}}$$

$E_i \rightarrow$ intrinsic energy level

$$\boxed{n = n_i e^{(E_F - E_i)/KT}}$$

$$\boxed{p = n_i e^{(E_i - E_F)/KT}}$$

$$\frac{n}{n_i} = e^{(E_F - E_i)/KT}$$

$$\Rightarrow \log_e\left(\frac{n}{n_i}\right) = \frac{E_F - E_i}{KT}$$

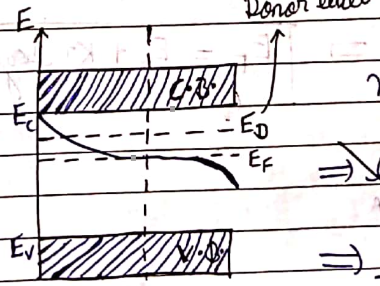
$$\Rightarrow E_F - E_i = KT \log_e\left(\frac{n}{n_i}\right)$$

$$\Rightarrow \boxed{E_F = E_i + KT \log_e\left(\frac{n}{n_i}\right)}$$

Similarly, $\boxed{E_F = E_i - KT \log_e\left(\frac{p}{n_i}\right)}$

★ Extrinsic Semiconductor

• N-type



$$n \simeq N_D = N_c e^{-(E_c - E_F)/KT}$$

$$\Rightarrow \cancel{\log N_D = \log N_c - \left(\frac{E_c - E_F}{KT}\right)}$$

$$\Rightarrow \frac{N_D}{N_c} = e^{-(E_c - E_F)/KT}$$

$$\Rightarrow \log\left(\frac{N_D}{N_c}\right) = -\frac{(E_c - E_F)}{KT}$$

$$\Rightarrow \log\left(\frac{N_c}{N_D}\right) = \frac{E_c - E_F}{KT}$$

$$\Rightarrow E_c - E_F = KT \log\left(\frac{N_c}{N_D}\right)$$

$$\Rightarrow \boxed{E_F = E_c - KT \log\left(\frac{N_c}{N_D}\right)}$$

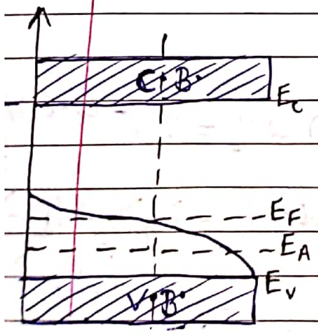
- $p \simeq N_A = N_v \, e^{E_v - E_F/KT}$

$$\Rightarrow \frac{N_A}{N_v} = e^{E_v - E_F/KT}$$

$$\Rightarrow \log \frac{N_A}{N_v} = \frac{E_v - E_F}{KT}$$

$$\Rightarrow -\log\left(\frac{N_v}{N_A}\right) = \frac{E_v - E_F}{KT}$$

$$\Rightarrow -KT \log\left(\frac{N_v}{N_A}\right) = E_v - E_F$$



$$\Rightarrow \boxed{E_F = E_v + KT \log\left(\frac{N_v}{N_A}\right)}$$

★ Mass Action Law states that (If n is the conc. of e^-s & p is the conc. of holes) the product of conc. of e^-s & holes is always constant at fixed temp.

for n type $\quad e^- \Rightarrow n_n$ & $p \Rightarrow p_n \quad \boxed{n_n p_n = n_i^2}$

or $\simeq \boxed{N_D p_n = n_i^2}$

for p type $\quad e^- \Rightarrow n_p$ & $p \Rightarrow p_p \quad \boxed{n_p p_p = n_i^2}$

or

$\simeq \boxed{N_A p_p = n_i^2}$

$$\boxed{p_n = \frac{n_i^2}{n_n} \simeq \frac{n_i^2}{N_D}} \qquad \boxed{n_p = \frac{n_i^2}{p_p} \simeq \frac{n_i^2}{N_A}}$$

Q- In n-type Germanium, the donor conc. is one atom per 10^8 Germanium atoms. If the effective mass of electron is one-half ($\frac{1}{2}$) the true mass. Find the position of fermi level from the edge of the conduc band at room temp. Given that Ge atoms $= 4.4 \times 10^{22} / cm^3$

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

Sol$^n \Rightarrow \boxed{m_e^* = 0.55\, m_0}$

Given, $m_e^* = \frac{m_e^*}{2}$

$$\Rightarrow m_e^* = \frac{0.55 \times 9.1 \times 10^{-31}}{2}$$

$$\Rightarrow m_e^* = 2.502 \times 10^{-31} \text{ kg}$$

$$N_D = \frac{4.4 \times 10^{22}}{1 \times 10^8} = 4.4 \times 10^{14}$$

$\boxed{K = 1.38 \times 10^{-23} \text{ J/K} \quad h = 6.26 \times 10^{-34}}$

$T = 300K$

$$N_c = 2\left[\frac{2\pi m_e^* KT}{h^2}\right]^{3/2} = 2\left[\frac{2\pi \times 2.502 \times 10^{-31} \times 1.38 \times 10^{-23} \times 3}{(6.26 \times 10^{-34})^2}\right]$$

$$= 3.62 \times 10^{18} \text{ /cm}^3$$

for room temp. $N_C = 3.6\times10^{24}/m^3 = 3.6\times10^{18}/cm^3$ at room temp $\Rightarrow KT = 26\ mV = 0.026\ V$

$$E_C - E_F = KT \log \frac{N_C}{N_D}$$

$$= 0.026 \log_e\left(\frac{3.6\times10^{18}}{4.4\times10^{14}}\right)$$

$$E_C - E_F = 0.026 \log_e (8181.81)$$

$$= 0.026 \times 9.009$$

$$\Rightarrow \cancel{E_C - E_F = 0.234\ eV}$$

$$\Rightarrow \boxed{E_C - E_F = 0.234\ eV}$$

Q- Calculate the probability that a state is a C.B. is occupied by an e^- & calculate the thermal equillibrium electron conc. in Si at room temp. Given, $E_F = 0.25\ eV$ below the C.B. & value of N_C at room temp $2.8\times10^{19}/cm^3$

Sol$^n \Rightarrow$

$$f(E_C) = \frac{1}{1+e^{(E_C-E_F)/KT}} = \cancel{\frac{1}{1+e^{(0.25)/0.026}}}$$

$$\Rightarrow f(E_C) = e^{-(E_C-E_F)/KT}$$

$$= e^{-(0.25)/0.026}$$

$$\Rightarrow \boxed{f(E_C) = 6.6\times10^{-5}}$$

$$n = n_0 = N_C e^{-(E_C-E_F)/KT}$$

$$= 2.8\times10^{19}\times6.5\times10^{-5} = 1.82\times10^{15}/cm^3$$

for intrinsic E_i always lies in the middle

Q- In an n-type Si sample, the fermi level is 0.3eV below the conduc^n band. Find e^- & hole conc. at room temp. Given, for Si $E_G = 1.1\ eV$, $n_i = 1.5\times10^{10}/cm^3$, $K = 8.62\times10^{-5}\ eV/^\circ K$

Sol$^n \Rightarrow$

$$E_C - E_i = \frac{E_g}{2} = \frac{1.1}{2} = 0.55\ eV \quad —① $$

$$E_C - E_F = 0.3\ eV \text{ (Given)} \quad —②$$

on Subtracting, ① − ②

$$E_F - E_i = 0.25\ eV$$

$$n = n_i e^{(E_F-E_i)/KT}$$

$$= 1.5\times10^{10} e^{(0.25)/0.026}$$

$$\Rightarrow \boxed{n = 2.24\times10^{14}/cm^3}$$

$n = 2.2\times10^{14}/cm^3$
$p = 1.006\times10^{6}/cm^3$

$$p_n = \frac{n_i^2}{n} = \frac{(1.5\times10^{10})^2}{2.4\times10^{14}} =$$

Q. For a p-type material, the fermi level is 0.28 eV above the valence band, at room temp of 300K. Find the new position of fermi level if temperature is increased to 400K. Draw the corresponding energy band diagram.

Sol^n ⇒

$$E_F = E_V + KT \log_e\left(\frac{N_V}{N_A}\right)$$

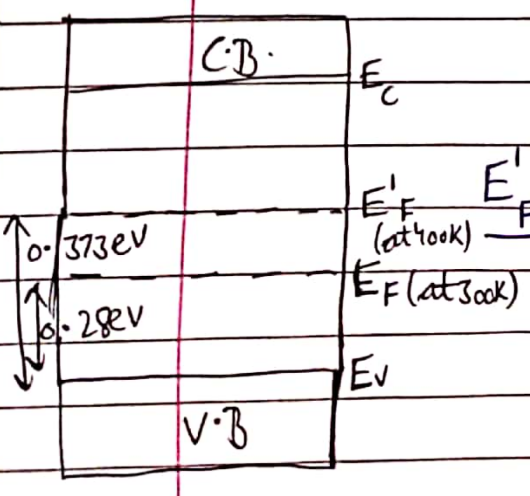
$$\Rightarrow E_F - E_V = KT \log_e\left(\frac{N_V}{N_A}\right)$$

$$\Rightarrow 0.28 = 300K \log_e\left(\frac{N_V}{N_A}\right) \quad \text{--- } (1)$$

Assume new fermi level is E_F'

$$\Rightarrow E_F' - E_V = 400K \log_e\left(\frac{N_V}{N_A}\right)$$

$$\Rightarrow \frac{E_F' - E_V}{400} = K \log_e\left(\frac{N_V}{N_A}\right) \quad \text{--- } (2)$$



from (1) & (2)

$$\frac{E_F' - E_V}{400} = \frac{0.28}{300}$$

$$\Rightarrow E_F' - E_V = \frac{0.28}{300} \times 400$$

$$\Rightarrow E_F' - E_V = 0.3733 \text{ eV}$$

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Q- Consider a particular material with fermi energy of 6.25 eV and the electrons in the material follow the Feric Dirac Distribution Function. Calculate the temp. at which there is 1% probability that at state 0.30 eV below the fermi energy level will not contain an electron.

Sol^n ⇒ Not contain an electron ⇒ empty Space

for empty state ⇒ $1-f(E) = 1 - \frac{1}{1+e^{E-E_F/KT}}$ —(1)

Given, $E = E_F - 0.30\ eV$, $E_F = 6.25\ eV$

$K = 8.62 \times 10^{-5}\ eV/K$ $T = 300\ K$

$\Rightarrow E = 6.25 - 0.30 = 5.95\ eV$

from equ^n (1)

$$0.01 = 1 - \frac{1}{1+e^{5.95-6.25/8.62\times10^{-5}\times T}}$$

$$\Rightarrow \frac{1}{1+e^{-0.3/8.62\times10^{-5}T}} = 1-0.01$$

$$\Rightarrow 1 = 0.99 + 0.99\, e^{-0.3/8.62\times10^{-5}T}$$

$$\Rightarrow 0.01 = 0.99\, e^{-0.3/8.62\times10^{-5}T}$$

$$\Rightarrow \log_e(0.01) = \log_e(0.99) - \frac{0.3}{8.62\times10^{-5}T}$$

$$\Rightarrow -4.605 = -0.01 - 0.$$

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★ Transport of charge Carriers

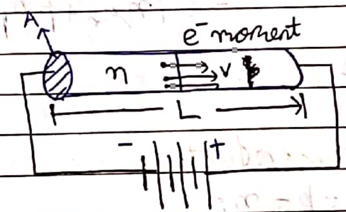
→ Two Mechanisms (1) Drift (2) Diffusion

★ Drifting of charge carriers

→ Mobility, conductivity, Resistivity and Current density

Drift Velocity $E \propto V_d \Rightarrow \boxed{V_d = \mu_e E}$

$E \rightarrow$ electric field
$V_d \rightarrow$ drift velocity
$\mu_e \rightarrow$ mobility of e^- (m^2/Vs)



$A \rightarrow$ cross sectional area
$E \rightarrow$ electric field
$n \rightarrow$ no. of e^- per unit volume
$V \rightarrow$ velocity of e^-
$L \rightarrow$ length

$I = \frac{Q}{t} = \frac{Ne}{t}$ —(1)

$N \rightarrow$ no. of e^-s
$e \rightarrow$ charge on e^- $(1.6\times10^{-19}\ C)$

$V = \frac{L}{t} \Rightarrow \boxed{t = \frac{L}{V}}$

$\boxed{I = \frac{Nev}{L}}$ —(2)

Current Density

$J = \frac{I}{A} = \frac{Nev}{LA}$

$\Rightarrow J = \frac{Nev}{V}$ $(V \rightarrow$ volume $= L$

$\Rightarrow \boxed{J = neV} \Rightarrow \boxed{J = ne V_d}$

$\boxed{J = \rho V_d}$ where $\rho = ne \rightarrow$ charge densi
coulomb/

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Current Density, $\boxed{J = ne\mu_e E}$

$\boxed{J = \sigma E}$ where $\boxed{\sigma = ne\mu_e}$ → conductivity $(ohm\text{-}m)^{-1}$

$\sigma = \frac{1}{\text{resistivity}} \Rightarrow \boxed{\text{resistivity} = \frac{1}{ne\mu_e}}$

$\boxed{\sigma_n = ne\mu_e}$ conductivity of electrons

$\boxed{\sigma_p = pe\mu_p}$ conductivity of holes

Total conductivity $\sigma = \sigma_n + \sigma_p$
$= e[n\mu_e + p\mu_p]$

μ_e → mobility of e^-s
μ_p → mobility of holes

→ for intrinsic semiconductors
$n = p = n_i$

$\sigma_i = e[n_i\mu_e + n_i\mu_p] = en_i[\mu_e + \mu_p]$

→ for n-type semiconductors
$\boxed{\sigma_n = ne\mu_e}$

$\boxed{n \simeq N_D} \Longrightarrow \boxed{\sigma_n \simeq N_D e\mu_e}$

→ for p-type semiconductors
$\boxed{\sigma_p = pe\mu_p}$

$\boxed{p \simeq N_A} \Longrightarrow \boxed{\sigma_p \simeq N_A e\mu_p}$

Current Density → A/m^2 conductivity → $(\Omega m)^{-1}$
Electric field → V/m Resistivity → Ωm

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Drift Current Density, $J = ne\mu_e E$

due to e^- $\boxed{J_n = ne\mu_e E}$
due to holes $\boxed{J_p = pe\mu_p E}$

Total Current density
$J = J_n + J_p$
$= ne\mu_e E + pe\mu_p E$
$\boxed{J = eE(n\mu_e + p\mu_p)}$

$\boxed{R = \frac{\rho l}{A}}$ ρ → Resistivity $\boxed{\rho = \frac{1}{ne\mu_e}}$

Q- Find the conductivity & resistivity of an intrinsic semiconductor at room temp. given that
$n_i = 2.5 \times 10^{13}/cm^3$ μ_e or $\mu_n = 3800\ cm^2/Vs$
μ_p or $\mu_h = 1800\ cm^2/Vs$

Solⁿ ⇒
$\sigma_i = en_i[\mu_e + \mu_p] = (2.5\times10^{13})(1.6\times10^{-19})[3800+1800]$
$= 0.0224 = 2.24\times10^{-2}\ \Omega^{-1}cm^{-1}$

resistivity $= \frac{1}{\sigma} = 44.642\ \Omega cm$

Q- The intrinsic concentration n_i for Si at the room temp is $1.5\times10^{10}/cm^3$. If the mobility of e^-s & holes are μ_e or $\mu_n = 1300\ cm^2/Vs$ and μ_p or $\mu_h = 450\ cm^2/Vs$. What is conductivity of the Si at room temp? If Si is doped with $10^{18}/cm^3$ Boron atom then what will be its conductivity?

Solⁿ ⇒ $\sigma_i = n_i e(\mu_e + \mu_p) = (1.5\times10^{10})(1.6\times10^{-19})[1300+450]$
$= 4.2\times10^{-6}\ \Omega^{-1}cm^{-1}$

when doped with Boron
$\sigma_p = pe\mu_p = (10^{18})(1.6\times10^{-19})(450)$
$= 72\ \Omega^{-1}cm^{-1}$

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

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Q- An n-type semiconductor have a resistivity of $10\ \Omega$-cm. Calculate the no. of donor atoms which must be added to achieve the given $\mu_d = 500\ cm^2/Vs$

Solⁿ ⇒

$\boxed{\sigma_n = N_D e \mu_e} \Rightarrow 0.1 = N_D (1.6 \times 10^{-19}) 500$

$N_D = \frac{0.1}{1.6 \times 10^{-19} \times 500}$

$N_D = 1.25 \times 10^{15} / cm^3$ Ans

Q- The specimen of pure Ge at room temp. has a density of charge carriers $2.5 \times 10^{19}/m^3$. It is doped with donor impurity at the rate of 1 impurity atom for every 10^6 Ge atoms. All impurity atoms may be supposed to be ionised. The density of Ge atoms is $4.2 \times 10^{28}/m^3$. Find the resistivity of doped Ge. Given, $\mu_e = 0.36\ m^2/Vs$

$n_i = 2.5 \times 10^{19}/m^3$

Solⁿ ⇒

$n_i = 2.5 \times 10^{19}/m^3 \quad N_D = \frac{4.2 \times 10^{28}}{10^6} = 4.2 \times 10^{22}/m^3$

$\sigma_n = N_D e \mu_e = 4.2 \times 10^{22} \times 1.6 \times 10^{-19} \times$

$= 2419.2\ \Omega^{-1} m^{-1}$

$\text{Resistivity} = \frac{1}{2419.2} = 4.13 \times 10^{-4}\ \Omega m$

Q- A bar of n-type semiconductor has length of 4 cm and circular cross-sectional of $10\ mm^2$

$1\mu m = 10^{-6} m \quad 1\mu m = 10^{-4} cm$

$1\mu m^2 = 10^{-12} m^2 \quad 1\mu m^2 = 10^{-8} cm^2$

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when it is subjected to a voltage of 1V applied across it's length, the current flowing through it is 5 mA. Calculate (i) conc. of free e⁻'s (ii) Drift velocity. Given $\mu_e = 1300\ cm^2/Vs$

Solⁿ ⇒

$L = 4 cm \quad A = 10\ mm^2 = 10 \times 10^{-4} cm^2 = 10^{-3} cm^2$

$I = 5 mA = 5 \times 10^{-3} A$

~~$I = NeV$~~

Is method se bhi kr skte hai

$R = \frac{V}{I} \Rightarrow R = \frac{1}{5 \times 10^{-3}}$

$\Rightarrow R = 200\ \Omega$

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

$\Rightarrow \frac{200 \times 10^{-3}}{4} = \rho$

$\Rightarrow \rho = 0.05$

$\Rightarrow \frac{1}{\rho} = ne\mu_e$

$n =$

$\sigma = ne\mu_e$

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

$J = \frac{I}{A} = \frac{5 \times 10^{-3}}{10^{-3}} = 5 A/cm^2$

$E = \frac{V}{L} = \frac{1}{4} = 0.25\ V/cm$

$n = \frac{J}{e\mu_e E} = \frac{5}{1.6 \times 10^{-19} \times 1300 \times 0.25}$

$= 9.615 \times 10^{16}\ cm^3$

$V_d = \mu_e E = 325\ cm/s$

Q- A Si bar of 0.1 cm long, $100\ \mu m^2$ cross sectional area is doped with $10^{17}/cm^3$ Phosphorus atoms. Find the value of current at room temp. when 10V is applied. Given $\mu_e = 700\ cm^2/Vs$

Solⁿ ⇒ $L = 0.1 cm \quad A = 100\ \mu m^2 = 100 \times 10^{-8} = 10^{-6} cm^2$

$E = \frac{V}{L} = \frac{10}{0.1} = 100\ V/cm$

$J = ne\mu_e E$

$J = N_D e \mu_e E$

$= (10^{17})(1.6 \times 10^{-19})(700)$

$= 1120\ A/cm^2$

$J = \frac{I}{A} \Rightarrow I = J \times A$

$= 1120 \times 10^{-6}$

$= 1.12 \times 10^{-3} A$

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Q- Calculate the current produced in a small Ge, plate of area 1 cm^2 and thickness of 0.3 mm, when a potential difference of 2 volt is applied across the faces. Given $n_i = 2 \times 10^{19}/m^3$, $\mu_e = 0.35\ m^2/Vs$ $\mu_p = 0.17\ m^2/Vs$

Sol^n

$A = 1 \times 10^{-4}\ m^2$ $\quad L = 0.3 \times 10^{-3}\ m$, $V = 2\ V$

$\mu_e = 0.35\ m^2/Vs$ $\quad \mu_p = 0.17\ m^2$

$$E = \frac{V}{L} = \frac{2}{0.3 \times 10^{-3}} = 6666.66\ V/m$$

~~J = σE ⇒ J =~~ $\sigma_i = n_i e(\mu_e + \mu_p)$

$$\Rightarrow \sigma_i E = n_i e(\mu_e + \mu_p) \times E$$

$$\Rightarrow J = n_i e(\mu_e + \mu_p) \times E$$

$$\Rightarrow \frac{I}{A} = n_i e(\mu_e + \mu_p) \times E$$

$$\Rightarrow I = n_i e(\mu_e + \mu_p) \times \frac{V}{L} \times A$$

$$= 1.6 \times 10^{-19} \times 2 \times 10^{19}(0.35 + 0.17) \times \frac{2}{0.3 \times 10^{-3}} \times 10^{-4}$$

$$= 1.11\ A$$

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Q- Show that the minimum conductivity of semiconductor sample occurs when $n = n_i\sqrt{\frac{\mu_p}{\mu_n}}$. What is the expression for minimum conductivity σ_{min}?

Sol^n

$$\sigma = e(n\mu_n + p\mu_p)$$

$$\Rightarrow \sigma = en\mu_n + ep\mu_p \quad \text{— (1)}$$

$$np = n_i^2 \Rightarrow p = \frac{n_i^2}{n} \quad \text{— (2)}$$

on putting equ^n (2) in equ^n (1)

$$\Rightarrow \sigma = en\mu_n + e \cdot \frac{n_i^2}{n} \cdot \mu_p \quad \text{— (3)}$$

On differentiating above equ^n w.r.t 'n'

$$\Rightarrow \frac{d\sigma}{dn} = e\left[\mu_n - \frac{n_i^2}{n^2}\mu_p\right]$$

$$\frac{d\sigma}{dn} = 0 \Rightarrow 0 = e\left[\mu_n - \frac{n_i^2}{n^2}\mu_p\right]$$

$$\Rightarrow \mu_n - \frac{n_i^2}{n^2} \cdot \mu_p = 0$$

$$\Rightarrow \frac{n_i^2}{n^2} = \frac{\mu_n}{\mu_p}$$

$$\Rightarrow n^2 = n_i^2 \cdot \frac{\mu_p}{\mu_n} \Rightarrow \boxed{n = n_i\sqrt{\frac{\mu_p}{\mu_n}}} \quad \text{— (4)}$$

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Q- Given that the density of states relative effective masses of electrons & holes in Si are approximately 1.08 m_0 & 0.56 m_0 respectively and e^-s & holes drift mobilities at room temp. 1350 cm^2/Vs & 450 cm^2/Vs respectively Calculate intrinsic conc. & intrinsic resistivity.

Sol^n)

$$n_i = \sqrt{N_c N_v}\, e^{-E_g/2KT} \quad \text{—(1)}$$

$$N_c = 2\left[\frac{2\pi m_e^* q KT}{h^2}\right]^{3/2}$$

$$= 2\left[\frac{2\pi \times 1.08 \times 9.1\times10^{-31} \times 1.6\times10^{-19} \times 0.026}{(6.63\times10^{-34})^2}\right]^{3/2}$$

$$\Rightarrow N_c = 2.82\times10^{25}/m^3$$

$$= 2.82\times10^{19}/cm^3$$

$$N_v = 2\left[\frac{2\pi m_h^* q KT}{h^2}\right]^{3/2}$$

$$= 2\left[\frac{2\times3.14\times0.56\times(9.1\times10^{-31})(1.6\times10^{-19})\,0.026}{(6.63\times10^{-34})^2}\right]^{3/2}$$

$$\Rightarrow N_c = 1.05\times10^{25}/m^3$$

$$= 1.05\times10^{19}/cm^3$$

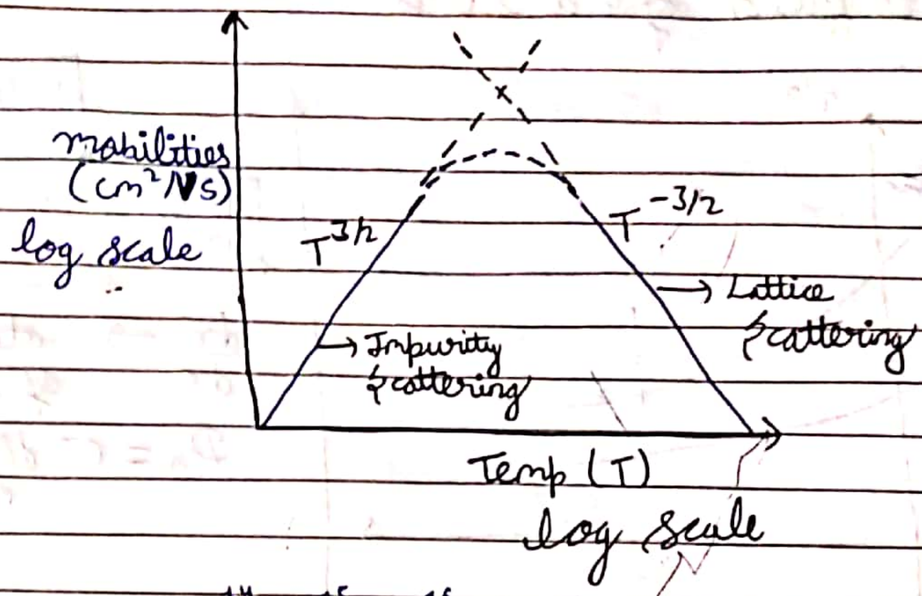
→ E_g for Si = 1.1 eV

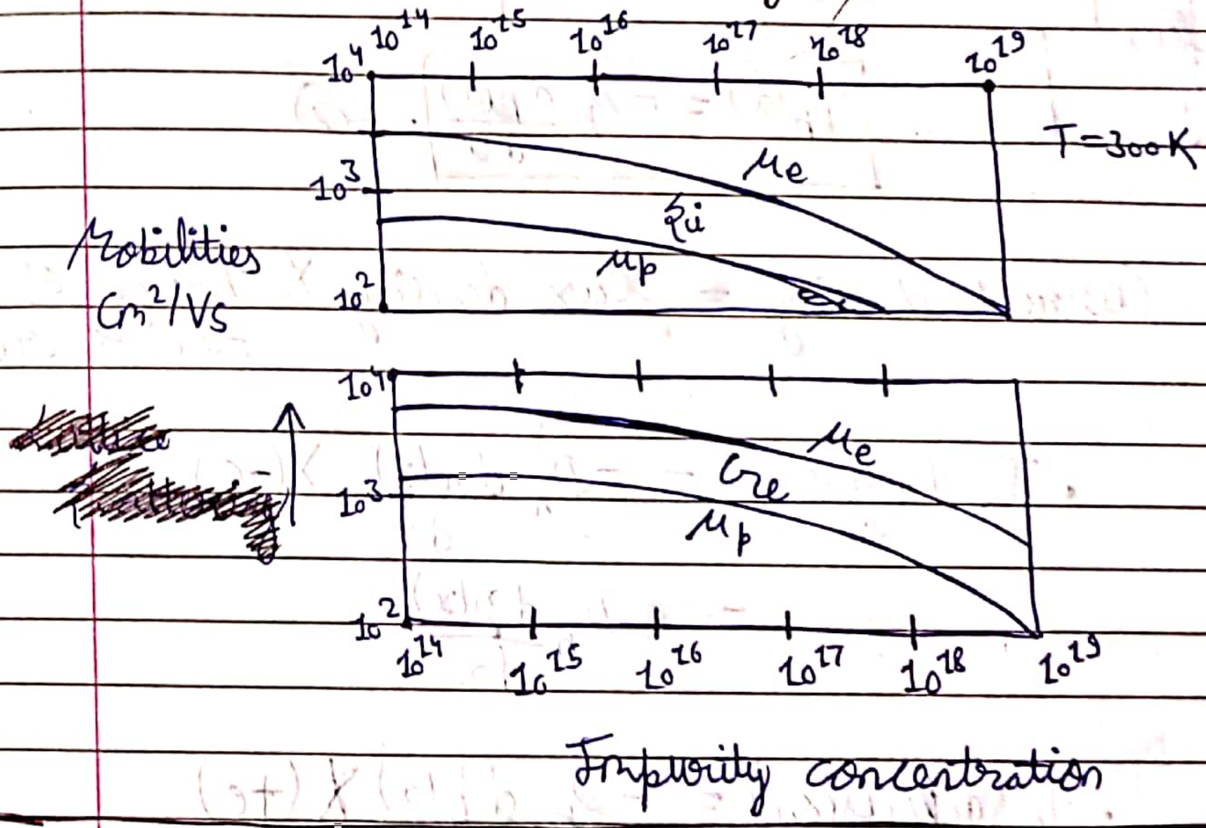
$$n_i = \sqrt{N_c N_v}\; e^{-E_g/2KT}$$

$$= \sqrt{(2.82\times10^{19})(1.05\times10^{19})}\cdot e^{-1.1/2\times0.026}$$

$$= 1.118\times10^{10}/cm^3$$

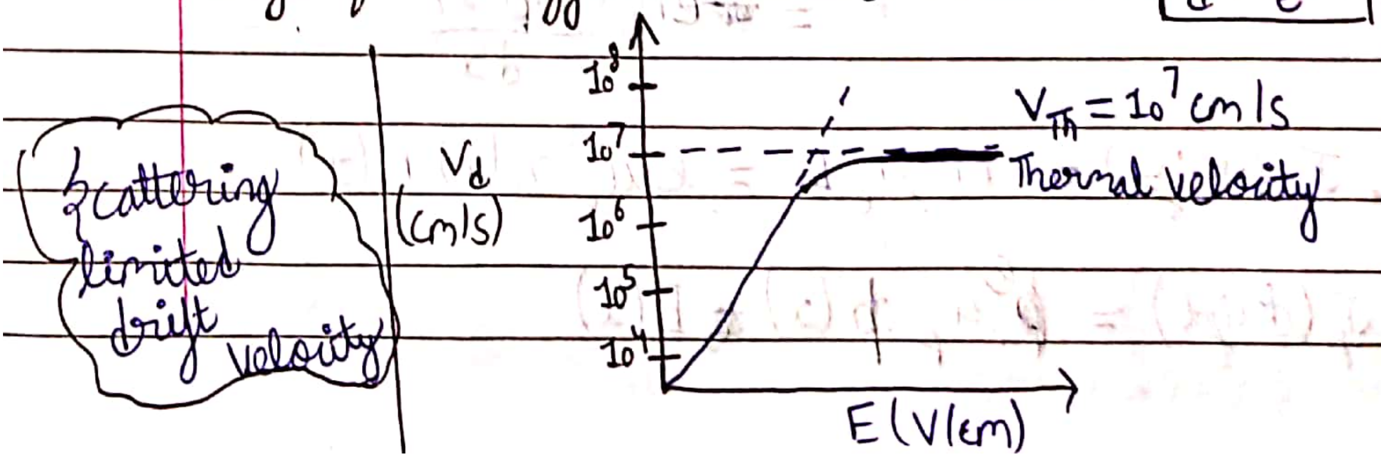
$$\boxed{\frac{1}{\mu} = \frac{1}{\mu_l} + \frac{1}{\mu_i}}$$



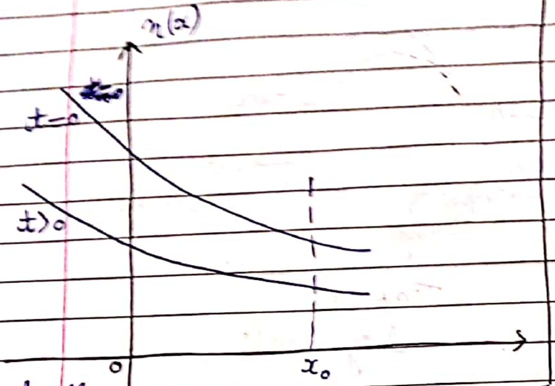


* High field Effect

$V_d \propto E \Rightarrow \boxed{V_d = \mu_e E}$



* Diffusion of Carriers



$\phi_n(x)$ e^- flux density

$\boxed{\phi_n(x) \propto \frac{dn(x)}{dx}}$

$\boxed{\phi_n(x) = -D_n \frac{dn(x)}{dx}}$ — (1)

$\frac{dn}{dx} \rightarrow$ rate of change of conc.

$D_n = e^-$ diffusion coefficient

hole flux density

$\boxed{\phi_p(x) = -D_p \frac{dp(x)}{dx}}$ — (2)

Current density = flux density X charge of the carrier

• J_n (diffusion) $= -D_n \frac{dn(x)}{dx} \times (-e)$

$= e D_n \frac{dn(x)}{dx}$

• J_p (diffusion) $= -D_p \frac{dp(x)}{dx} \times (+e)$

$= -eD_p \cdot \frac{dp(x)}{dx}$

• J_n (drift) $= ne\mu_e E = e\mu_e n(x) E(x)$

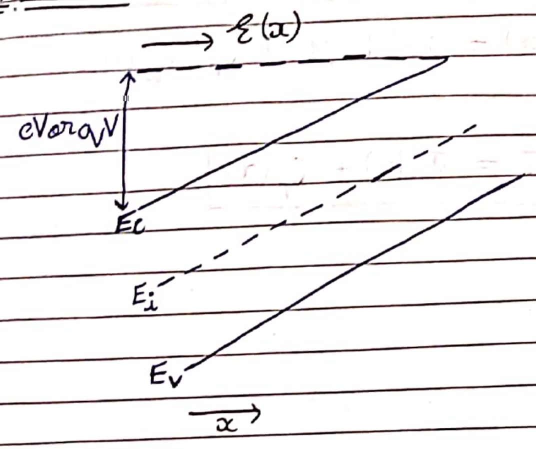
• J_p (drift) $= e\mu_p p(x) E(x)$

• $\boxed{J_n(x) = J_n(\text{drift}) + J_n(\text{diffusion})}$

• $\boxed{J_p(x) = J_p(\text{drift}) + J_p(\text{diffusion})}$

• $\boxed{J = J_n(x) + J_p(x)}$

★ Einstein Relation



$$\mathcal{E}(x) = \frac{-dV(x)}{dx} \quad \text{--- (1)}$$

Electric field

$$E_i = -qV(x)$$

$$V(x) = \frac{-1}{q} \cdot E_i \quad \text{--- (2)}$$

$$\mathcal{E}(x) = \frac{-d}{dx}\left(\frac{-E_i}{q}\right)$$

$$\Rightarrow \mathcal{E}(x) = \frac{1}{q}\frac{dE_i}{dx} \quad \text{--- (3)}$$

$$J_p(x) = p(x)\mu_p e\mathcal{E}(x) - eD_p\frac{dp(x)}{dx}$$

at equillibrium $J_p(x) = 0$

$$\Rightarrow 0 = p(x)\mu_p e\mathcal{E}(x) - eD_p\frac{dp(x)}{dx}$$

$$\Rightarrow p(x)\mu_p e\mathcal{E}(x) = eD_p\frac{dp(x)}{dx}$$

$$\Rightarrow \mathcal{E}(x) = \frac{1}{p(x)} \cdot \frac{D_p}{\mu_p} \cdot \frac{dp(x)}{dx}$$

$$\Rightarrow \boxed{\mathcal{E}(x) = \frac{D_p}{\mu_p} \cdot \frac{1}{p(x)} \cdot \frac{dp(x)}{dx}} \quad \text{--- (4)}$$

$$p(x) \text{ or } p_o = n_i\, e^{(E_i - E_F)/KT}$$

$$\frac{dp(x)}{dx} = n_i \cdot e^{(E_i - E_F)/KT} \cdot \frac{1}{KT}\left\{\frac{dE_i}{dx} - \frac{dE_F}{dx}\right\}$$

$$= p(x) \cdot \frac{1}{KT}\left\{\frac{dE_i}{dx} - \frac{dE_F}{dx}\right\}$$

$$\Rightarrow \frac{1}{p(x)} \cdot \frac{dp(x)}{dx} = \frac{1}{KT} \cdot \left[\frac{dE_i}{dx} - \frac{dE_F}{dx}\right] \quad \text{--- (5)}$$

on putting equ^n (5) in equ^n (4), we get

$$\mathcal{E}(x) = \frac{D_p}{\mu_p} \cdot \frac{1}{KT}\left[\frac{dE_i}{dx} - \frac{dE_F}{dx}\right]$$

at equillibrium $\frac{dE_F}{dx} = 0$

$$\mathcal{E}(x) = \frac{D_p}{\mu_p} \cdot \frac{1}{KT} \cdot \frac{dE_i}{dx} \rightarrow \boxed{\frac{1}{q}\cancel{\frac{dE_i}{dx}} = \frac{D_p}{\mu_p} \cdot \frac{1}{KT}\cancel{\frac{dE_i}{dx}}}$$

from eq

$$\Rightarrow \boxed{\frac{D_p}{\mu_p} = \frac{KT}{q}}$$

In general $\boxed{\frac{D}{\mu} = \frac{KT}{q}}$

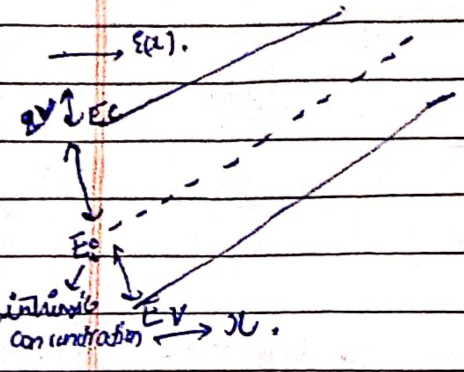
Diffusion coeff.

at equilibrium
fermi level is not varying with 'x'.

10 marks derivation

Einstein Relation -

e^- drift in the opposite direction of E.F.



$$\mathcal{E}(x) = -\frac{dV(x)}{dx} \quad — (1)$$

$$E_i = -qV(x).$$

$$V(x) = -\frac{1}{q} E_i \quad — (2)$$

$$\mathcal{E}(x) = -\frac{d}{dx}\left(\frac{E_i}{q}\right).$$

$$\mathcal{E}(x) = \frac{1}{q} \cdot \frac{dE_i}{dx} \quad — (3).$$

$\sigma = ne\mu_e$
$J = \sigma E$
$J_n = ne\mu_e E$
$J_p = pe\mu_p E.$

$$J_p(x) = p(x)\mu_p e\mathcal{E}(x) - e D_p \frac{dp(x)}{dx}.$$

$$p(x)\mu_p \cancel{e}\, \mathcal{E}(x) = \cancel{e} D_p \frac{dp(x)}{dx}$$

$$\mathcal{E}(x) = \frac{1}{p(x)} \cdot \frac{D_p}{\mu_p} \cdot \frac{dp(x)}{dx} = \frac{D_p}{\mu_p} \frac{1}{p(x)} \frac{dp(x)}{dx}.$$

Equilibrium constt. for holes. — $p(x)$ or $p_0 = n_i e^{(E_i - E_f)/KT}$

$$\frac{dp(x)}{dx} = n_i e^{(E_i - E_f)/KT} \cdot \frac{1}{KT}\left[\frac{dE_i}{dx} - \frac{dE_f}{dx}\right]$$

$$= p(x) \cdot \frac{1}{KT}\left[\frac{dE_i}{dx} - \frac{dE_f}{dx}\right]$$

$$\frac{1}{p(x)}\frac{dp(x)}{dx} = \frac{1}{KT}\left[\frac{dE_i}{dx} - \frac{dE_f}{dx}\right]$$

$$\mathcal{E}(x) = \frac{D_p}{\mu_p} \frac{1}{KT}\left[\frac{dE_i}{dx} - \frac{dE_f}{dx}\right]$$

at equilibrium $\frac{dE_f}{dx} = 0.$

*. When e^- reach its maximum level — then through scattering it looses the energy of its own & reach to the bottom

$$\mathcal{E}(x) = \frac{D_p}{\mu_p} \cdot \frac{1}{KT}\frac{dE_i}{dx} \Rightarrow \frac{1}{q}\frac{d\cancel{E_i}}{\cancel{dx}} = \frac{D_p}{\mu_p}\frac{1}{KT}\frac{\cancel{dE_i}}{\cancel{dx}}$$

$$\boxed{\frac{D_p}{\mu_p} = \frac{KT}{q}}$$

In general,

$$\boxed{\frac{D}{\mu} = \frac{KT}{q}}$$

Excess Carriers-

$n \cdot p = n_i^2$ (at equilibrium)

$n \cdot p > n_i^2$

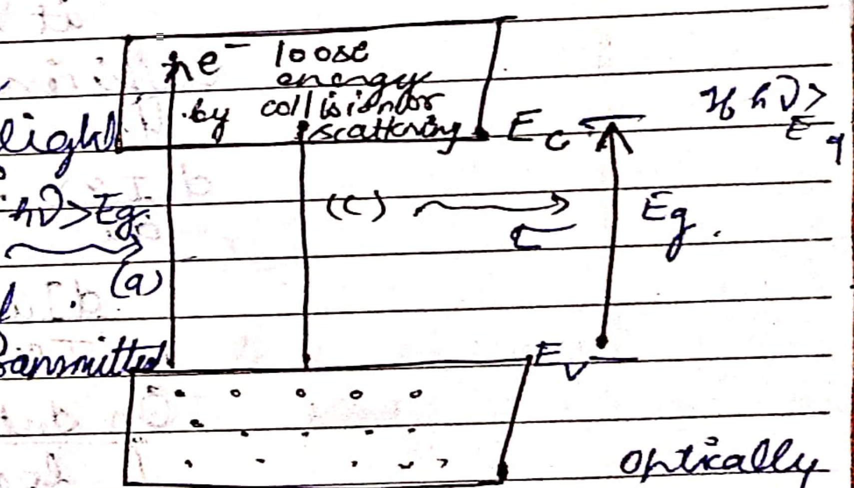
Optical Absorption

light $h\nu$ — SC

$h\nu > E_g$ — Absorb light by the SC.

$h\nu < E_g$ — light transmitted through SC.

Optical Absorption is the process in which when a light beam make pass over the semiconductor, then if $h\nu > E_g$ photons get absorbed and if $h\nu < E_g$ the photons get transmitted through SC."

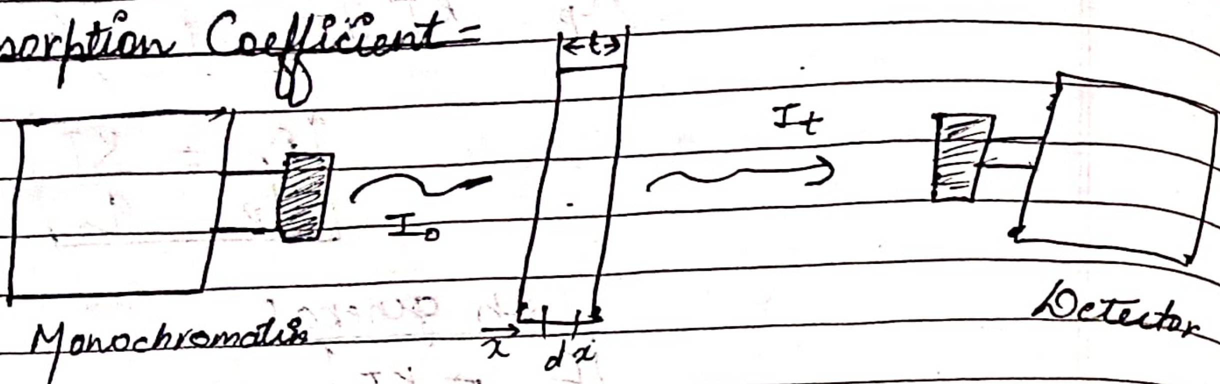


If $h\nu > E_g$, Photon is absorbed by the S.C.

Optically generated EHP.

of the C.B.

Absorption Coefficient -



Let the intensity of beam at a distance 'x' and the degradation of the Intensity is given by $-\frac{dI(x)}{dx}$ & it is proportional to the intensity remaining at 'x'.

$$-\frac{dI(x)}{dx} \propto I(x)$$

$$-\frac{dI(x)}{dx} = \alpha \cdot I(x)$$

where, α is proportionality constt. and it is known as optical absorption coefficient.

$$\frac{dI(x)}{dx} = -\alpha I(x).$$

$$\frac{dI(x)}{I(x)} = -\alpha\, dx.$$

On Integrating both sides.

$$\boxed{\log_e I(x) = -\alpha x + K}$$

at $x = 0$,

$$K = \log_e I(0)$$
$$= \log_e I_0$$

$$\boxed{\log_e I(x) = -\alpha x + \log_e I_0}$$

$$\log_e I(x) - \log_e I_0 = -\alpha x$$

$$\log_e \frac{I(x)}{I_0} = -\alpha x$$

$$\log_e \frac{I(x)}{I_0} = -\alpha x$$

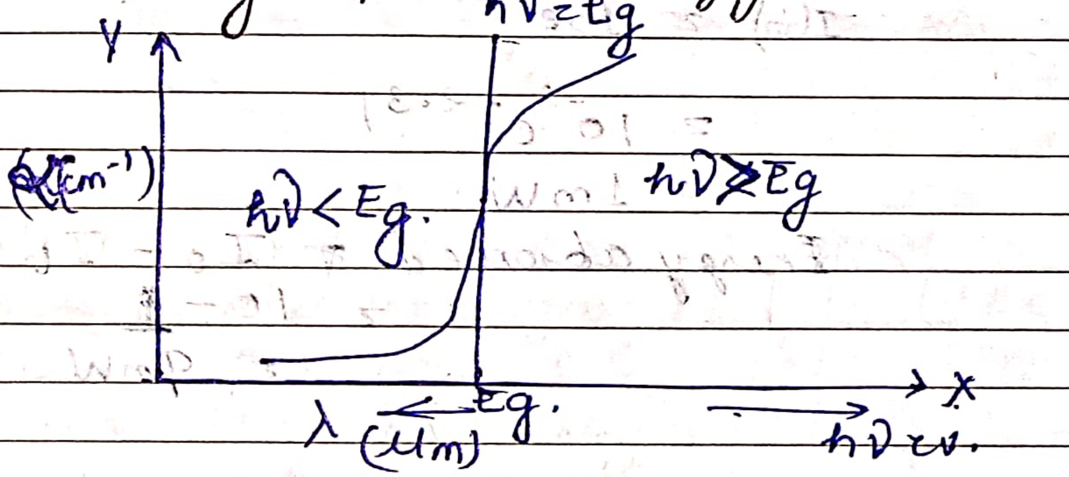
$$\frac{I(x)}{I_0} = e^{-\alpha x}$$

$$I(x) = I_0 e^{-\alpha x}$$

$$\boxed{I(t) = I_0 e^{-\alpha t}}$$

$$\boxed{\frac{I_t}{I_0} = e^{-\alpha t}} \quad (m^{-1})$$

Variation of optical absorption coefficient (α) as a function of photon energy $h\nu$ (eV) -



Recombination disappear in μs or nano sec

i) When $h\nu < E_g$. α is negligible & most of the light transmitted through the sample where sample is Transparent.

ii) When $h\nu = E_g$. has photon energy increases α also increases. and it begin to rise rapidly when $h\nu$ approaches to E_g.

When $h\nu > E_g$, When the photon Energy is more than E_g

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then photon absorbed in the semiconductor.

Ques. 0.46 μm thick sample of GaAs is illuminated with monochromatic light of $h\nu$ of 2eV. The absorption coefficient α is $5\times10^4\ cm^{-1}$. The power incident on the sample is 10 milliwatt. Find the total energy absorbed by the sample per sec.

$$\alpha = 5\times10^4\ cm^{-1}$$

$$\cancel{P = 1mW}$$

$$I_0 = 10mW$$

$$t = 0.46\ \mu m = 0.46\times10^{-4}\ cm$$

$$I(t) = I_0 e^{-\alpha t}$$

$$I(t) = 10 e^{-5\times10^4\times0.46\times10^{-4}}$$

$$= 10^{-2}(e^{-2.3})$$

$$= 1mW$$

Energy absorbed $= I_0 - I_t$

$$= 10 - 1$$

$$= 9mW$$

(1)
(2)
(3)
The g...
emi...

In elemental semiconductor → energy released in terms of heat | In or direct " compound semiconductor → energy released in term of light.

★ Luminescence —

General property of light emission is called Luminescence.

Emission & excitation happens when the recombination process happens then this luminescence happens.

- Photo Luminescence,
- Cathode Luminescence.
- Electro "

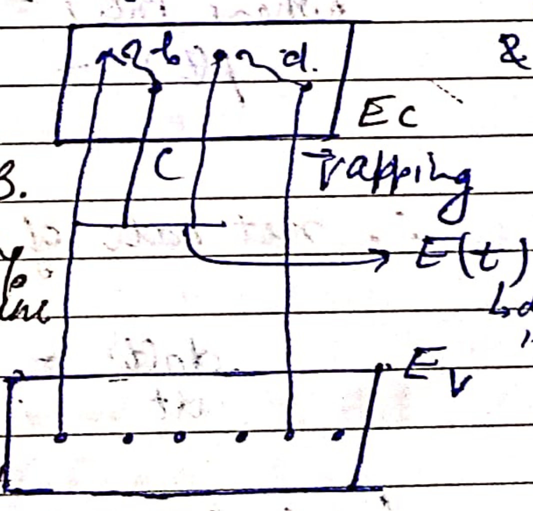
} depending upon excitation.

Two step Process
1. Excitation
2. Emission.

→ Direct or fast process. fluorescence ($\leq 10^{-8}$ sec.)

→ Slow process Phosphorescence.

In the slow process of emission, first the e^- gets excited & move to C.B. & when due to scattering they want to get recombine then they get trapped by any type of defect level present i.e. denoted by E(t) here. after sometimes they able to move again to C.B & then Recombination process happens.



• Initially get excited, & due to scattering the e^- get start to move & get trapped by level E(t). then after it e^- travel to the conduction band again & then go in V.B. for recombination process.

change in concentration happen $\Delta n = \bar{n} - n_0$ $\Delta n = \Delta p$ (true)

$\Delta p = \bar{p} - p_0$

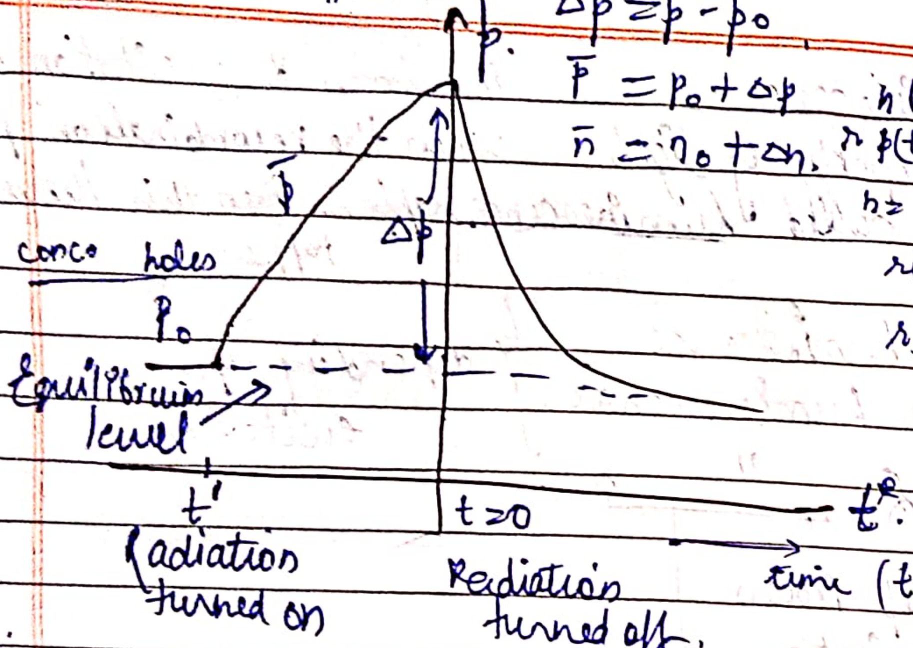
$\bar{p} = p_0 + \Delta p$ $n(t)$ $r_i = \alpha_r n_i^2$

$\bar{n} = n_0 + \Delta n$, $p(t)$

$n = p = n_i$

$r_i \propto n_0 p_0$

$r_i = \alpha_r n_0 p_0 = g_i$ → ①



*check.
conc. of charge carriers with time,

The Decay also shows the life time.
At any time the rate of decay of charge carriers → electron (holes or electrons)
is proportional to the no. of e⁻'s remaining at time 't'. The decay rate $\frac{dn(t)}{dt} = \alpha_r n(t) p(t)$ — ②

where $n(t)$ = conc. of e^- at time 't'
$p(t)$ = conc. of holes at time 't'.

∴ net rate of change of C.B. e^- conc.
= generation rate − decay rate.

$$\frac{dn(t)}{dt} = \alpha_r n_0 p_0 - \alpha_r n(t) p(t) \quad ③$$

Let the instantaneous concentration of excess carriers is given by $\delta n(t)$ & $\delta p(t)$.

$n = p$
$\Delta n = \Delta p$.
$\delta n(t) = \delta p(t)$.

$n(t) = n_0 + \delta n(t)$
$p(t) = p_0 + \delta p(t)$.

$\tau \rightarrow$ charge carrier lifetime.

Put values of $n(t)$ & $p(t)$ in eqn ③.

$$\frac{d\delta n(t)}{dt} = \alpha_r n_0 p_0 - \alpha_r[n_0 + \delta n(t) \cdot p_0 + \delta p(t)]$$

$\delta n(t) = \delta p(t)$.

$$= -\alpha_r[(n_0 + p_0) \cdot \delta n(t) + \delta n^2(t)]$$

If the instantaneous concentration is too small.

neglect $\delta n^2(t)$.

$$\frac{d\delta n(t)}{dt} = -\alpha_r[(n_0 + p_0)\delta n(t)].$$

If the material of p-type. $p_0 >> n_0$

$$= -\alpha_r p_0 \delta n(t)$$

If material of n-type $n_0 >> p_0$.

$$\boxed{\frac{d\delta n(t)}{dt} = -\alpha n_0 \delta n(t)}$$

$$\frac{d\delta n(t)}{dt} = -\alpha_r p_0 \delta n(t)$$

$$\int \frac{d\delta n(t)}{\delta n(t)} = -\alpha_r p_0 \int dt.$$

$$\log_e \delta n(t) = -\alpha_r p_0 t + K$$

at $t = 0$, $\delta n(t) = \Delta n$.

$$K = \log_e \Delta n.$$

$$\log_e \delta n(t) = -\alpha_r p_0 t + \log_e \Delta n.$$

$$\log_e \frac{\delta n(t)}{\Delta n} = -\alpha_r p_0 t.$$

$$\frac{\delta n(t)}{\Delta n} = e^{-\alpha_r p_0 t}.$$

$$\boxed{\delta n(t) = \Delta n e^{-\alpha_r p_0 t}}$$

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$$\boxed{\delta n(t) = \Delta n e^{-t/\tau_n}}$$

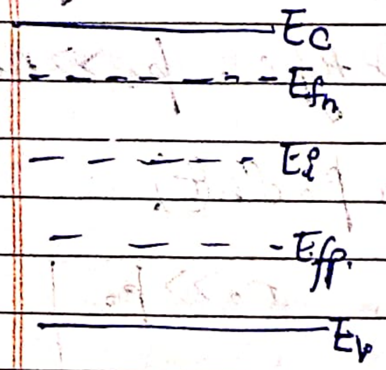
where
$$\tau_n = \frac{1}{\alpha_r p_0}$$

$$\boxed{\tau_n = \frac{1}{\alpha_r (n_0 + p_0)}}$$

optical

Quasi Fermi level –

E_{fn} and E_{fp}.



$n_0 = n_i e$
$p = n_i e^{E_i - E_f / kT}$

$n = n_i e^{E_{fn} - E_i / kT}$

$p = n_i e^{E_i - E_{fp} / kT}$

$$\boxed{np = n_i^2 e^{E_{fn} - E_{fp} / KT}}$$

here n & p are the optical charge carrier concentration i.e. diff. from n_0 & p_0.

Importance of Quasi fermi level –

① $(E_{fn} - E_{fp})$ The separation is direct measure of deviation from equilibrium caused by optical excitation. ② The concept is very useful in visualising the majority & minority carrier concentration when these quantities varies with position.

Thermal equilibrium ← $g(T) = \alpha_r n_0 p_0$

$g_{op} =$
↳ optical generation) equilibrium

$$g_t^{total} = g(T) + g_{op}$$

$$g(T) + g_{op} = \alpha_r np$$
$$= \alpha_r[(n_0 + \delta n)(p_0 + \delta p)]$$

If we assume instead carrier conc. is very small

$$\cancel{g(T)} + g_{op} = \cancel{\alpha_r n_0 p_0} + \alpha_r[(n_0 + p_0)\cdot \delta n + \cancel{\delta n^2}]$$

$\delta n = \delta p$

$$g_{op} = \alpha_r(n_0 + p_0)\delta n = \frac{\delta n}{\tau_n}$$

where $\tau_n = \dfrac{1}{\alpha_r(n_0 + p_0)}$

Calculate the carrier lifetime of Si when e^-s as minority carriers are injected in p-type region having a hole conc. $10^{18}/cm^3$, the injected e^- density is small as compared to the density of majority carriers. α_r for Si $= 1.79 \times 10^{-15}\ cm^3/s$

$\tau = ?$, $\alpha_r = 1.79 \times 10^{-15}\ cm^3/s$

$$\tau = \frac{1}{\alpha_r(n_0 + p_0)}$$

$p_0 = 10^{18}$

$$= \frac{1}{1.79 \times 10^{-15}(10^{18})}$$

$$= \frac{1}{1790}$$

$$\boxed{\tau = 5.58 \times 10^{-4}}$$

Ques. Excess carriers are generated in a S.C. to a conc. of $10^{16}/cm^3$, The excess carrier lifetime is 5×10^{-6} sec. The Source generating the excess carriers is switched off at $t=0$, Calculate the excess e^- concentration at $t = 1\mu s$.

$\Delta n = 10^{16}$
$\tau = 5\times10^{-6}$ s.
$t = 1\,\mu s$
1×10^{-6} s.

$$\delta n(t) = \Delta n\, e^{-t/\tau_n}$$

$$= 10^{16}\, e^{-1\times10^{-6}/5\times10^{-6}}$$

$$= \cancel{10^{16}\times0.0735}$$

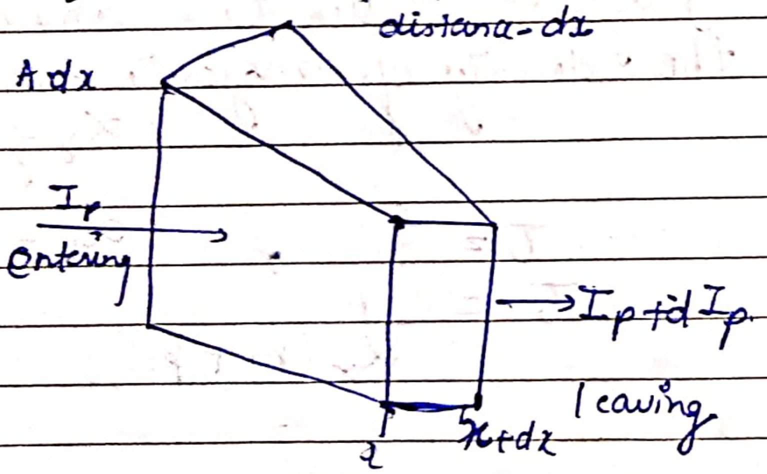
$$= 10^{16}\times0.818730753$$

$$\boxed{\delta n(t) = 8.18\times10^{15}}$$

Continuity Equation -

Area - A in cm^2
distance - dx

Volume - $A\,dx$



(i) Decrease in no. of holes/sec $= \dfrac{dI_p}{e}$.

Decrease in concentration of holes/sec $= \dfrac{dI_p}{e}\cdot\dfrac{1}{A\,dx}$

$$= \frac{1}{e}\frac{d}{dx}\cdot\frac{I_p}{A} = \frac{1}{e}\frac{d}{dx}\cdot J_p \quad \left(\because \frac{I_p}{A} = J_p\right)$$

$e^{-\frac{1\times10^{-6}}{5\times10^{-6}}}$ $e^{-1/5}$ $10^{16}\times e^{-1/5}$

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i.) Due to thermal generation.

increase in conc. of holes. $g_p = \frac{p_0}{\tau_p}$.

ii.) Due to Recombination

dec. in holes conc., $r = \frac{p}{\tau_p}$.

Total conc. per unit time,

$\frac{\partial(\delta p)}{dt}$ = (generation) − (recombination) − hole flux density.

$$\frac{\partial p}{dt} = \frac{p_0}{\tau_p} - \frac{p}{\tau_p} - \frac{1}{e}\frac{d}{dx}.J_p.$$

$$* \quad \boxed{\frac{\partial(\delta p)}{dt} = \frac{p_0 - p}{\tau_p} - \frac{1}{e}\frac{d}{dx}J_p} \quad -*$$

Continuity eq^n for holes.

$$\boxed{\frac{\partial(\delta n)}{dt} = \frac{n_0 - n}{\tau_n} - \frac{1}{e}\frac{d}{dx}J_n} \quad \text{for } e^-\text{'s}$$

$$\boxed{\begin{aligned} J_n\ (\text{diffusion}) &= e D_n \frac{dn}{dx} = e D_n \frac{d\delta n}{dx} \\ J_p\ (\text{diffusion}) &= -e D_p \frac{d\delta p}{dx} \end{aligned}}$$

Put value of J_p in eq *.

$$\frac{d(\delta p)}{dt} = \frac{p_0 - p}{\tau_p} - \frac{1}{\cancel{e}}\frac{d}{dx} - \cancel{e} D_p \frac{d\delta p}{dx}$$

$$\delta p = \frac{p_0 - p}{\tau_p} + \frac{d^2}{dx^2} D_p \delta p$$

$\delta p(x)$ Carrier ~~conc~~ depend on Time & distance both.
concn.

$$J_p(x) = -eD_p \frac{d(\delta p)}{dx}$$

$$= -eD_p \frac{d(\Delta p e^{-x/L_p})}{dx}$$

$$= -e \times \frac{-1}{L_p} \cdot D_p \cdot \Delta p \cdot e^{-x/L_p}.$$

$$\boxed{J_p(x) = \frac{e D_p}{L_p} \delta p(x).}$$

$\tau_p \rightarrow$ Carrier lifetime

$D_p \rightarrow$ Diffusion constt. for holes

$$\boxed{D_p \frac{d^2 \delta p}{dx^2} = \frac{\delta p}{\tau_p}}$$

$L_p \rightarrow$ diffusion length.

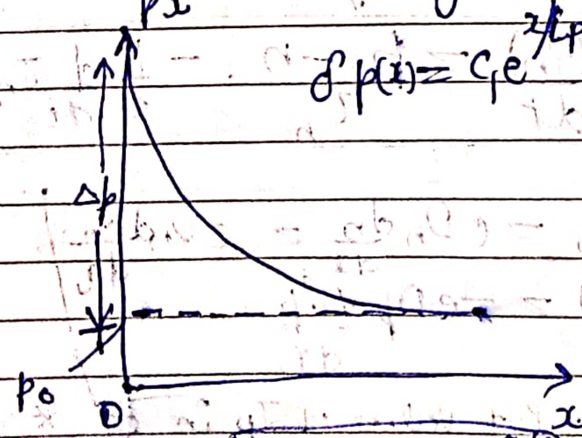
$$\boxed{\frac{d^2 \delta p}{dx^2} = \frac{\delta p}{D_p \tau_p} = \frac{\delta p}{L_p^2}} \quad \boxed{\text{where } L_p = \sqrt{D_p \tau_p}}$$

$$\frac{d^2 \delta n}{dx^2} = \frac{\delta n}{D_n \tau_n} = \frac{\delta n}{L_n^2} \quad \text{where } L_n = \sqrt{D_n \tau_n}$$

L_p & L_n are called diffusion length.

<u>Diffusion length</u> is defined as the distance travelled by free carriers before recombination. It is also defined ~~by~~ as the average distance covered by an excess carriers during its lifetime.

$$\delta p(x) = C_1 e^{x/L_p} + C_2 e^{-x/L_p}.$$



$$\boxed{\delta n(x) = C_1 e^{x/L_n} + C_2 e^{-x/L_n}}$$

for $x = \infty$,
$\hookrightarrow \delta p(x) = 0$ $\quad C_1 = 0.$

for $x = 0$, $\quad C_1 = 0$

$\delta p = \Delta p$, $\quad C_2 = \Delta p$

$$\boxed{\delta p(x) = \Delta p \, e^{-x/L_p}}$$

$\delta p(x)$ Carrier ~~conc~~ concen. depend on Time & distance both.

$$J_p(x) = -eD_p \frac{d(\delta p)}{dx}$$

$$= -eD_p \frac{d(\Delta p e^{-x/L_p})}{dx}$$

$$= -e \times \frac{-1}{L_p} \cdot D_p \cdot \Delta p \cdot e^{-x/L_p}.$$

$$\boxed{J_p(x) = \frac{e D_p}{L_p} \delta p(x).}$$

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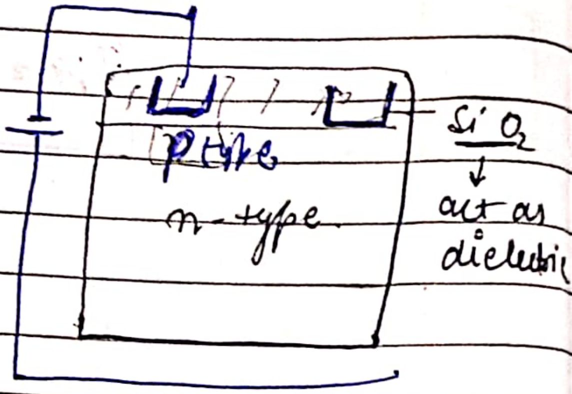
* p-n junction

fabrication steps for p-n junction

1. The wafer preparation & thermal oxidation

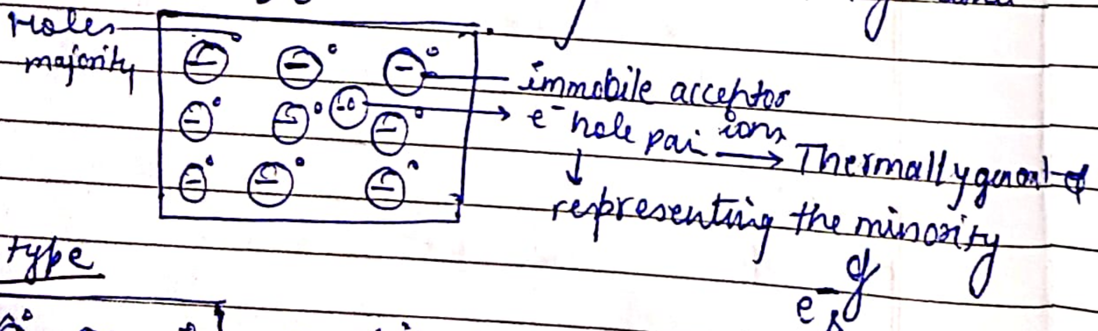
P	N

2. Diffusion
3. Ion implantation.
4. Photolithography.
5. Etching.
6. Metallization.

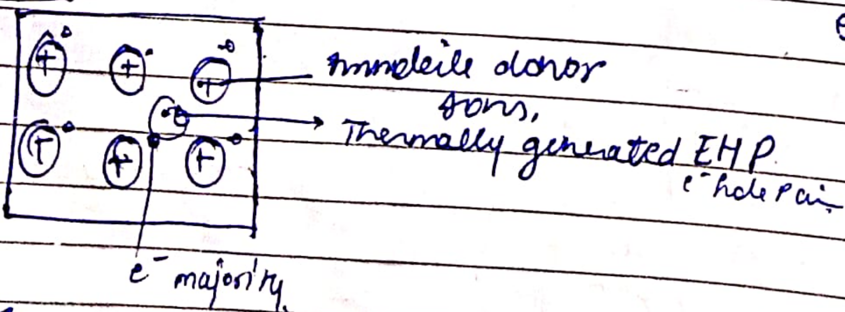


The impurity (acceptor ion) added in p-type makes acceptor immobile ions (-ve charge) it is electrically neutral.

as in that type of semiconductor. e^-s are in minority. So, the trivalent impurity added in that compensate with the holes in p-type for making it electrically neutral



n-type



Electrically Neutral.

Same type of process happened in n-type as the impurity added in this termed as donor type impurity so as it gain +ve charge. then these immobile donor ions compensate with the e^-s in n-type for making it electrically neutral.

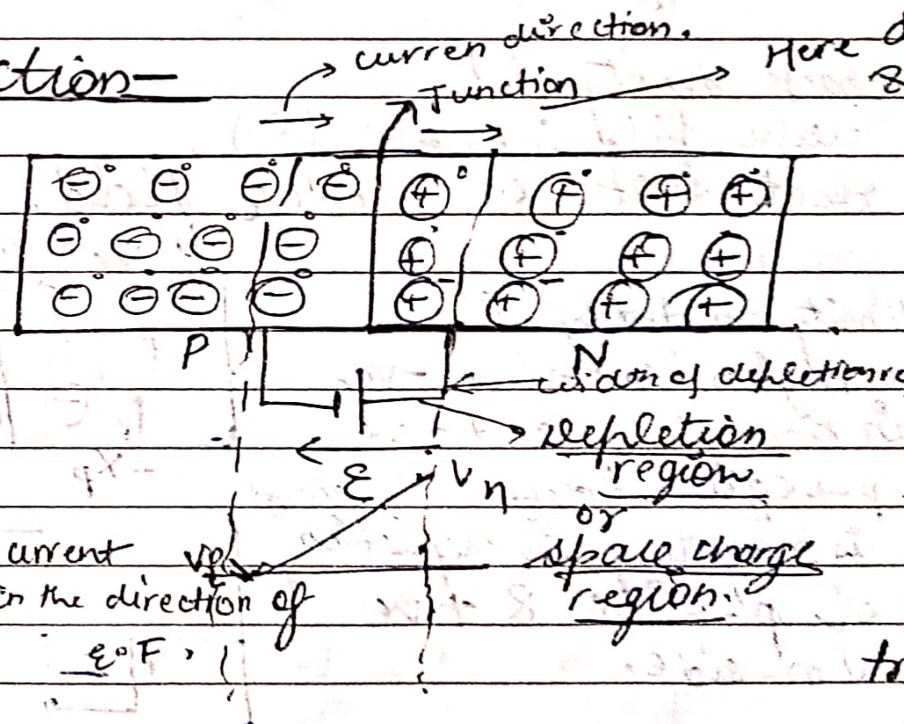
Types of p-n junctions.

Step junction (conc. of p & n s are same)

graded junction (conc. of p & n s are not same)

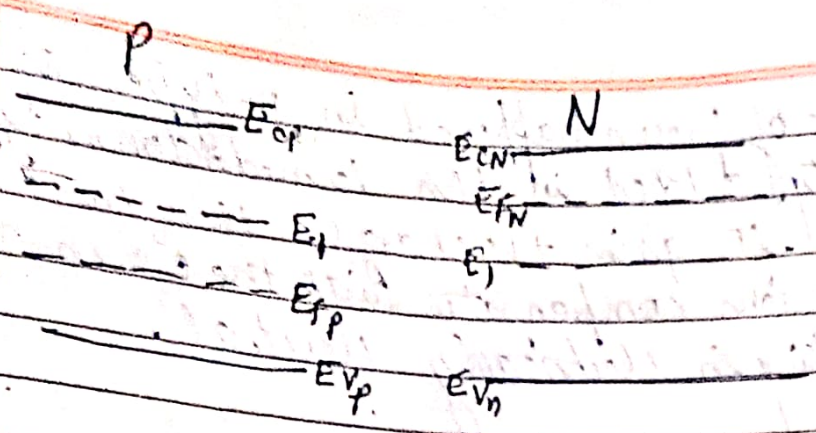
diffused or implantation junction.

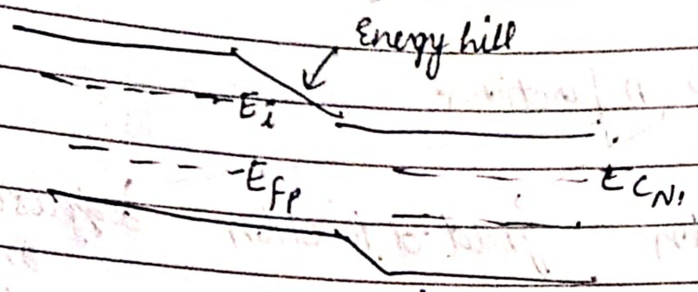
p n junction—



Barrier potential is the potential which stops the further transportation from either side of junction

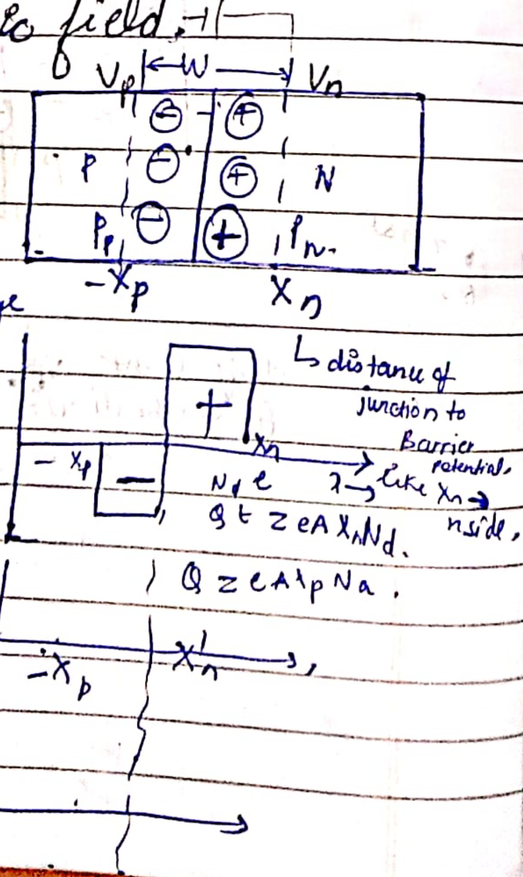
$V_n - V_p = V_B \rightarrow$ Barrier potential





* When junction form the fermi level get aligned. 12/10/22
at equilibrium, fermi level lie on same Energy level.

(i) charge density (ρ)
(ii) Electric field intensity (ε).
(iii) Electrostatic or Electric field.



→ Charge density denoted by 'ρ'.
Space charge region contains -ve ion in n-region and +ve ion in p-region, therefore the charge density is negative in depletion region of p-side & +ve ρ for n-side.

The value of ρ is zero at junction.

$\rho = ne = N_d e = N_d e$

$$J = \frac{I}{A} = nev$$

$$I = nevA$$

$$Q = it = i \times \frac{x_m}{v} \qquad t = \frac{x_m}{v}$$

$$Q = nevA \cdot \frac{x_m}{v}$$

$$= N_d x_n eA = eAx_n N_d$$

An electric field is established from ~~left~~ Right to left in depletion region because the depletion region towards the left of the junction contains negative charge and towards right contain positive charge. So, the Relation between Electric field intensity and charge ~~p~~ density.

$$\mathcal{E} = \int \left(\frac{\rho}{\epsilon}\right) dx$$

ϵ → permittivity of semiconductor material

The Relationship between charge distribution and electrostatic potential can be obtained by Poisson's equation → it says that the second derivative of the potential w.r.t the distance is directly proportional to the charge density.

$$\frac{d^2V}{dx^2} = -\frac{\rho}{\epsilon}$$

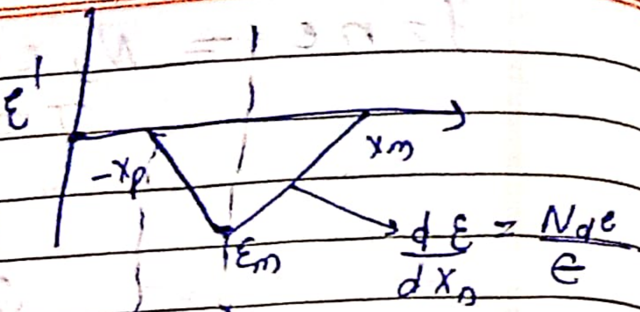
ϵ — epsilon.

$$\frac{d}{dx} \cdot \frac{dV}{dx} = -\frac{\rho}{\epsilon}$$

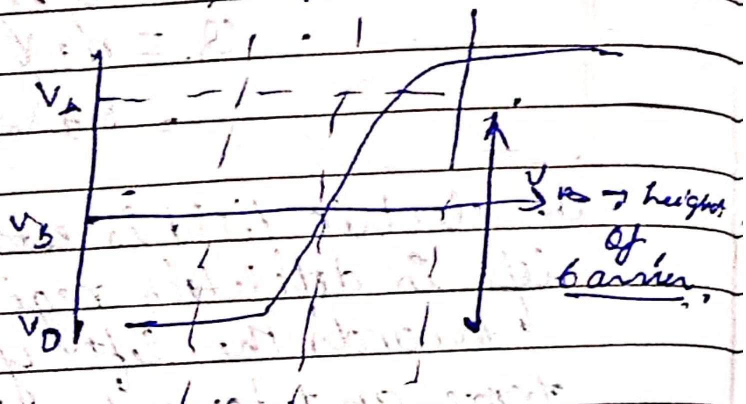
$$+\frac{d}{dx}\mathcal{E} = +\frac{\rho}{\epsilon}$$

$$\frac{d\mathcal{E}}{dx} = \frac{\rho}{\epsilon}$$

$$\mathcal{E} = -\frac{dV}{dx}, \qquad \frac{\rho}{\epsilon} = \frac{N_d e}{\epsilon}$$



J_n (drift) + J_p (diffusion) $= 0$



Calculation of contact or barrier potential V_B or V_0.

$$J_p\,(\text{diffusion}) = -eD_p \frac{dp(x)}{dx}$$

$$J_p\,(\text{drift}) = e\mu_p\, p(x)\, \mathcal{E}(x)$$

$$e\mu_p\, p(x)\, \mathcal{E}(x) = eD_p \frac{dp(x)}{dx}$$

$$\frac{\mu_p}{D_p}\mathcal{E}(x) = \frac{1}{p(x)}\frac{dp(x)}{dx} \longrightarrow (1)$$

$$\frac{D_p}{\mu_p} = \frac{KT}{q} \Rightarrow \frac{\mu_p}{D_p} = \frac{q}{KT} \quad \& \quad \mathcal{E}(x) = -\frac{dV(x)}{dx},$$

Now, the eq^n become,

$$-\frac{q}{KT}\frac{dV(x)}{dx} = \frac{1}{p(x)}\frac{dp(x)}{dx} \longrightarrow (2)$$

$$-\frac{q}{KT}\int_{V_p}^{V_n} dV = \int_{p_p}^{p_n} \frac{1}{p}\,dp$$

$$-\frac{q}{KT}(V_n - V_p) = \log_e p_n - \log_e p_p$$

$$= \log_e \frac{p_n}{p_p}$$

$N_a p_n = n_i^2$

$N_a n_p = n_i^2$,

$$-\frac{q}{KT}(V_B) = \log_e \frac{P_n}{P_p}$$

$$-V_B = \frac{KT}{q} \log_e \frac{P_n}{P_p}$$

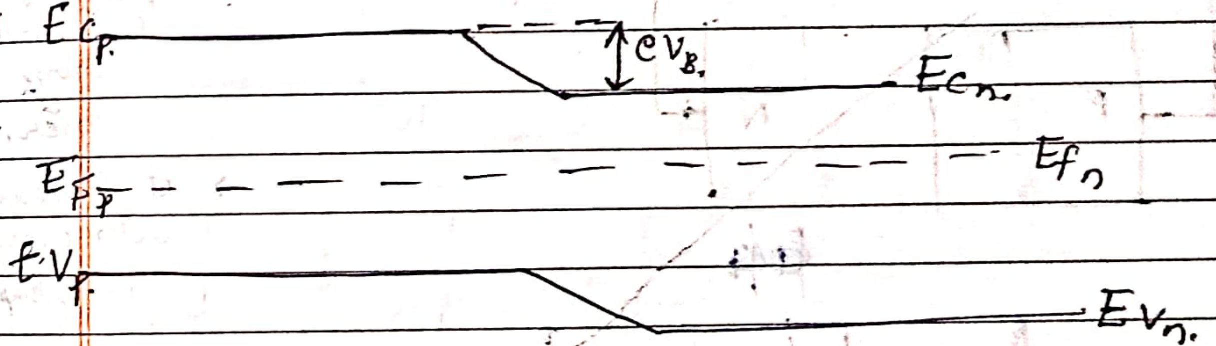
6.026

or

$$\boxed{V_B = \frac{KT}{q \text{ or } e} \log_e \frac{P_p}{P_n}}$$

$$V_B = \frac{KT}{q} \log \frac{N_a N_d}{n_i^2}$$

P N Junction-



If P_p & P_n are hole conc. at transition region

$$V_B = \frac{KT}{q} \log_e \frac{P_p}{P_n}$$

$$\log \frac{P_p}{P_n} = \frac{qV_B}{KT}$$

$$\frac{P_p}{P_n} = e^{qV_B/KT}$$

E_{F_p} & E_{V_p} are energies of fermi level & valance band of p-side.

$$P_p = N_V e^{-(E_{F_p} - E_{V_p})/KT}$$

Similarly, $P_n = N_V e^{-(E_{f_n} - E_{V_n})/KT}$.

$$\frac{P_P}{P_n} = \frac{N_V e^{-(E_{fp} - E_{V_p})/KT}}{N_V e^{-(E_{fn} - E_{V_n})/KT}}$$

$$e^{qV_B/KT} = e^{(-E_{fp} + E_{V_p} + E_{fn} - E_{V_n})/KT}$$

$$\frac{qV_B}{KT} = \frac{-E_{fp} + E_{V_p} + E_{fn} - E_{V_n}}{KT}$$

At equilibrium, $E_{fn} = E_{fp}$

$$\boxed{qV_B = E_{V_p} - E_{V_n} \quad \text{or} \quad E_{V_p} - E_{V_n} = eV_B}$$

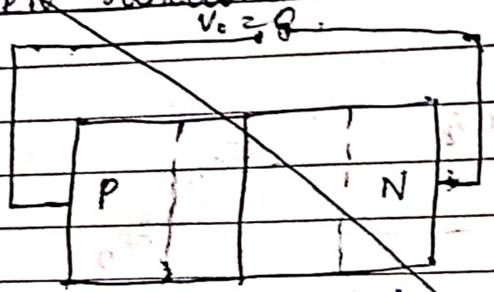
* Knee voltage / cut-in voltage / Forward voltage $\begin{cases} Si - 0.7V \\ Ge - 0.3V \end{cases}$

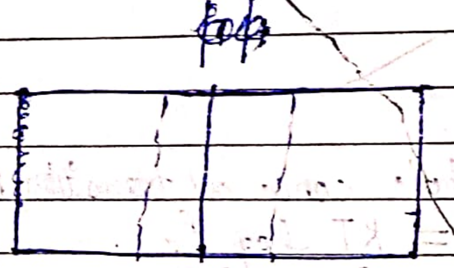
*. Reverse saturation current known like this because it produced by minority charge carriers.

→ it increase with every $10^\circ C$ temperature

• otherwise it remains const.

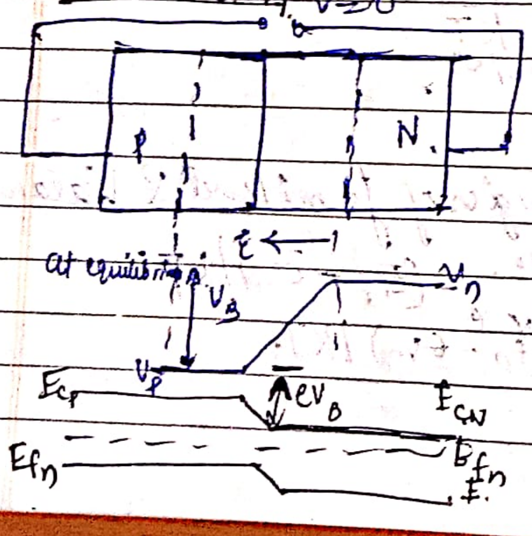
~~PN Junction~~



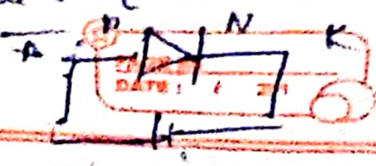


P-N Junction $V = 0$

No bias

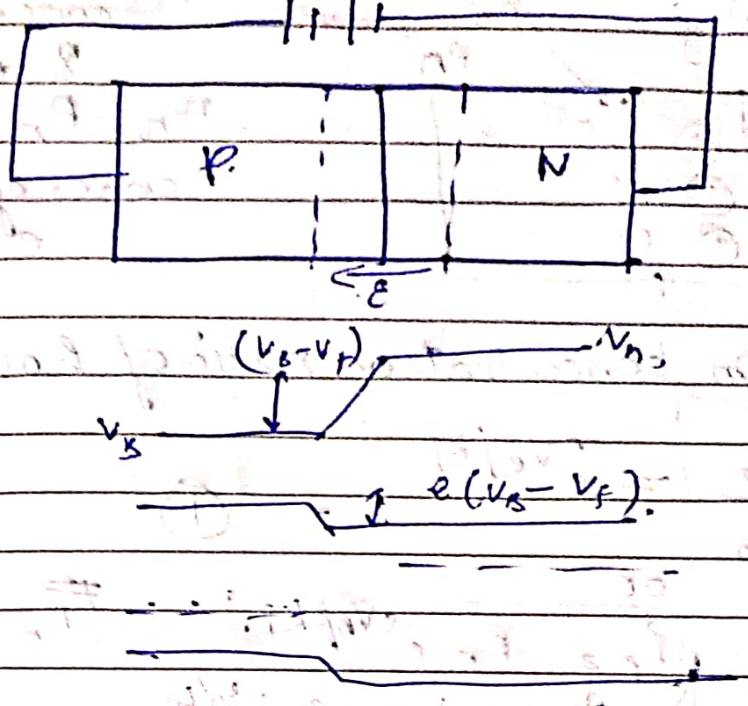


Equation or derivation to contact potential & the diode & eq dem

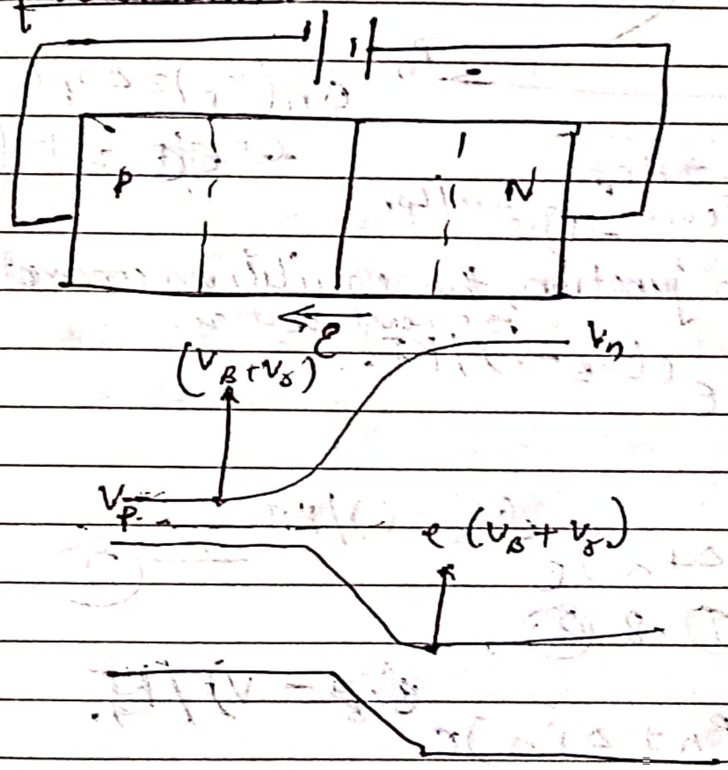


Forward Bias -

$V = V_f$



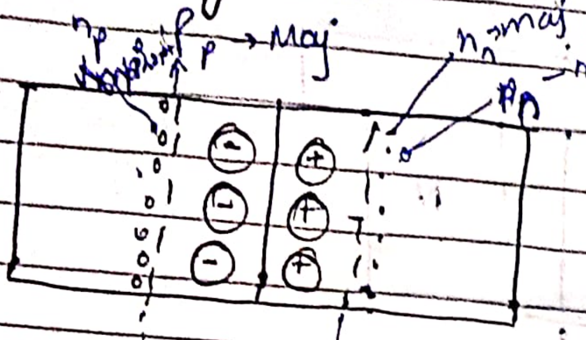
Reverse Bias -



here this process happening with diffusion and the current comes ~~out~~ as $\boxed{\text{drift + diffusion}}$

Carrier Injection.

$2/11/22$



$p_p\ n_p \to$ In P-region conc. of holes & electrons.

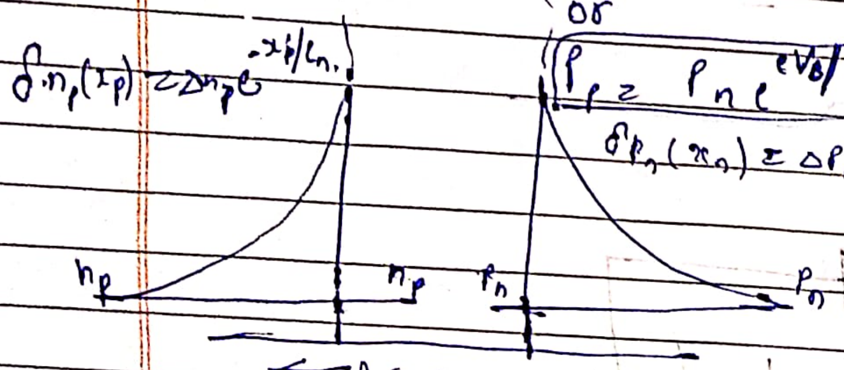
$n_n \cdot p_n \to$ In n-region conc. of holes & e^-s.

The equilibrium concentration ratio of holes –

$$\frac{P_p}{P_n} = e^{eV_B/KT} \quad \text{— (1)}$$

or

$$\boxed{P_p = P_n e^{eV_B/KT}} \quad P_n + \Delta P_n$$



$$\delta n(x_p) = \Delta n_p e^{-x_p/L_n}$$

$$\delta_p(x_n) = \Delta p_n e^{-x_n/L_p}$$
$$= P_n[e^{eV/KT} - 1] \cdot e^{-x_n/L_p}$$

$$\delta n_p = n_p[e^{eV/KT} - 1]e^{-x_p/L_n}$$

→ After open ckt of p-n junction, the equilibrium conc. ratio of holes.

$$\frac{P_p}{P_n + \Delta P_n} = e^{e(V_B - \overset{\to \text{ forward voltage}}{V})/KT}$$

$$P_p = (P_n + \Delta P_n)e^{e(V_B - V)/KT} \quad \text{— (2)}$$

Equate eqn (1) & (2),

$$P_n e^{eV_B/KT} = (P_n + \Delta P_n)e^{e(V_B - V)/KT}$$

$$P_n \cancel{e^{eV_B/KT}} = (P_n + \Delta P_n)\cancel{e^{eV_B/KT}} \cdot e^{-eV/KT}$$

$$P_n = (P_n + \Delta P_n)e^{-eV/KT}$$

$(p_n + \Delta p_n) = p_n e^{eV/KT}$.

$\Delta p_n = p_n e^{eV/KT} - p_n$.

$$\boxed{\Delta p_n = p_n \left[e^{eV/KT} - 1\right]}$$ excess holes in n-region.

where

V = forward Voltage $\quad e^{V/\frac{KT}{e}} = V_T$
$= 26\,mV$.

$$\boxed{\Delta n_p = n_p\left[e^{eV/KT} - 1\right]}$$

excess e^-s in p region.

$$\boxed{\begin{aligned} p(x_n) &= \Delta p_n e^{-x_n/L_p} \\ n(x_p) &= \Delta n_p e^{-x_p/L_n} \end{aligned}}$$

A p-n junction is formed from Germanium of conductivity $0.8\,\Omega\,cm^{-1}$ on the p-side & $1.6\,\Omega\,cm^{-1}$ on n-side. Calculate the potential Barrier of the junction.

$n_i = 2.1 \times 10^{13}/cm^3$

$\mu_p = 2000\ cm^2/Vs$

μ_e or $\mu_n = 4000\ cm^2/Vs$.

$$V_B = \frac{KT}{q}\log\frac{N_a N_d}{n_i^2}.$$

$\sigma_n = \overset{N_d}{n} e\mu_e$ $\qquad \sigma_n = N_d e\mu_e$

$\sigma_p = p e\mu_p$ $\qquad 1.6 = N_d \times e \times 4000$

$\quad N_a$ $\qquad N_d = \dfrac{1.6}{e \times 4000}$. $\Rightarrow N_d = 1.471 \times 10^{-4}$.

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$\sigma_p = N_a e \mu_p$

$\frac{0.8}{e \times 2000} = N_a$

$N_a = 1.471 \times 10^{-4}$

$V_b = \frac{KT}{q} \log \frac{N_a N_d}{n_i^2}$

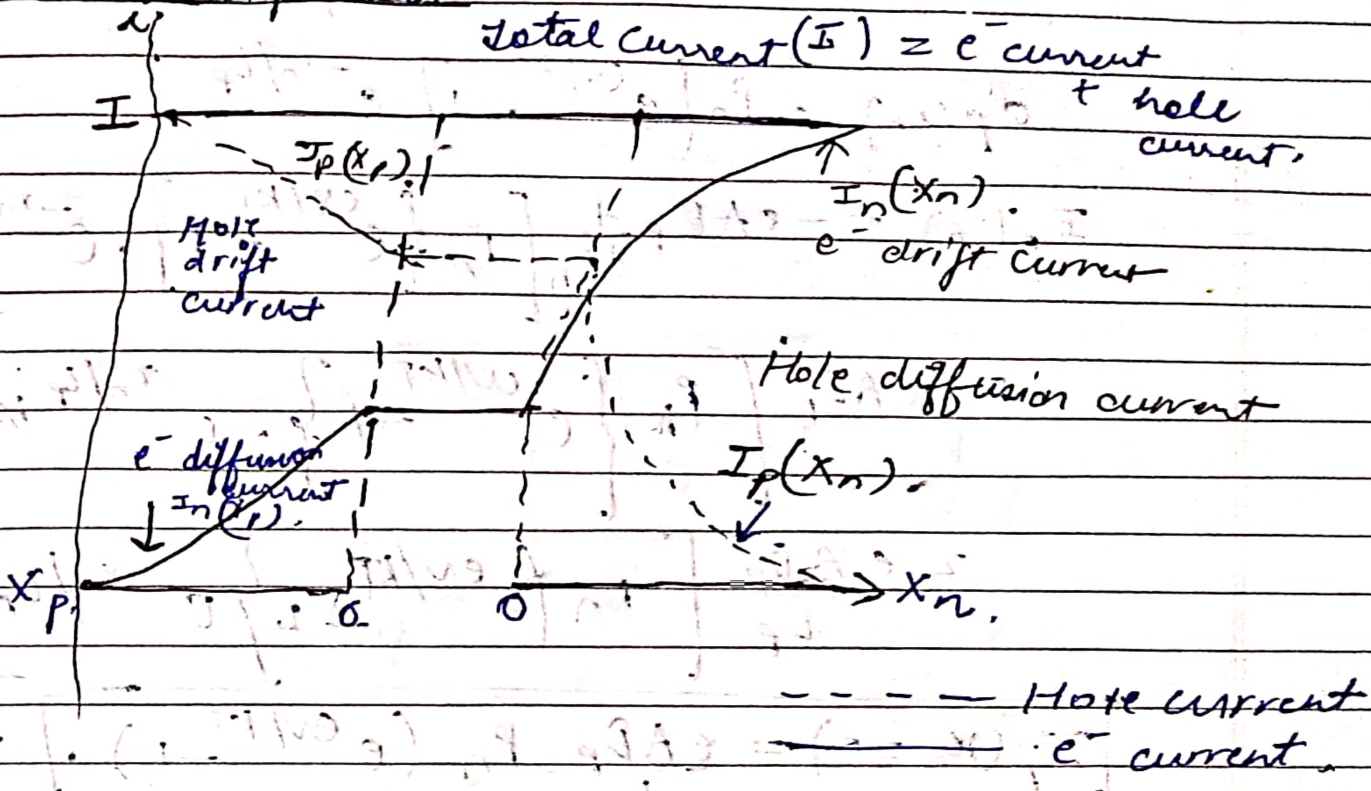
$= 0.026 \log \left(\frac{1.47 \times 10^{-4} \times 1.47 \times 10^{-4}}{(2.1 \times 10^{13})^2} \right)$

$= 5.698 \times 10^{-10}$

$= 0.026 \log \left(\frac{2.1609 \times 10^{-8}}{4.41 \times 10^{26}} \right)$

$= 0.026 \times \log 0.49 \times 10^{-34}$

Current Components –



Diode Current Equation –

$I_p(x_n) \longrightarrow$ Hole Current in N-material (minority).

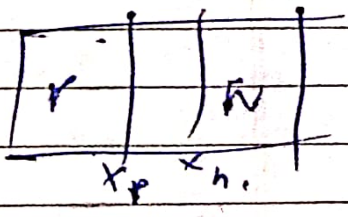
$I_p(x_n = 0) \longrightarrow$ Total hole current.

$I_n(x_p) \longrightarrow$ e⁻ current in p-material (minority)

$I_n(x_p = 0) \longrightarrow$ Total e⁻ current.

Total current I is constt.

$$\boxed{\therefore I = I_p(x_n = 0) + I_n(x_p = 0)}$$



The majority (e⁻) current

$$I_n(x_n) = I - I_p(x_n)$$

The majority (hole) current.

$$I_p(x_p) = I - I_n(x_p).$$

$$J_p(x) = -eD_p \frac{dp(x)}{dx}$$

$$J_p(x_n) = -eD_p \frac{\delta\, dp(x_n)}{dx_n} = \frac{I_p(x_n)}{A}.$$

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$$I_p(x_n) = -eAD_p \frac{d\,\delta p(x_n)}{dx_n}$$

$$\delta p(x_n) = p_n\left[e^{eV/KT} - 1\right] e^{-x_n/L_p}$$

$$I_p(x_n) = -eAD_p \frac{d}{dx_n}\left[p_n\left\{e^{eV/KT} - 1\right\} \cdot e^{-x_n/L_p}\right]$$

$$= eAD_p\left[p_n\left\{e^{eV/KT} - 1\right\} \cdot e^{-x_n/L_p} \times -\frac{1}{L_p}\right]$$

$$= \frac{eAD_p}{L_p}\left[p_n\left\{e^{eV/KT} - 1\right\} e^{-x_n/L_p}\right]$$

$$\boxed{I_p(x_n = 0) = \frac{eAD_p}{L_p} p_n\left(e^{eV/KT} - 1\right)}$$

$$\boxed{I_n(x_p = 0) = -\frac{eAD_n}{L_n} n_p\left(e^{eV/KT} - 1\right)}$$

Total Current -

$$I = I_p(x_n = 0) - I_n(x_p = 0)$$

$$= \frac{eAD_p}{L_p} p_n\left(e^{eV/KT} - 1\right) + \frac{eAD_n}{L_n} n_p\left(e^{eV/KT} - 1\right)$$

$$I = eA\left(e^{eV/KT} - 1\right)\left[\frac{D_p p_n}{L_p} + \frac{D_n n_p}{L_n}\right]$$

$$\boxed{I = I_0\left(e^{eV/KT} - 1\right)} \rightarrow \text{Diode Current Equation}$$

where, $I_0 = eA\left[\frac{D_p}{L_p} p_n + \frac{D_n}{L_n} n_p\right]$ * ans

$I_0 \rightarrow$ Reverse Saturation Current

Ques

$D_p = 1$

$n_n p_n = n_i^2$; $p_p n_p = n_i^2$.

$p_n = \frac{n_i^2}{n_n} = \frac{n_i^2}{N_D}$; $n_p = \frac{n_i^2}{p_p} = \frac{n_i^2}{N_A}$.

$$I_0 = eA\left[\frac{D_p}{L_p}\frac{n_i^2}{N_D} + \frac{D_n}{L_n}\frac{n_i^2}{N_A}\right]$$

$$\boxed{I_0 = eAn_i^2\left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right]}$$

$$I = I_0\left[e^{V/\eta V_T} - 1\right]$$

where $V_T = \frac{KT}{e} = 0.026\ V$ at Room temp

$\eta = 1$ for large curr

$\eta = 2$ for small current.

$\eta = 1$ for Ge

$\eta = 2$ for Si

We take 2 only when Si material mentioned otherwise we take 1 as general in p-n jx^n diode

Find the Reverse Saturation Current Density in an abrupt Si junction with the following data –

$N_D = 10^{21}/m^3$, $N_A = 10^{22}/m^3$

$D_n = 3.4 \times 10^{-3} m^2/s$, $L_n = 7.1 \times 10^{-4} m$

$2 \times 10^{-3} m^2/s$; $L_p = 3.5 \times 10^{-4} m$, ; $n_i = 1.6 \times 10^{16}/m^3$

$$\frac{I_0}{A} = en_i^2\left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right]$$

$$= e(1.6 \times 10^{16})^2\left[\frac{1.2 \times 10^{-3}}{(3.5 \times 10^{-4})(10^{21})} + \frac{3.4 \times 10^{-3}}{(7.1 \times 10^{-4})(10^{22})}\right]$$

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$J_0 = 1.6 \times 10^{-7} A/m^2$
$= 0.16 \mu A/m^2$.

Ques: The current flowing through a certain p-n junction at room temp. when reverse biased is 0.15 μA. Determine the current flowing through the diode when the applied voltage is 0.12 V.

$I_0 = 0.15$.

$V = 0.12$

$I = I_0 (e^{eV/kT} - 1)$

$I = 0.15 (e^{0.12/0.026} - 1)$.

$= 1.5 \times 10^{-5} A$

$= 15 \mu A$.

Ques: The saturation current density of pn junction Ge diode is 250 mA/m². (m² at room temp.) Find the voltage that would have to be applied across junction to cause forward current density of 10^5 A/m².

$\Rightarrow \frac{I}{A} = \frac{I_0}{A} \left[e^{V/\eta V_T} - 1 \right]$.

$J = J_0 \left[e^{V/\eta V_T} - 1 \right]$.

$J_0 = 250 mA/m^2 \quad = 0.25$.

$J = 10^5 A/m^2$.

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$$\Rightarrow \frac{J}{J_0} = \left[e^{V/\eta V_T} - 1\right]$$

$$\left(\frac{J}{J_0} + 1\right) = e^{V/\eta V_T}.$$

$$\log\left(\frac{J}{J_0}+1\right) = \frac{V}{\eta V_T}$$

$$V = 0.026 \log\left(\frac{J}{J_0}+1\right)$$

$$\Rightarrow V = 0.026 \log\left(\frac{10^5}{0.25}+1\right)$$

$$\boxed{V = 0.33\,V}$$

A silicon p-n junction diode consists of p & n regions with conductivities of $1000\,(\Omega m)^{-1}$ & $20\,(\Omega m)^{-1}$ respectively. The minority carrier lifetime in the two regions are $5\,\mu s$ & $1\,\mu s$ respectively. Determine the ratio of hole current to e^- current in the depletion layer, The Reverse saturation current density & total current density flowing through the junction for a forward bias of 0.4 V.

Given:- $\mu_n = 0.13\,m^2/Vs$
$\mu_p = 0.5\,m^2/Vs$
$n_i = 1.5 \times 10^{19}/m^3$

$$= \frac{KT}{q}$$

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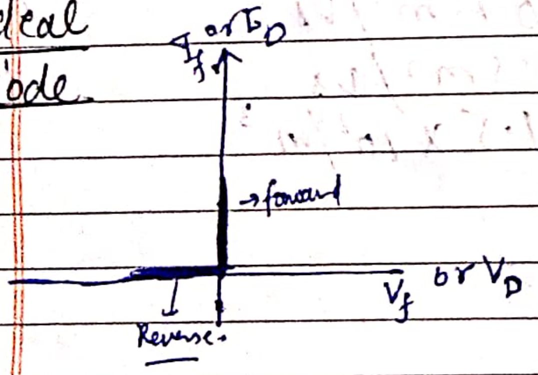
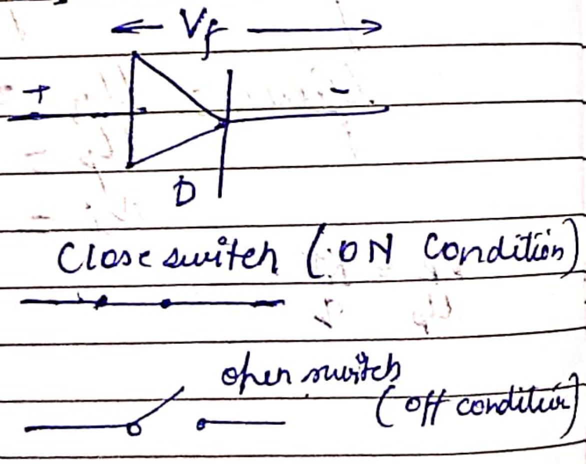
Equivalent circuits or Models of diode

1. Ideal Diode
2. Simple Equivalent Circuit.
3. Piecewise Equivalent Circuit.

Ideal Diode.





Simple Equivalent Circuit.

* Diode only conducts when the value of current is equivalent or greater than V_T ~~as~~

Here, we get to know that the graph of current shows at V_T point before that we see the straight line of current on axis itself.

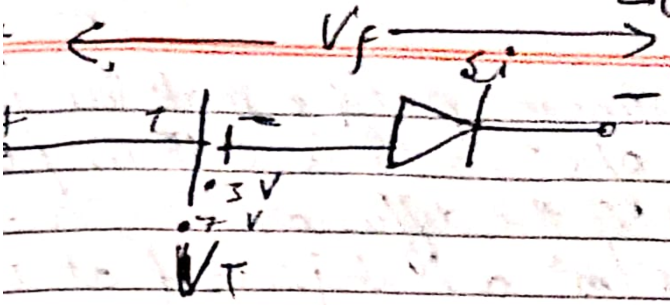
0.7

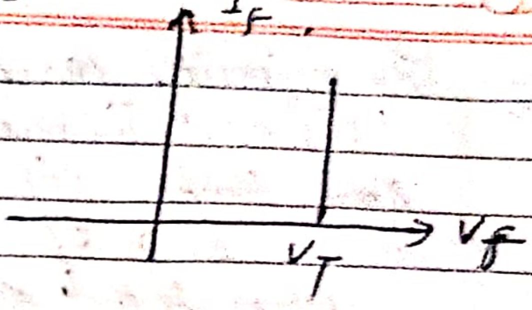
Semesters → Ques- Explain the working & Principle of p-n diode with VI characteristics └(in both bias)

Ques- diode working & construction

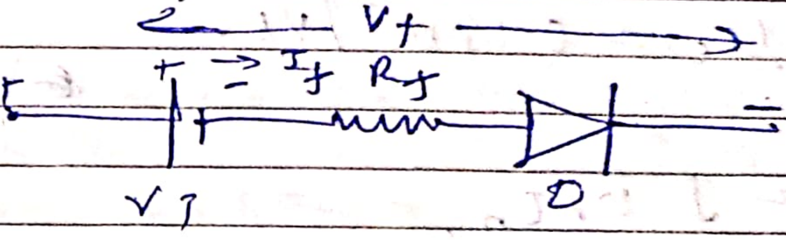
Ques- Num. on Barrier

Ques- p-n diode's Potential



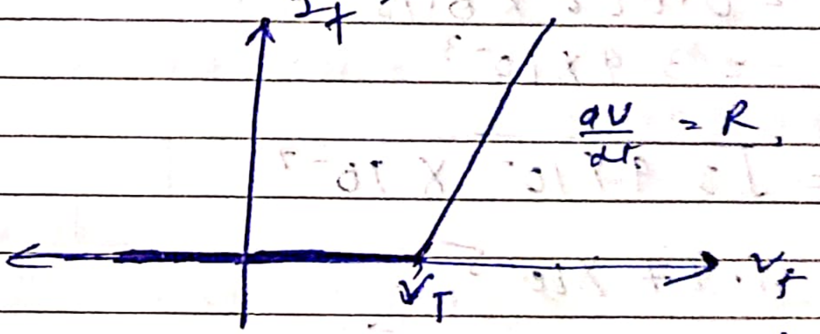


Piecewise Equivalent Circuit



In this the conduction happens only when the value of $V_f = V_T + I_f R_f$.

the value of V_T more than V_f then it happens.



• Diode offers resistance

Piece of the diode that also shows it internal impedance

We can say that the particular component when effect the value of current in a circuit then we said it Piecewise.

Ques. Derive an expression for Diode current & p-n junction

Ques. derive an expression for Diffusion & Drift. & derive continuity eqn.

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Ques. The minority carrier lifetime in p-type material is 10^{-7} sec. The mobility of e^- in Si is $0.15\ m^2/Vs$ at Room temp. (i) What is the diffusion length.
(ii) If $10^{20}\ e^-/m^3$ are injected at $x=0$ What is the diffusion current density at $x=0$.

$$\tau_n = 10^{-7}\ sec$$

$$\mu_e = 0.15\ m^2/Vs.$$

for e^-'s diffusion

$$L_n = \sqrt{D_n \tau_n}$$

$$D_n = \frac{KT}{q}\mu_e$$

$$= 0.026 \times 0.15$$

$$= 3.9 \times 10^{-3}$$

$$L_n = \sqrt{3.9 \times 10^{-3} \times 10^{-7}}$$

$$L_n = 1.97 \times 10^{-5}\ m.$$

(ii) $J_n = e D_n \frac{dn(x)}{dx}$

$$= e \frac{D_n}{L_n} \Delta n$$

$$J_n = e \cdot \frac{3.9 \times 10^{-3}}{1.97 \times 10^{-5}} \times 10^{20}$$

5.38×10^{22}

Imp Quesn: Diff. b/w ABD & Zener breakdown
Imp Quesn: Discuss about ABD & ZBD.

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Unit - 4

BreakDown Mechanisms :-

1) Zener Breakdown (at low Voltages)
2) Avalanche Breakdown (at high or larger voltages)

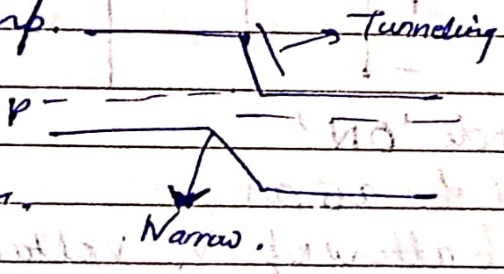
Zener breakdown

⇒ In heavily doped, E.F value will be high, then. ★ $E = \frac{V}{d}$.
Zener breakdown happen & reverse saturation current happen.

→ If the value of d is less in heavily doped then the E.F will be more.

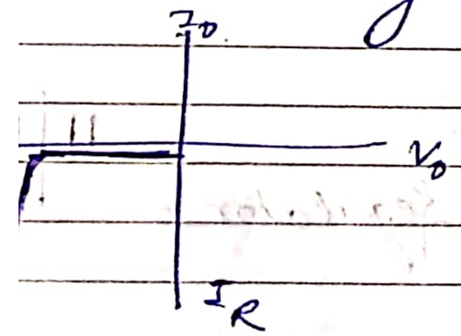
∴ due to high E.F.

The VI curve is very sharp.



It can be used after junction Zener breakdown happens.

at low voltage



→ Depletion Region is small.

→ The device is which it happen known as Zener Diode.

→ Zener diode is -ve temp. coefficient

Avalanche Breakdown :- due to collision of charge carriers, lightly doped.

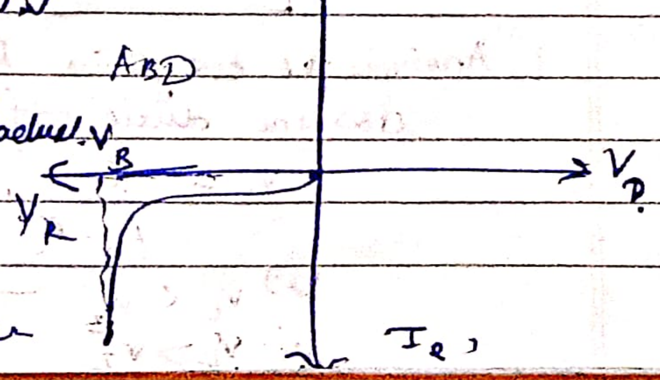
When Voltage get increased then the minority charge carriers gain velocity & then their Energy get increased by $E = \frac{1}{2}mv^2$ So, as they strike with stationary particles, then it break the junction & this known Avalanching Breakdown.

→ it happens gradually
Hence it's VI characteristic is gradual.

Depletion Region is large.

lightly doped.

ABD is +ve temp. coeffn



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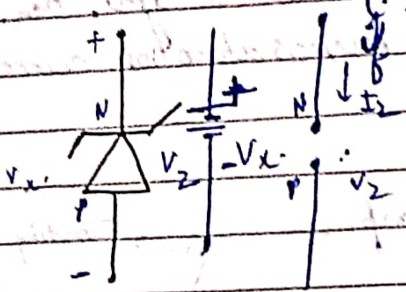
→ When temp get increased, the minority charge carriers will increase Hence slightly reverse saturation current increases.

★ Zener Diode as
Load connected in parallel.
→ Regulated - doesn't get effect due to input voltage.
→ Unregulated → changes on the basis of inputs.



(i.) If $V_x < V_z$ (applied voltage), Zener diode 'off'.
It will act as an open circuit. $I_z = 0$

(ii) $V_x > V_z$,
Zener diode 'ON'
This will be act as a battery of V_z voltage.

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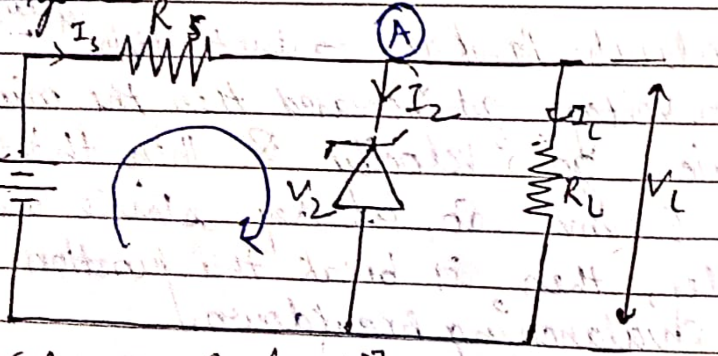
Zener Diode as a Voltage Regulator -

Circuit Diagram -



R_L → load resistance

["Analysis for Everything is fixed"]
Assume diode off!

$V_L = \frac{R_L}{R_s + R_L} \cdot V_s$ —— (1)

(then compare this with V_z, this comparison tells us diode is off or on).

(i) $V_L < V_z$ → (off) $I_z = 0$ —(2)
$I_s = I_L = \frac{V_L}{R_s + R_L}$ —(3)

(ii) $V_L > V_z$

→ V_S → Voltage source only just reverse biasing the Zener diode.

(i) In the condition ; $V_L < V_Z$, Diode will not act as Voltage Regulator.

(ii.) $V_L > V_Z$. 'ON' , ~~$I = \frac{V}{R_S + R_L}$~~ — ①.

$$V_L = V_Z \quad — ② \quad \star$$

$$I_L = \frac{V_L}{R_L} \text{ or } \frac{V_Z}{R_L} \quad — ③ \quad \star$$

★ → these points should be remember for the condition of Diode 'ON'

applying KVL at the loop.

$$V_S - I_S R_S - V_Z = 0$$

$$I_S R_S = V_S - V_Z$$

$$I_S = \frac{V_S - V_Z}{R_S} \quad — ④ \quad \star$$

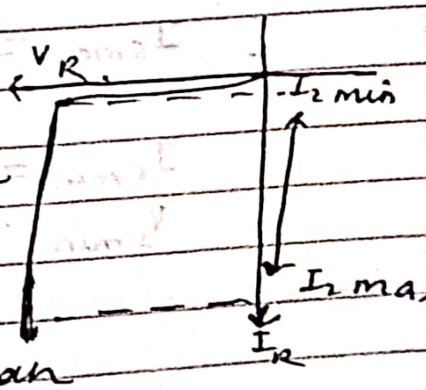
applying KCL at Node Ⓐ,

$$I_S = I_Z + I_L$$

or

$$I_Z = I_S - I_L \quad — ⑤ \quad \star$$

If value of I_z min decreases then the zener diode's breakdown region breaks So, it will not act as Voltage Regulator or I_z max then again value of current become greater than Z. D. not act as V. R.



Conditions -

① V_S varying R_L fixed. } Zener diode is 'ON'

② V_S fixed R_L varying }

(a)

$$\underset{\text{increasing}}{I_S} = \overset{\text{increasing}}{I_Z} + \underset{\text{constt.}}{I_L}.$$

→ $V_S \uparrow \quad I_S \uparrow$

→ $I_L = \frac{V_Z}{R_L}$ R_L constt. I_L = constt.

(b) $I_S = I_Z + I_L$ $\quad I_Z > I_{Z min}$

$\downarrow \quad \downarrow$ const.

(c) $V_S = I_S R_S + V_Z$

$V_{S max} = I_{S max} R_S + V_Z$ → const. → const.

$I_{S max} = I_{Z max} + I_L$

$I_{S min} = I_{Z min} + I_L$

$V_{S min} = I_{S min} R_S + V_Z$

(2) V_S fixed R_L varying -

(a) $V_L = V_Z$

(b) $I_L = \frac{V_Z}{R_L}$ → fixed, → R_L is max

I_L is min.

$I_S = \frac{V_S - V_Z}{R_S}$ → this value remains const.

(c) $I_S = I_Z + I_L$ → min. $\quad I_Z < I_{Z max}$.

const. $\quad \downarrow$ max

Ques.

30V

$I_{S max} = I_{S min} + I_L$. $\quad \therefore R_{L max} = \frac{V_L}{I_{L min}}$

$I_{S min} = I_{Z min} + I_L$.

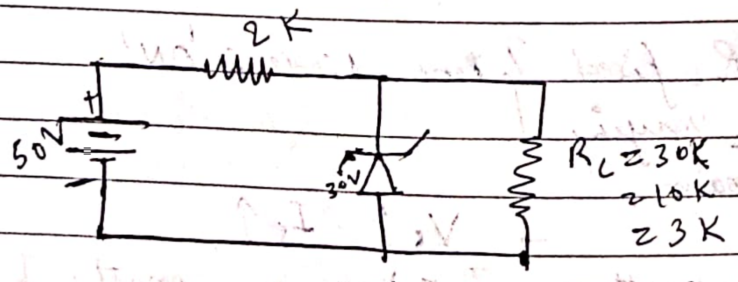
$V_{S min} = I_{S min} R_S + V_Z$.

$I_S = I_{Z max} + I_{L min}$

$I_{L min} = I_S - I_{Z max}$.

$I_{L max} = I_S - I_{Z min}$

Ques



Determine I_Z = ?

$\Rightarrow$ R_L is varying here.

$$I_L = \frac{V_Z}{R_L}$$

I_L

$V_Z = 30V$

$$I_L = \frac{30}{30} \qquad I_L = \frac{30}{10} \qquad I_L = \frac{30}{3}$$

$I_L = 1$, $\quad I_L = 3A$, $\quad I_L = 10A$.

$$I_Z = I_S - I_L$$

$$I_S = \frac{V_S - V_Z}{R_S}$$

$$= \frac{50-30}{2}$$

$$= \frac{20}{2}$$

$$= 10$$

$I_Z = 10 - 1$

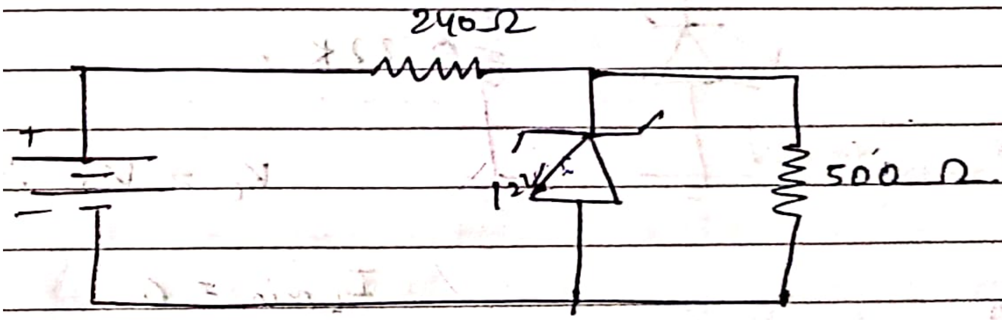
$\boxed{I_Z = 9.}$

$I_Z = 10 - 3$

$\boxed{I_Z = 7}$

$I_Z = 10 - 10$

$\boxed{I_Z = 0}$



Load voltage drop across series resistance current through the diode,

$$V_L = \frac{R_L}{R_S + R_L} \cdot V_S.$$

$V_L = V_Z$ i.e. 12V

$$= \frac{500}{240+500} \times 30$$

$\boxed{V_L = 20.27}$, i.e. $V_L > V_Z$. i.e. it is ON.

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$$I_L = \frac{V_z}{R_L}$$

$$= \frac{12}{500}$$

$$\boxed{I_L = 0.024}$$

$\Rightarrow$ $V_s = \underbrace{I_s R_s}_{V_R} + V_z$ $\qquad I_s =$

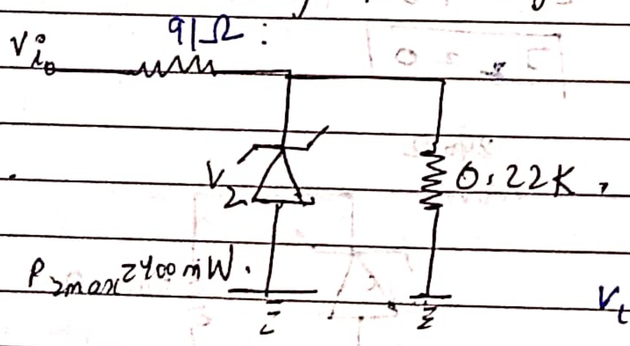
$\qquad I_z =$

$\therefore V_s = V_R + V_z$

$V_R = V_s - V_z$ $\qquad V_R = 18$

$30 -$

Que: For the network shown in fig. Determine the Range of V_i, that will maintain V_L at 8V & not exceed the max rating power of Zener diode



I_z min
max

$V_L = V_z = 8V$

$I_{L\,min} = 0$

$P_{zmax} = V_z I_{zmax}$

$\cancel{P_{zmax}}$

$400 \times 10^{-3} = 8 \times I_{zmax}$

$$I_{zmax} = \frac{400}{8}$$

$$\boxed{I_{zmax} = 50mA}$$

Assume $I_{L\,min} = 0$ $\qquad I_s = I_z + I_L$

$\qquad I_s = 50 + 0$

$\Rightarrow$ $V_{zmax} =$

Que

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$I_L = \frac{8}{91} = 0.087.$

$I_L = \frac{V_z}{R_L}$

$V_z = I_L R_L$

$I_{smax} = I_{zmax} + I_L$
$= 50 + 36.36$
86.36

$V_{smax} = I_{smax} R_{sn} + V_z$

$V_{smax} = 86.36 \times 91 + 8$

$V_{smax} = 15.90\ V$

$I_{smin} = I_{zmin} + I_L$
$= 0 + 36.36$

$\boxed{I_{smin} = 36.36} = 0.03636\ mA$

$V_{smin} = I_{smin} R_s + V_z$
$= 0.03636 \times 91 + 8$
$= 11.3$

Range $\boxed{11.3V < V_i < 15.85V}$

For a Zener voltage Regulator input voltage = 30 V fixed. Calculate the Range of Load Resistance over which the output voltage remains constt.

$V_z = 5V$, $I_{zmin} = 2mA$, $I_{zmax} = 20mA$,
$R_s = 1K\Omega$

$R_L = ?$ $\frac{V_z}{I_{Lmin}}$

$V_s = 30\ V.$

$I_s = I_{zmax} + I_{Lmin}$

$= 20 + I_{Lmin}$

$I_s = 20 + I_{Lmin}$

$25 = 20 + I_{Lmin}$

$25 - 20 = I_{Lmin}$

$I_s = \frac{V_s - V_z}{R_s}$

$= \frac{30 - 5}{1000}$

$I_s = 0.025$

$= 25\ mA.$

$$R_L = \frac{V_2}{I_{Lmin}}$$

$$R_L = \frac{5}{5}$$

$$R_L = 1\,K\Omega$$

$I_S = I_{Zmin} = I_{Lmax}$

$25 - 2 = I_{Lmax}$

$\boxed{I_{Lmax} = 23\ mA}$

$$R_{Lmin} = \frac{V_2}{I_{Lmax}}$$

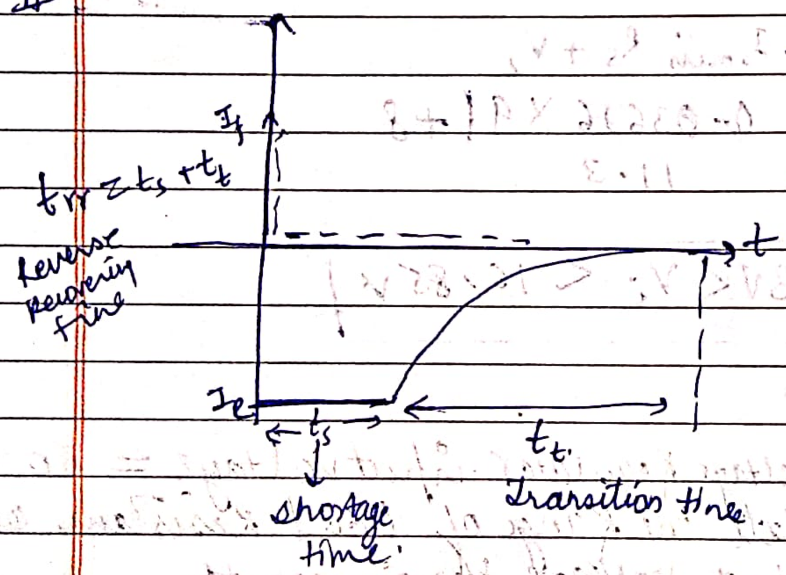
$$= \frac{5}{23}$$

$= 0.217$

$= 217\,\Omega$

Schottky Diode (application) -

#

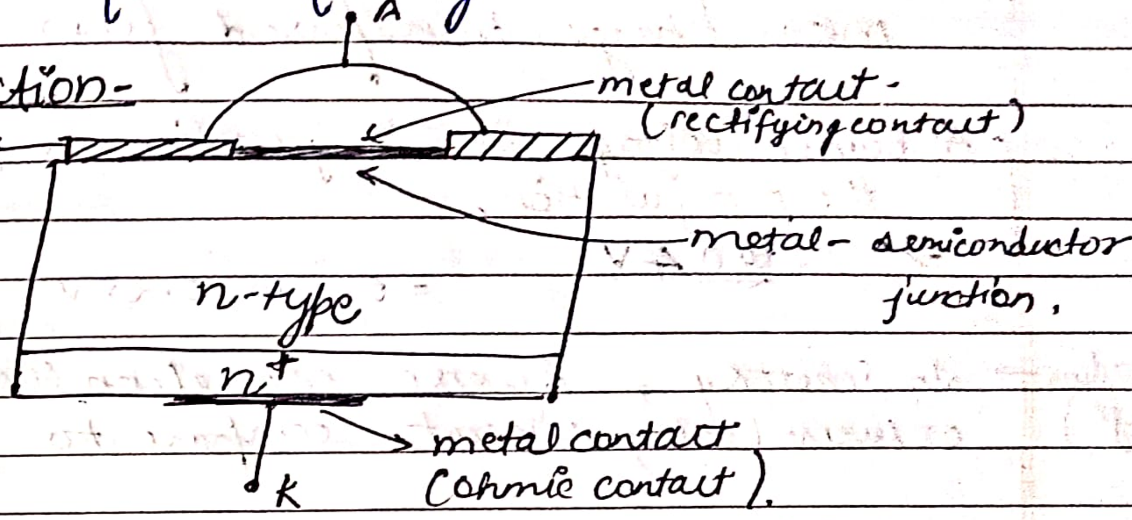


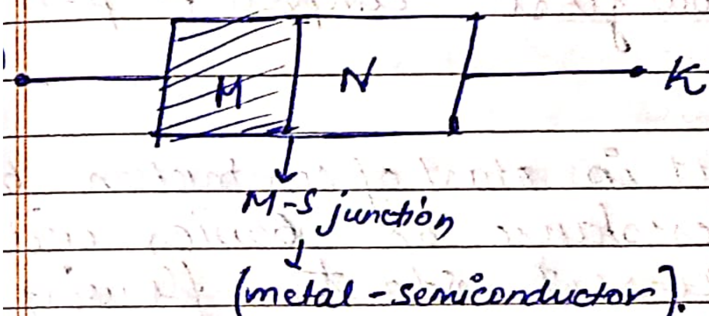
→ This graph showing some defect so, for improving it, we will use Schottky diode.

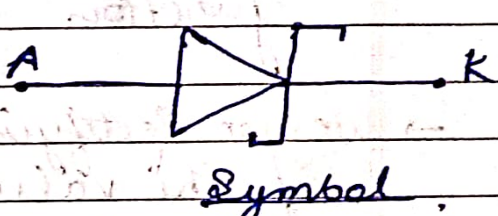
Schottky Diode -

In this, Reverse Recovery time is less.

Construction-







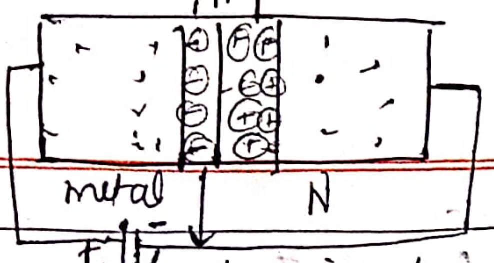
→ Rectifying contact - VI curve non-linear
at one instt. Resistance decrease, & I rapidly increase.
Barrier height is more.
→ Resistance - more.

→ Ohmic contact
VI-curve is linear.
Barrier heigh is less
so Resistance is less.

★ This is also known as Hot Carrier Diode.

que polarity device.

harge n type to metal side due to the potential energy of
s move from charge carriers at n-side is more.
compare to the side of metal.
re the n-side become +ve & metal side become -ve.



→ Forward biasing

depletion layer become less.

Here barrier at metal side is less because the more charge transferred from N-side to it

A barrier voltage in this junction is very less than the p-n junction.
→ 0 to 0.4 V,

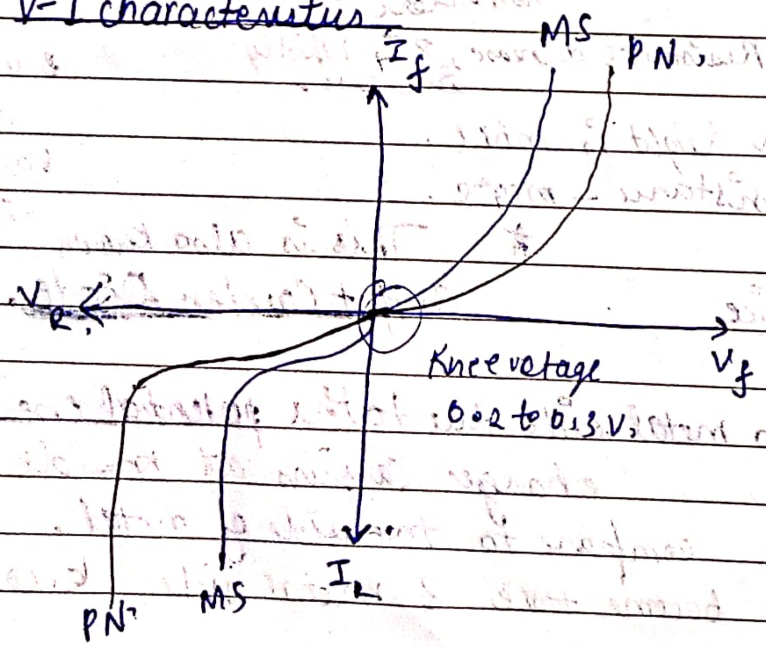
= 0.2 to 0.25 V,

(Disadvantage) → In Schottky, Reverse saturation current is more or reverse leakage current compare to p-n junction

→ In schottky current flow first compare to p-n junction

→ We use Rectifying contact is start of construction because if the value of Resistance of barrier will be less then the current starts flowing at the same instant?

V-I characteristics



Advantages of Schottky diode -

i) Low junction Capacitance. (storage time is less in it)
↳ Depletion layer charge storing.

-) fast Reverse Recovery time.
High Current Density
Low forward Voltage, (or Turn on Voltage)
High Efficiency
Operate at high frequencies.
-) Having less unwanted noise.

Application

Used in Radio-frequencies.
Used in power - supplies.
Used in logic gate circuits.

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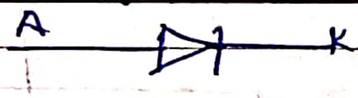
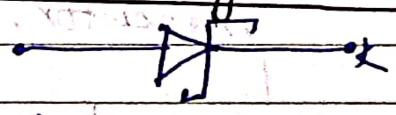
Comparison b/w P.N junction diode & Schottky diode

Parameters	P N junction diode	Schottky diode
Circuit Symbol		
Junction	junction formed b/w p & n type S.C.	Jxn forms b/w metal & N-type S.C.
Conduction	In this the conduction takes place due to minority & majority charge carriers	In this, conduction takes place due to majority carriers only.
Forward Vol drop	0.7V for Si, 0.3 for Ge.	0 to 0.4 V or 0.2 to 0.3 V.
Reverse st. current	Small or low	High or large.

6.	Switching speed.	Low	Very high
7.	Utility	suitable for low frequency operation	suitable for high frequency operation
8.	Applications	Rectifiers.	Oscillators, RF application

Transistors –

- Transistor
  - BJT (Bipolar Junction Transistor.)
    - NPN
    - PNP.
  - FET (Field Effect Transistor.)
    - JFET (Junction Field Effect Transistor.)
      - n channel.
      - P channel
    - MOSFET. (Metal oxide semiconductor Field Effect tran...)
      - P-channel depletion type (DE-MOSFET)
        - n channel
        - channel.
      - Enhancement type (E-MO...)
        - N-channel
        - P-chann...

BJT -

Current controlled Device. - → output current is controlled by input current then it is known as CCD

It is called as Bipolar because in this current flows ~~through~~ due to minority & majority carriers.

~~Read~~ (junction)

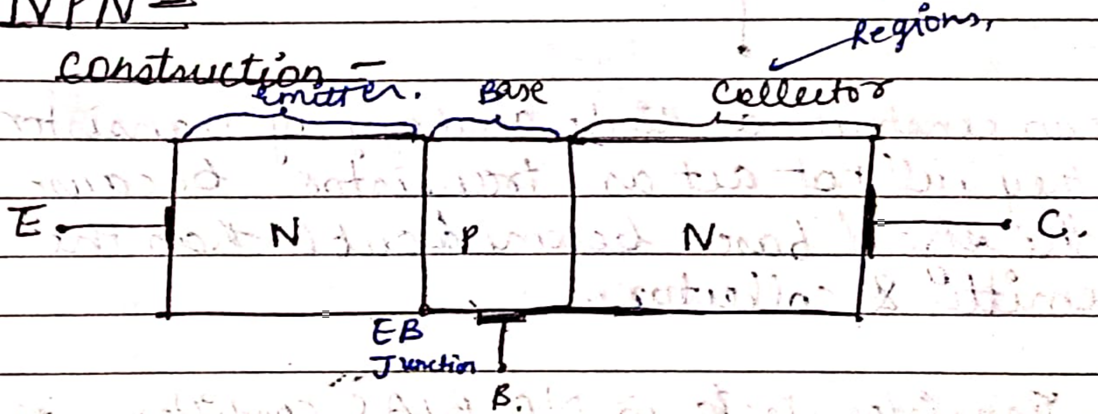
Transfer + Resistor here gives the transistor.

→ low to high region resistance ~~that~~ transfers & vice versa.

Types - ① NPN ② PNP.

NPN -

Construction -



Emitter

- electrons are emit by it.
→ heavily doped. (due to the emission)
→ Size is moderate.

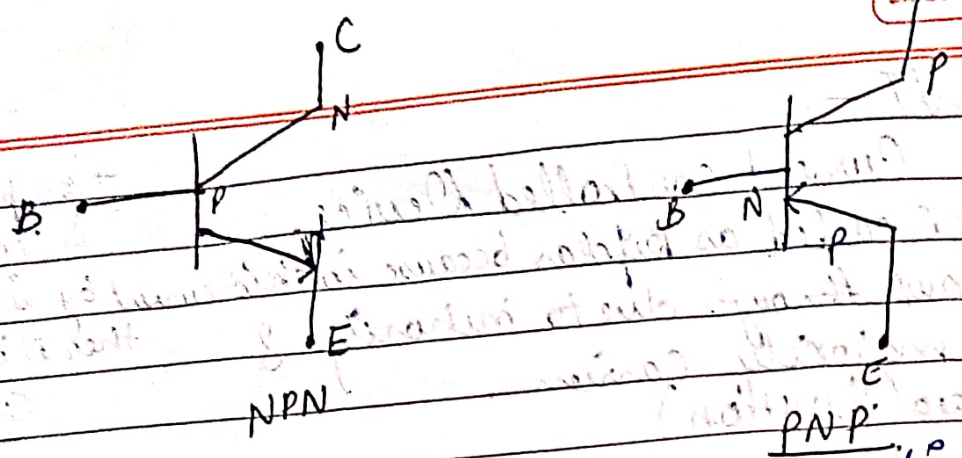
Base

→ lightly doped
→ size very small.
(These two factors set so as the maximum charge carriers can pass through base.)

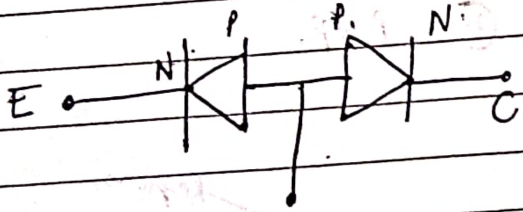
Collector

→ larger in size (it is bcz it collect the carriers which emitt-d by the emitter & pass through the base)
→ Moderate in Doping

→ In this Heat is more bcz it collects.

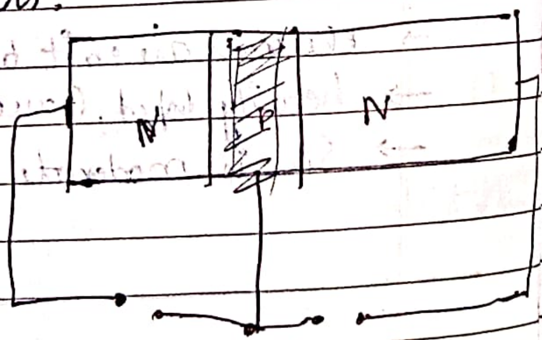


→ Arrow head shows the direction of conventional current as current always flow from p to N.



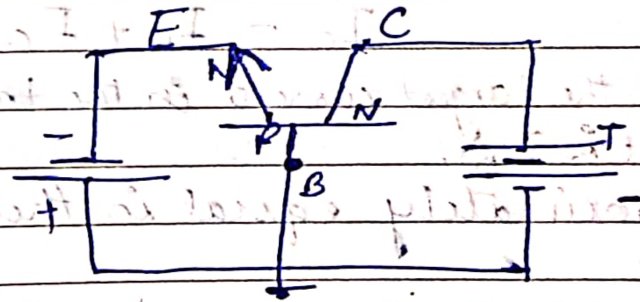
We can construct a diode analogy of transistor but they will not act as transistor because in it the size of base become double than the size of emitter & collector.

→ When Transistor is ~~ta~~ in NO BIAS condition, then Depletion layer formation happens.

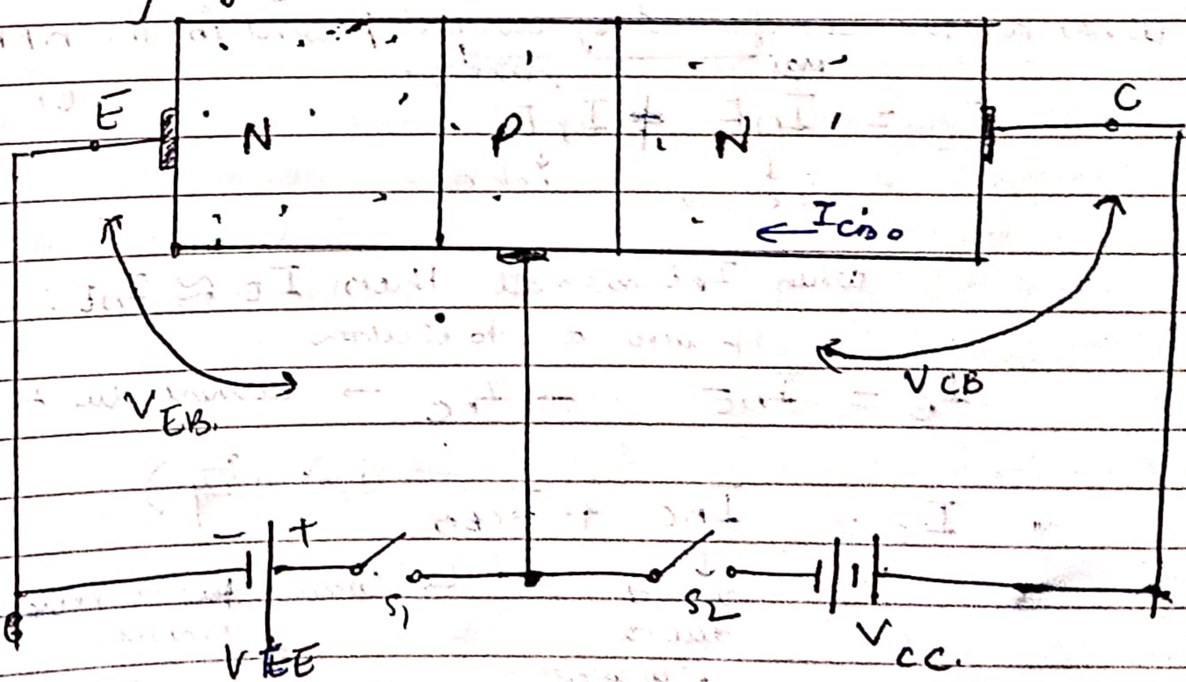


Modes of Transistor –

S.	EB Junction (J_E)	CB Junction (J_C)	Modes of transistor	Application
	Forward Bias	Reverse Bias	Active	Amplifier.
	Forward Bias	Forward Bias	Saturation	closed switch
	Reverse Bias	Reverse Bias	Cut off.	open switch
	Reverse Bias	Forward Bias	Inverted.	



Working of NPN transistor –



	S_1	S_2	
Case I –	open	open	– unbiased.

II - closed open - pn junction forward bias condition.

III - open closed - I_{CBO} (pn junction Reverse biasing current flow due to minority charge carrier).

* I_{CBO} → Current b/w collector & base
I_{CO} → When third terminal i.e. emitter is open

IV closed closed - I_{CO}.

$$I_E = I_B + I_C$$

I_E is the largest current in the transistor & smallest current is I_B.

→ I_E & I_C are approximately equal in their values.

$$I_E \approx I_C$$

↳ bcz I_B is very very small current so, we can neglect it.

→ What are the component of current present in the npn transistor or pnp transistor

npn

$$I_E = \underset{\substack{\downarrow \\ e^- \text{ current}}}{\overset{\text{maj}}{I_{nE}}} + \underset{\substack{\downarrow \\ \text{hole curr}}}{\overset{\text{minority}}{I_{pE}}}$$

when I_{pE} is small then $I_E \approx I_{nE}$.

$$I_B = \underset{\text{current due to electron}}{I_{nE}} - I_{nC}$$ → current due to e's in collector.

$$I_C = \underset{\substack{\downarrow \\ \text{current due to } e^- \text{ in collector}}}{I_{nC}} + I_{CBO}$$ → (minority)

↳ Current due to reverse saturation current.

Emmitter Efficiency -

It is defined as the ratio of current of injected carriers at j_E divided to the ~~ratio~~ total emitter current.

$$\text{Efficiency} = \frac{I_{nE}}{I_{nE} + I_{pE}} = \frac{I_{nE}}{I_E} = 0.987.$$

Base transport factor -

It is defined as the ratio of injected carrier current reaching j_C (collector junction) to the injected carrier current at j_E (emitter base junction).

$$\text{Efficiency} = \frac{I_{nC}}{I_{nE}}$$

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Revision Ques

A section of Silicon device is kept at Room temp. This Si is doped with $10^{15}/cm^3$ of acceptor atoms. A stream of minority carriers is injected at $x=0$ & thus distribution in the sample is assumed to be linear, decreasing from a value of $10^{11}/cm^3$ at $x=0$ to the equilibrium value at $x = 10\mu m$. Determine the diffusion current density of electrons.

given $\mu_e = 1331\ cm^2/Vs$ & $n_0 = 1 \times 10^5/cm^3$

$$J_n = e D_n \frac{dn(x)}{dx}$$

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

$\mu_e = 1331\ cm^2/Vs$

$$\frac{D_n}{\mu_e} = \frac{kT}{q} \quad ; \quad \frac{D_n}{1331} = 0.026$$

$$\boxed{D_n = 34.606}$$

$$J_n = 1.6\times10^{-19}\times 34.606\,\frac{dn(x)}{dx}$$

$$\frac{dn(x)}{dx} = \cancel{\quad}\ \frac{n_2-n_1}{x_2-x_1}$$

$$= \frac{10^{11}-10^{5}}{0-10\times10^{-6}}$$

$$= -9.99\times10^{15}$$

$$J_n = 1.6\times10^{-19}\times 34.606\times -9.99\times10^{15}$$

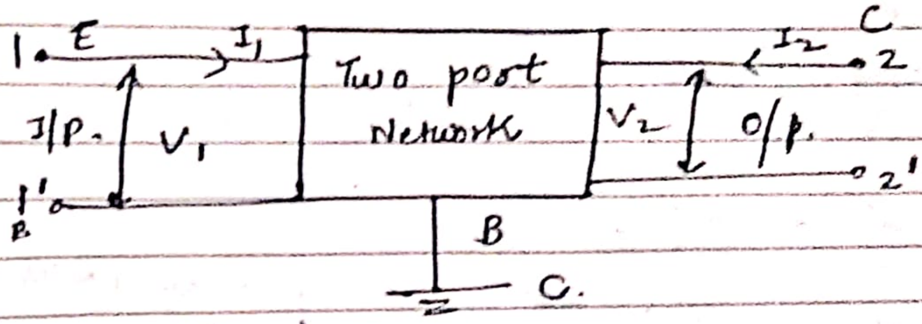
$$J_n = -0.0553$$

Comm

#

#

Transistor as a two port Network =



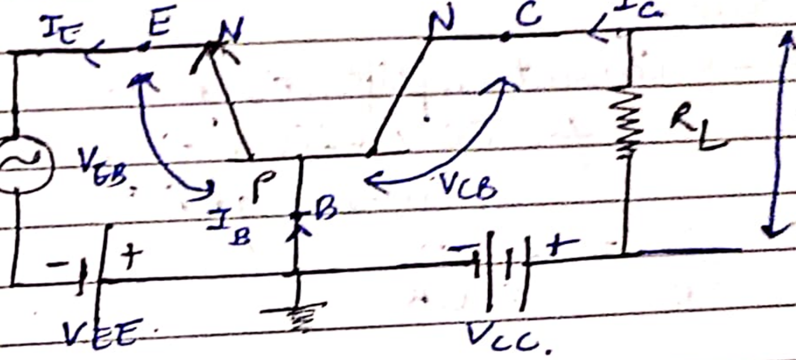
Transistor Configuration -

1. CB configuration.
2. CE "
3. CC "

I/P

I/P for base O/P from collector.

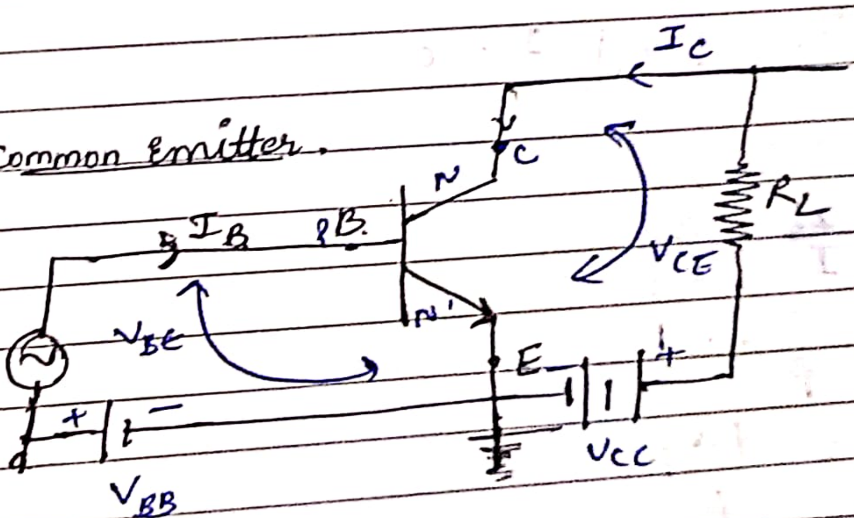
on Base



I/p → Emitter (I_E) current

O/p → Collector (I_C) current.

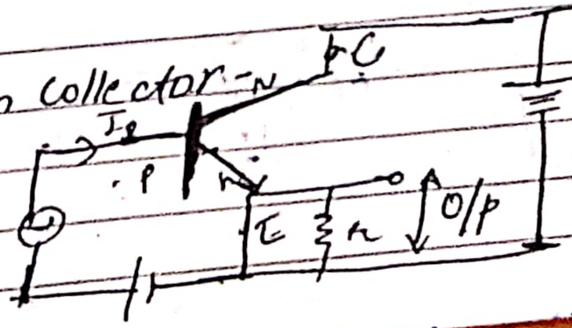
Common Emitter.



(I_B) Base - I/p current

(I_C) Collector - O/p current

Common Collector -



I/p current → I_B → Base

O/p current → I_E - Emitter

$V_{CE} = V_{CB} + V_{BE} = V_C - V_E$.

$= V_C - \cancel{V_B} + \cancel{V_B} - V_E$

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CB Configuration -

Current Amplification factor
Current gain α_{dc}

$\rightarrow \alpha = \frac{O/P \text{ current}}{I/P \text{ current}}$,

remaining emitted charge carriers

$\alpha_{dc} = \frac{I_C}{I_E} \Rightarrow \boxed{I_C = \alpha I_E + I_{CBO}}$ $\alpha = 0.986$

due to Reverse saturation current,

$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E}$

CE configuration -

$\beta \rightarrow$ Current amplification factor for CE configuration, or Current gain

$\beta \rightarrow$ almost 100

$\beta = \frac{I_C}{I_B} = \frac{2mA}{20\mu A}$

$I_C = \beta I_B + I_{CEO}$.

Relation b/w α & β

$\frac{I_E}{I_C} = \frac{I_B}{I_C} + \frac{I_C}{I_C}$

$\frac{1}{\alpha} = \frac{1}{\beta} + 1$

$\frac{1}{\alpha} = \frac{1+\beta}{\beta}$

$\boxed{\alpha = \frac{\beta}{1+\beta}}$ or $\boxed{\beta = \frac{\alpha}{1-\alpha}}$

Scanned with CamScanner

Reverse saturation current is more in CE than CB

Relation b/w I_{CEO} & I_{CBO}.

$$I_C = \alpha I_E + I_{CBO}$$
$$= \alpha (I_B + I_C) + I_{CBO}$$
$$I_C = \alpha I_B + \alpha I_C + I_{CBO}$$
$$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$
$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$
$$\boxed{I_C = \beta I_B + (1+\beta) I_{CBO}}$$
$$\boxed{I_{CEO} = (1+\beta) I_{CBO}}$$

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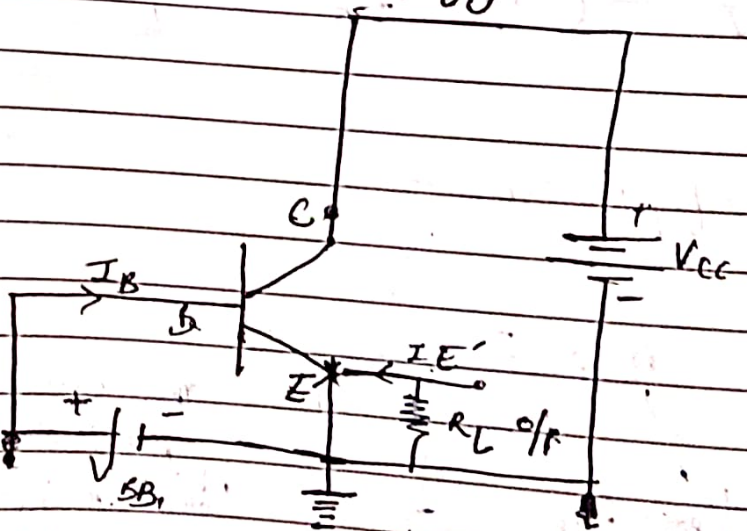
Common Collector Configuration.



current amplification factor or current gain

$$\gamma = \frac{I_E}{I_B}$$

or $I_E = \gamma I_B + I_{CEO}$

$= (1+\beta) I_B + I_{CEO}$

Relation b/w β & γ

$$I_C = \alpha I_E + I_{CBO}$$

divide by I_B

$$\frac{I_E}{I_B} = \frac{I_B}{I_B} + \frac{I_C}{I_B}$$

$$\boxed{\gamma = 1+\beta} \qquad \boxed{\gamma = \frac{1}{1-\alpha}}$$

$$I_B = I_E - I_C$$

$$\gamma = \frac{I_E}{I_B}$$

$$= \frac{I_E/I_C}{\frac{I_E}{I_E} - \frac{I_C}{I_E}} = \frac{1}{1-\alpha}$$

$$I_E = I_B + I_C$$

$$I_E = I_B + \alpha I_E + I_{CBO}$$

$$I_E(1-\alpha) = I_B + I_{CBO}$$

$$I_E = \frac{1}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO}$$

$$I_E = \gamma I_B + (1+\beta) I_{CBO}$$

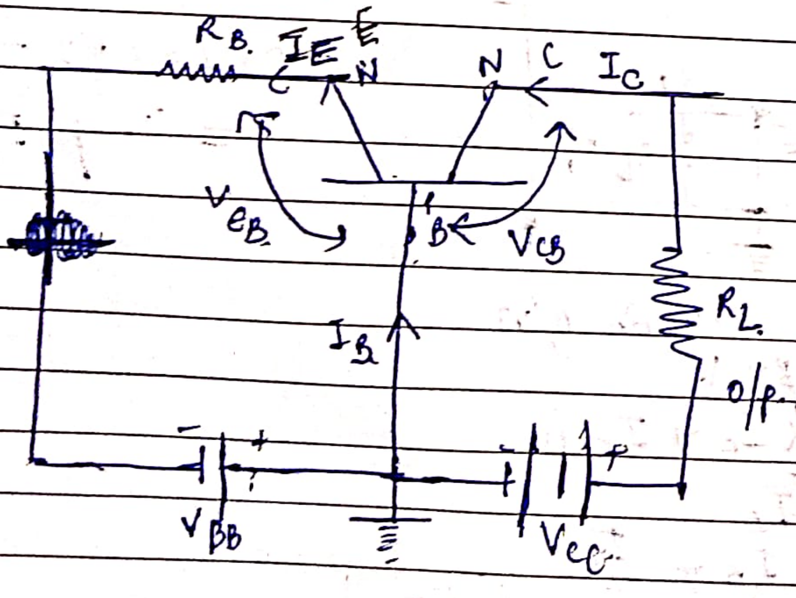
$$I_E = \gamma I_B + \gamma I_{CBO}$$

or

$$I_E = (1+\beta) I_B + \gamma I_{CBO}$$

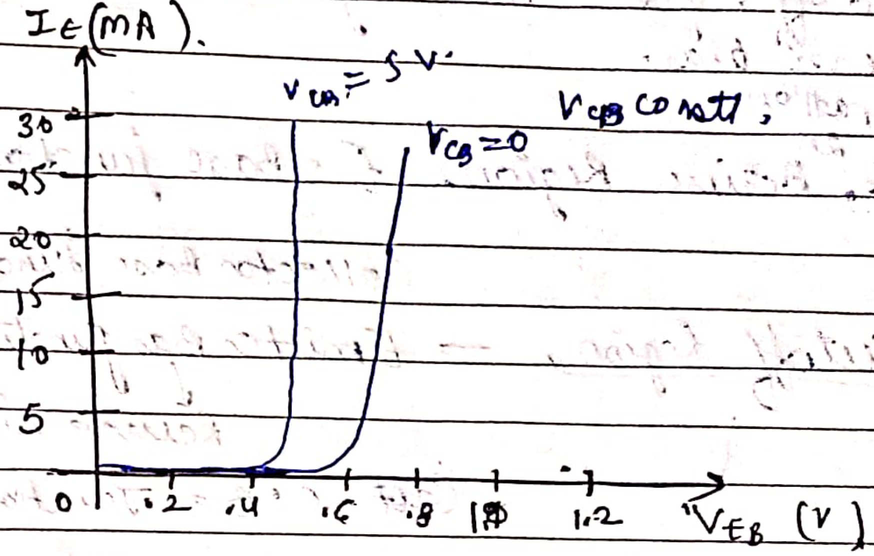
Common Base Configuration -

VI- characteristics -



The curve which is plotted between input volt V_{EB} Vs I_E keeping V_{CB} constt. (output voltage)

I/P characteristics -



In collector base jxⁿ; I_E will increase & hence the value of current shifted towards y-axis.

$I_E \uparrow = I_{nE} + I_{pE}$
I_{mag} ↳ min.

Base Width Modulation → In this the base width indirectly proportional to Votage ⇒ Vcc.

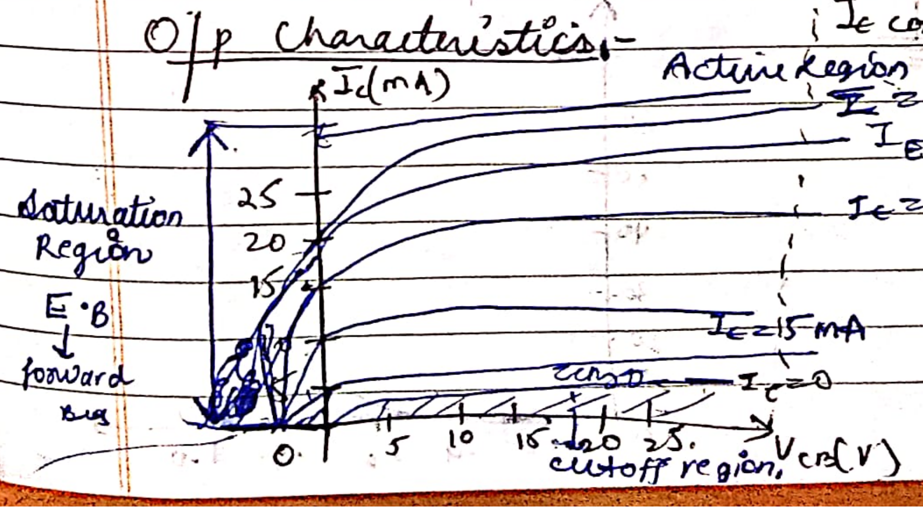
If Base width less so, the (current) e^-'s reach at collector side early.

→ Base width increment & decrement depend upon Reverse voltage.

Punch throug Voltage - The Reverse voltage at which the effective base width touches the emitter & hence the width becomes zero.

O/p Characteristics -

; I_E constt



The output charac curve which is plotted b/w V_{CB} & I_C
V_{CB} → output voltage
I_C → output current

I_E = constt.

* for cut-off region both the junction should be reverse bias.

Region of operation -

In this, Active Region, E. Base junction → Forward Bias.

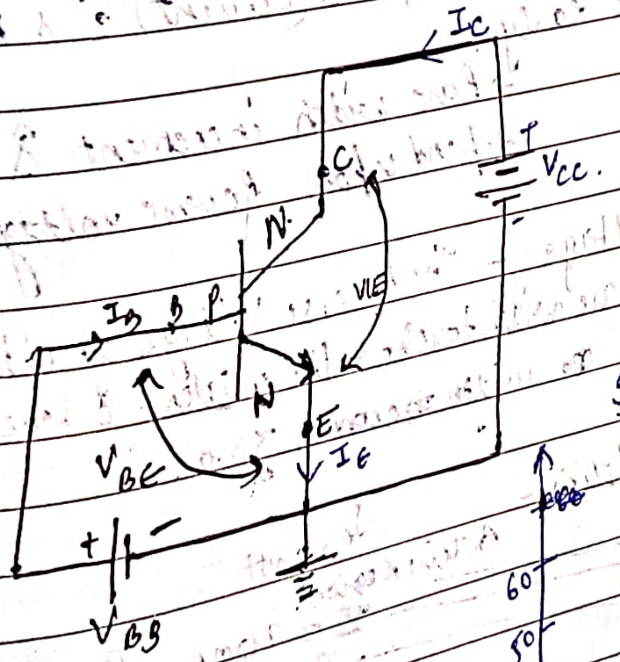
Collector Base Junction → Reverse Bias

In Cutoff Region, → Emitter Base junction ↓ Reverse Bias

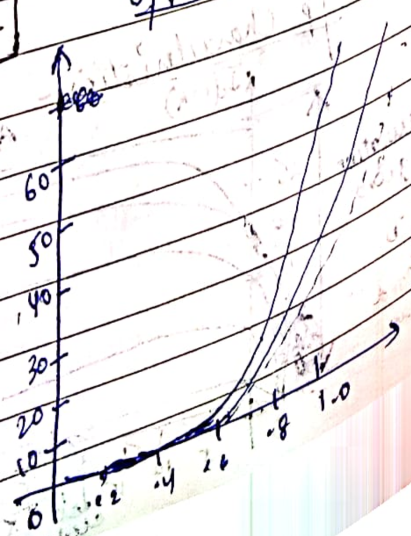
C.B. Junction → R.B.

In Saturation Region → E.B. → Forward Bias
→ C.B → Forward Bias.

Common-Emitter Configuration -



I/p characteristics.



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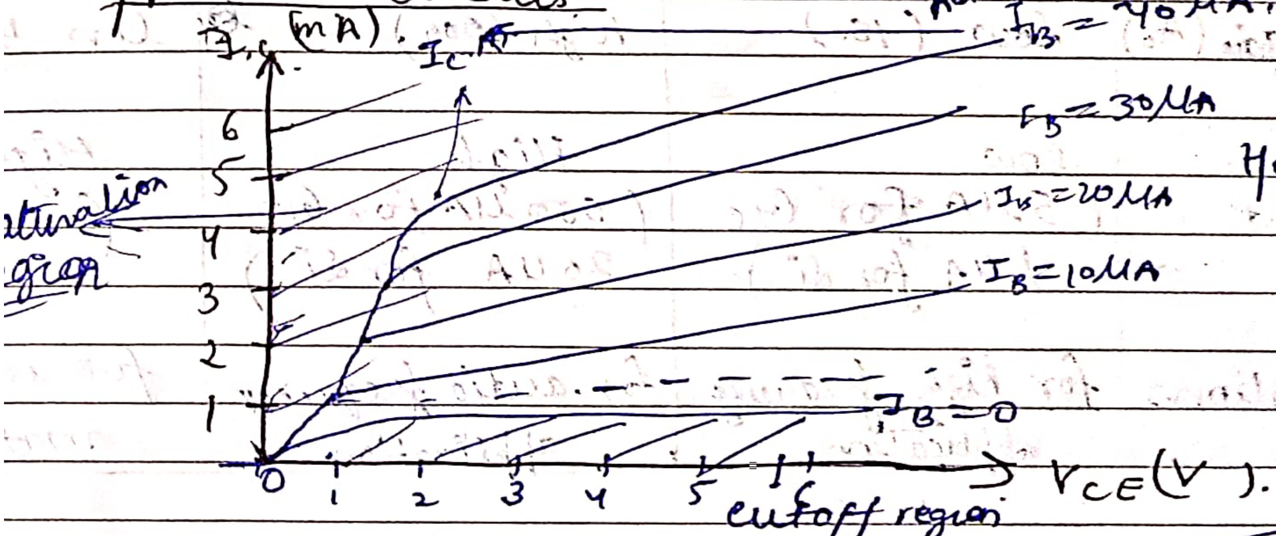
This graph is plotted between I_B Vs V_{BE} by keeping V_{CE} constt.

I_B ↓ input current. V_{BE} ↓ input voltage

I_B current here, is Recombination current so, as there recombination decreasing then I_B is also decreasing thats why here I_B vs V_{BE} shifted towards y-graph.

24/11/22

O/p characteristics -



Here I_B graph is greater than the CB graph bcz $(1+\beta) I_B$ factor.

Active Region → EB — Forward bias.
C-B → Reverse Bias.

Cutoff Region - EB — Reverse Bias
C-B — Reverse Bias

Saturation region - EB — Forward bias
C-B — Forward bias

→ why curve is not flat.
$V_{CE}\uparrow = V_{BE}\uparrow$?
$I_C = \beta I_B$.
$\beta = \frac{\alpha}{1-\alpha}$
→ smaller change in α, large change in β..

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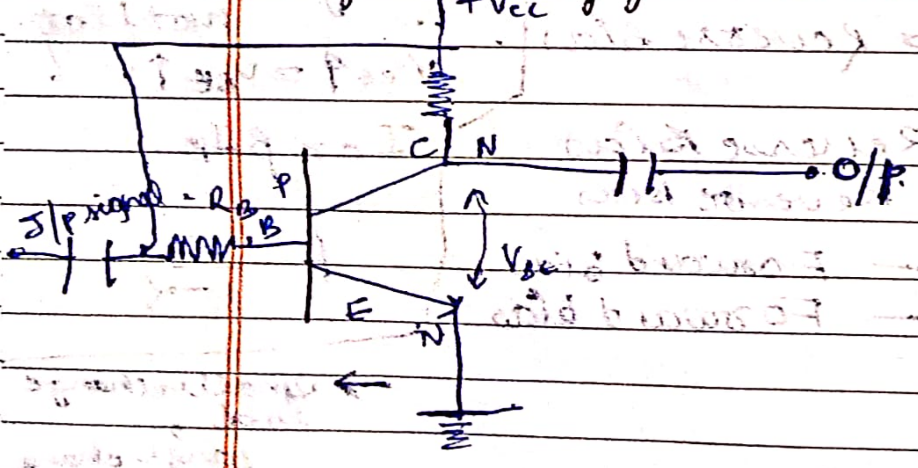
Parameters	C.B configuration	C.E configuration
I/P Resistance (R_s)	Very low ($20\ \Omega$)	low ($1K\ \Omega$)
O/p resistance (R_0)	Very high (100K)	high (10K)
Current gain (A_i)	Less than unity	High (100)
Voltage gain (A_v)	Low (150)	High (500)
Leakage current	low (5 uA for Ge, 1 uA for Si)	High (500 uA for Ge, 20 uA for Si)
Applications	for high frequency application.	for audio frequency application.

Only in CE configuration the output get superimp... (or give amplifi...)

only amplifi...



V-I characteristics of C... not form bcz. it no... amplifier.

→ Eber's moll model, BJT & configuration. mostly ques on BJT.
Small signal model of BC. MOSFET ↳ working of D-MOSFET or E-MOSFET

CC configuration

Very large (100K)

low (20-25 Ω)

High

less than unity

High.

for impedance matching.

base ... output of 180° shift).

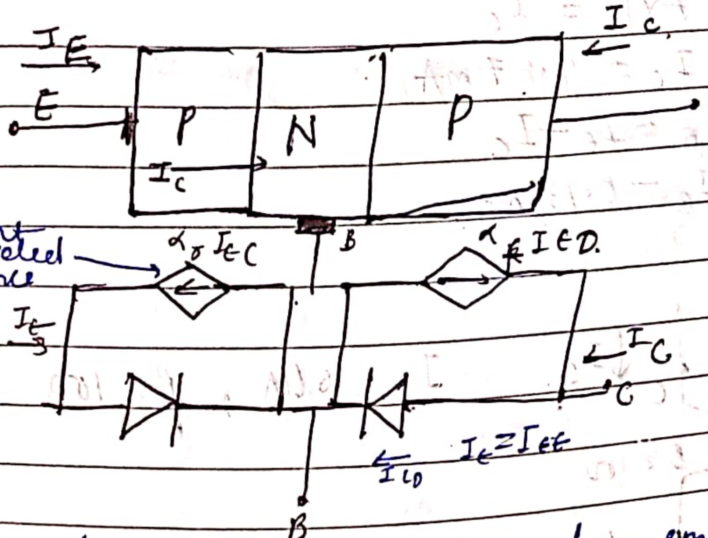
amplitude ... increases no change in frequency.

collector configuration ... used as

If the $V_{BE} < 0.7$ the p-n jx^n or transistor will be in off condition. i.e. act as open switch

If the $V_{BE} > 0.7$ then p-n jx^n or transistor will be in ON condition. i.e. act as closed switch.

EBER'S MOLL MODEL —



- α_F forward transmission from emitter to collector.
- α_r reverse transmission from collector to emitter.

$$I_E = I_{ED} - \alpha_R I_{CD}$$

$$I_C = I_{CD} - \alpha_F I_{ED}$$

I_{ES} → Reverse saturation current at emitter junction.

$$I_E = I_{ES}\left[e^{V_{EB}/V_T} - 1\right] - \alpha_R I_{CS}\left[e^{V_{CB}/V_T} - 1\right].$$

$$I_C = I_{CS}\left[e^{V_{CB}/V_T} - 1\right] - \alpha_F I_{ES}\left[e^{V_{EB}/V_T} - 1\right]$$

$$I_B = I_E - I_C.$$

Ques. Find the value of Base current, if the common base dc current gain of a transistor is 0.9878 emitter current is 10 mA.

$\alpha = 0.987$

$\alpha = \frac{I_C}{I_E}$

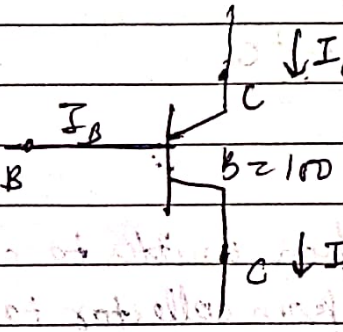
$0.987 \times 10 = I_C$

$I_C = 9.87\,mA$

$I_B = I_E - I_C$

$I_B = 0.13\,mA$

Ques.



$I_E = 10\,\mu A$, $\beta = 100$

$\alpha = \frac{\beta}{1+\beta} = 0.99$

$\alpha = \frac{I_C}{I_E} \Rightarrow 0.99 \times 10\,\mu A$

$I_C = 9.900\,\mu A$

$I_B = I_E - I_C = 0.099\,\mu A$

A certain transistor has $\alpha = 0.98$ & $I_{CO} = 5\,\mu A$ & $I_B = 100\,\mu A$. Find out the value of collector current & emitter current.

$I_C = ?$, $I_C = ?$

given $I_B = 100\,\mu A$, $I_{CO} = 5\,\mu A$, $\alpha = 0.98$

$$\alpha = \frac{I_C}{I_E}$$

$$\cancel{I_C = \beta I_B + I_{CEO}}$$

$$\cancel{I_C = \beta I_B + I_{CO}}$$

$$\cancel{I_{CO} = I_{CBO}}$$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98}$$

$$\boxed{\beta = 49}$$

$$\cancel{I_C = 49(100) + 5}$$

$$\cancel{I_C = 4905\,\mu A}$$

$$\boxed{\cancel{I_C = 4.9 \times 10^{-9}\,A}}$$

$$\boxed{I_E = I_B + I_C}$$

$$\cancel{\alpha = \frac{I_C}{I_E}} = 4.9 \times 10^{-9}$$

$$I_C = \beta I_B + (1+\beta) I_{CO}$$

$$= 49 \times 100 + (1+49) \times 5$$

$$\boxed{I_C = 5150\,\mu A}$$

$$\alpha = \frac{I_C}{I_E} \Rightarrow 0.98 = \frac{5150}{I_E}$$

$$I_E = \frac{5150}{0.98}$$

$$\boxed{I_E = 5255.10}$$

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As temp increases, then the I_{CBO} increases, & Power dissipation happens then, the ckt breaks due to excess heat.
Thermal Runaway – (In Power transistor it used)
↳ (Self destruction)

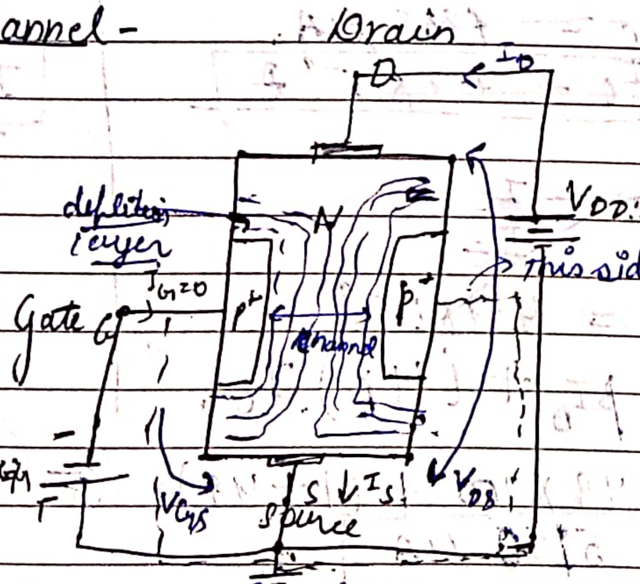
Unit-5

FET – Voltage Controlled device ('Unipolar')
(Input resistance is high, output resistance is low)
↓ used in transistor for amplifying.

In FET –
Input resistance is very high (∞) & output resistance is low)

FET Terminals → Gate, Drain, Source

N-channel –



I_D current is there in it.

This side gate is internally connected but we show from gate left side only

Significance of Source & Drain –
Source → through which charge enters into it.
Drain → through which charge carriers exit.

Gate is the terminal b/w Source & Drain which controls the flow of charge carriers. (current b/w them) b/w both source & drain.

Gate current i.e. I_G always equal to zero.

Working -

II. $V_{GS} = 0$

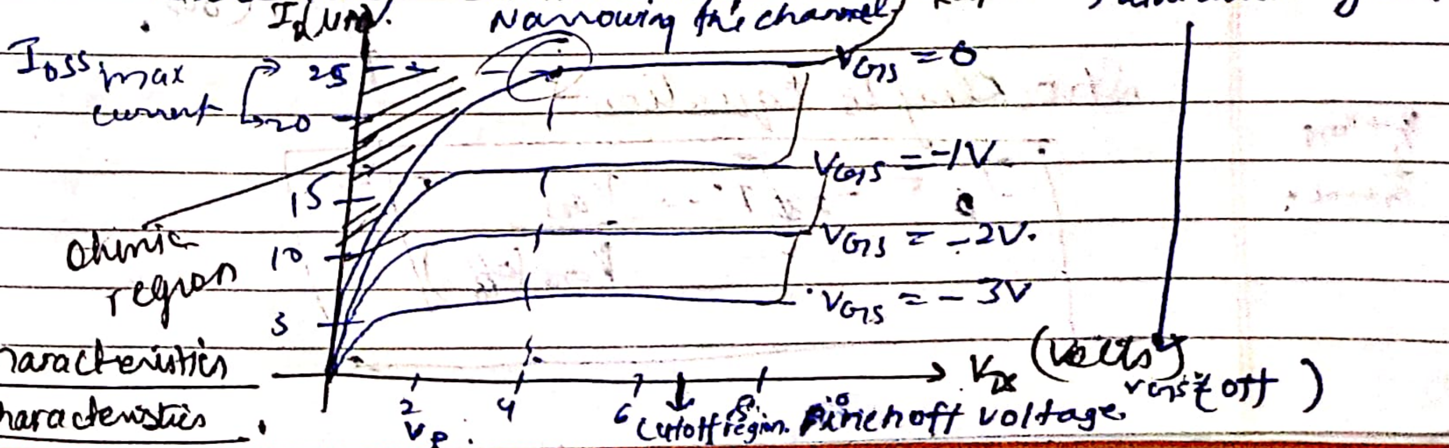
(I)
→ When no biasing is there, then depletion layer will form & the depletion layer forms N-side more because here p^+ i.e. it is heavily doped.

When V_{DD} is inc. the e^- repelling towards Drain & at same time N- region is reverse biased so, the depletion layer width increasing too.

(Pinch off voltage).

At one time due to increase in voltage continuously with depletion layer increasing and with some point the depletion layer of both sides touch each other & current become constt.
↓
Pinch off phenomenon

When V_{GG} continuously inc. by keeping V_{DD} zero then at the time depletion region increases then that known as cut off Voltage. & in this case I becomes zero or decreasing continuously



Characteristics

Characteristics

Pinchoff Voltage — The value of V_{DS} (Drain to source) after which the current becomes constt. is called as Pinchoff Voltage.

V_{GS} Off — The value of gate to source voltage, after which the current becomes zero. is called as V_{GS} off.

Controlling current.

$V_{GS} = 0 \therefore = I_{D max}$

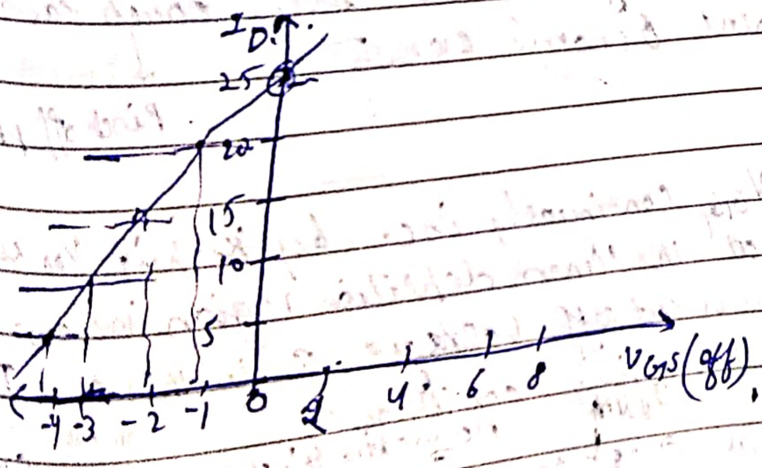
$V_{GS} = off$, current $\to 0$.

$I_{DSS} \to$ max. current $\to$ Drain to source saturation current.

Transfer characteristics

$V_{GS} = V_{GS}(off)$

$\therefore I_D = 0$



$V_P \to V_{GS}$ in books.

Shockley's Equation

$$\boxed{I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_{GS}(off)}\right]^2}$$

$V_{GS} = 0, \; I_D = I_{DSS}$

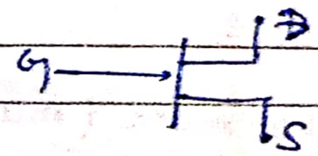
$V_{GS} = V_{GS(off)} \; ; \; I_D = 0$

→ Practically, the penetration of depletion layer is more at drain source due to the internal resistance.

Parameters of JFET → (Voltage controlled device)

Drain Resistance (r_d)
Transconductance (g_m)
Amplification Factor (μ).

JFET



→ $r_d = \left.\dfrac{\Delta V_{DS}}{\Delta I_D}\right|_{V_{GS}\ \text{constt.}}$

→ $g_m = \left.\dfrac{\Delta I_D}{\Delta V_{GS}}\right|_{V_{DS}\ \text{constt.}}$

output V.

→ $\mu = \left.\dfrac{\Delta V_{ds}}{\Delta V_{gs}}\right|_{I_D\ \text{constt.}}$

input voltage

$\mu = \dfrac{\Delta V_{ds}}{\Delta V_{gs}} \times \dfrac{\Delta I_D}{\Delta I_D}$

$$\boxed{\mu = r_d \times g_m}$$

→ $I_D = I_{DSS}\left[1 - \dfrac{V_{GS}}{V_P}\right]^2$

diff. w.r.t. V_{GS}

$\dfrac{dI_D}{dV_{GS}} = I_{DSS}\, 2\left[1 - \dfrac{V_{GS}}{V_P}\right] \times \dfrac{-1}{V_P}$

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$$\cancel{I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2}$$

$$g_m = \frac{-2 I_{DSS}}{V_p}\left[1 - \frac{V_{GS}}{V_p}\right]$$

MOSFET – (Metal Oxide Semiconductor (FET)

① Depletion type MOSFET

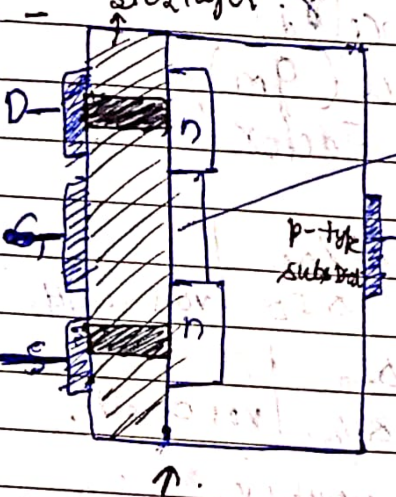
② Enhancement only MOSFET

(a.) DE – MOSFET. Normally 'ON' MOSFET.

channel is there!

Construction – SiO₂ layer

It has more (max). input impedance than other FET's like JFET, BJT.



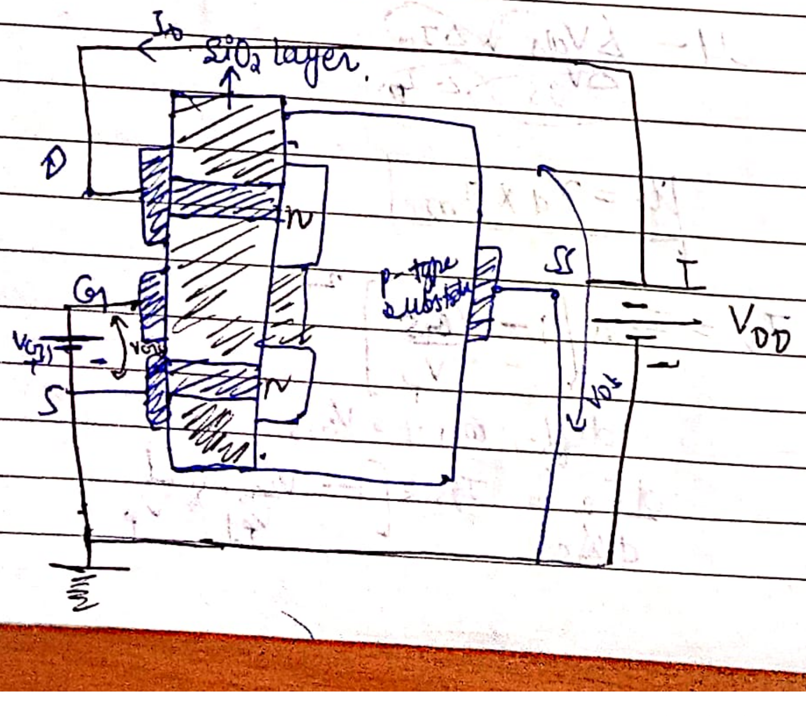
another name of MOSFET

IGFET

Insulated gate FET

N – channel De-MOSFET. (N MOS)

→ (P-channel → P MOS)



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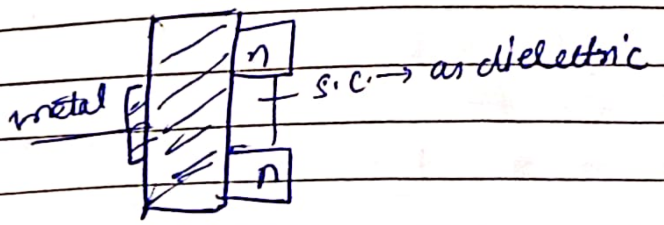
this the depletion layer towards drain formed.

MOS Capacitor -

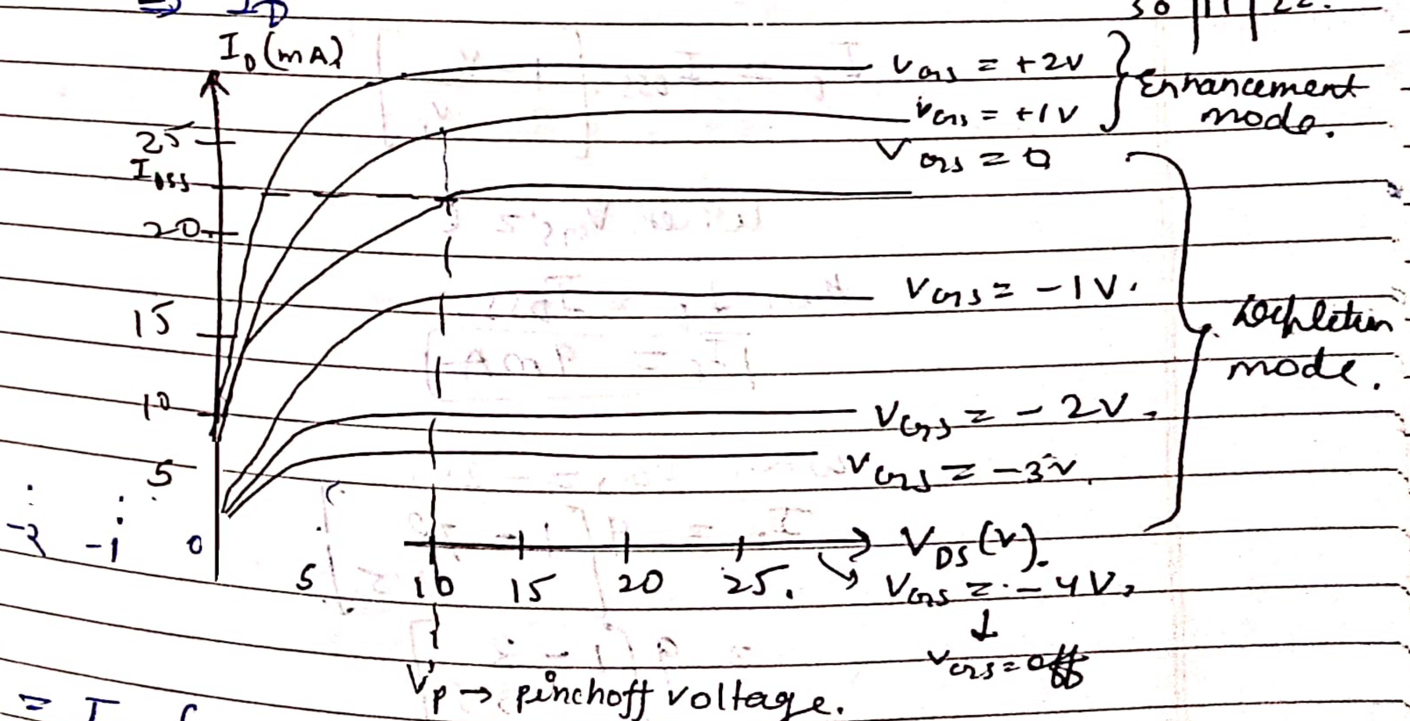


V_{GS} → due to its change, the value of current also inc- or dec. accordingly.

The graph of De-MOSFET is normal as like normal JFET.

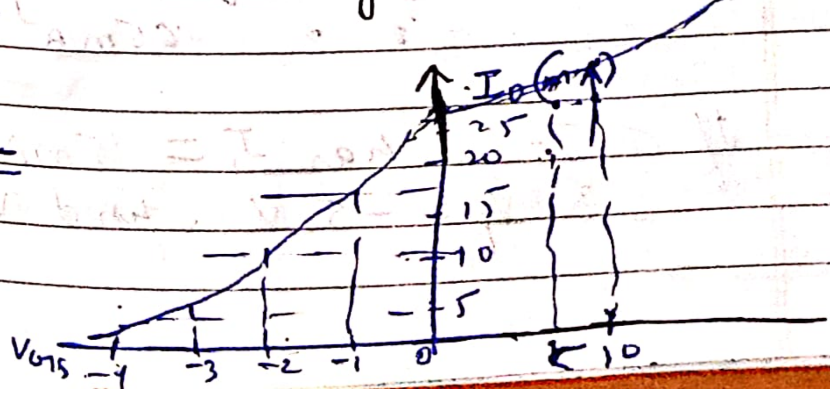
⇒ I_D

30/11/22.



$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_p}\right]^2$$

Transfer characteristics -



$$\frac{15}{25} = 1 - \frac{V_{GS}}{-5}$$

$$\frac{15}{25} - 1 = + \frac{V_{GS}}{+5}$$

$$\left(\frac{15}{25} - 1\right) \times 5 = V_{GS}$$

$$\boxed{V_{GS} = -1.12 \ V}$$

A JFET has $V_p = -4.5$ V, $I_{DSS} =$
Determine the transconductance.

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

$$g_m = -\frac{2 I_{DSS}}{V_p}\left[1 - \frac{V_{GS}}{V_p}\right]$$

$$= -2 \times \frac{10}{-4.5}\left[1 - \frac{V_{GS}}{V_p}\right]$$

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_p}\right]^2$$

$V_{GS} = -2.25$ V.

$g_m =$

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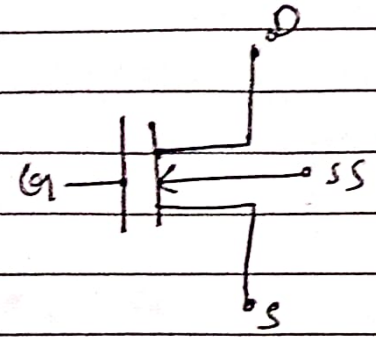
Que. Explain the working & VI characteristics of Enhancement MOSFET

Ans. ~~Of~~ Only Enhancement mode explained & VI charac. of it shown.



Que. Given for a FET, $I_{DSS} = 9mA$; $V_p = -3.5V$
Determine I_D when $V_{GS} = 0$
$V_{GS} = -2V$.

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_p}\right]^2$$

when $V_{GS} = 0$

then $I_D = I_{DSS}$,

$$\boxed{I_D = 9mA}$$

when $V_{GS} = -2V$.

$$I_D = 9\left[1 - \frac{\cancel{-}2}{\cancel{-}3.5}\right]$$

$$= 9\left[\frac{1}{1} - \frac{2}{3.5}\right]$$

$$I_D = 1.65mA$$

Que. If a JFET has $I_D = 15mA$, if $I_{DSS} = 25mA$ & $V_p = -5V$, find $V_{GS} = ?$

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

$$15 = 25\left[1 - \frac{V_{GS}}{-5}\right]^2$$

$$\frac{15}{25} = 1 - \frac{V_{GS}}{-5}$$

$$\frac{15}{25} - 1 = + \frac{V_{GS}}{+5}$$

$$\left(\frac{15}{25} - 1\right)\times 5 = V_{GS}^2$$

$$\boxed{V_{GS} = -1.12\ V}$$

A JFET has $V_p = -4.5\ V$, $I_{DSS} = 10mA$ & $I_{DS} = 2.5mA$. Determine the transconductance.

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

$$g_m = \frac{-2 I_{DSS}}{V_p}\left[1 - \frac{V_{GS}}{V_p}\right]$$

$$= -2 \times \frac{10}{-4.5}\left[1 - \frac{V_{GS}}{V_p}\right]$$

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_p}\right]^2$$

$V_{GS} = -2.25\ V.$

$$g_m = -2\frac{(10)}{-4.5}\left[1 - \frac{-2.25}{-4.5}\right]$$

$$\boxed{g_m = 2.22\ mA/V}$$

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Ques. An n-channel JFET has a pinch off voltage of $-4.5V$ & I_{DSS} of 9mA At what value of V_{GS} will I_{DS} equal to 3mA. & What its g_m at this I_{DS}.

⇒

$$V_p = -4.5V,$$
$$I_{DSS} = 9mA$$

$V_{GS} = ?$ $\quad I_{DS} = 3mA$

$g_m = ?$

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_p}\right]^2$$

$$3 = 9\left[1 - \frac{V_{GS}}{-4.5}\right]^2$$

$$\frac{3}{9} = \left(1 - \frac{V_{GS}}{-4.5}\right)^2$$

$$\sqrt{\frac{3}{9}} = 1 - \frac{V_{GS}}{-4.5}$$

$$\left(\sqrt{\frac{3}{9}} - 1\right) = \frac{-V_{GS}}{-4.5}$$

$$\boxed{V_{GS} = -1.90V}$$

$$g_m = \frac{-2 \times 9}{-4.5}\left[1 - \frac{(-1.90)}{-4.5}\right]$$

$$\boxed{g_m = 2.31\ mA/V}$$

$V_{GS} - V_{DS} > V_t$

$V_{DS} < V_{GS} - V_t$

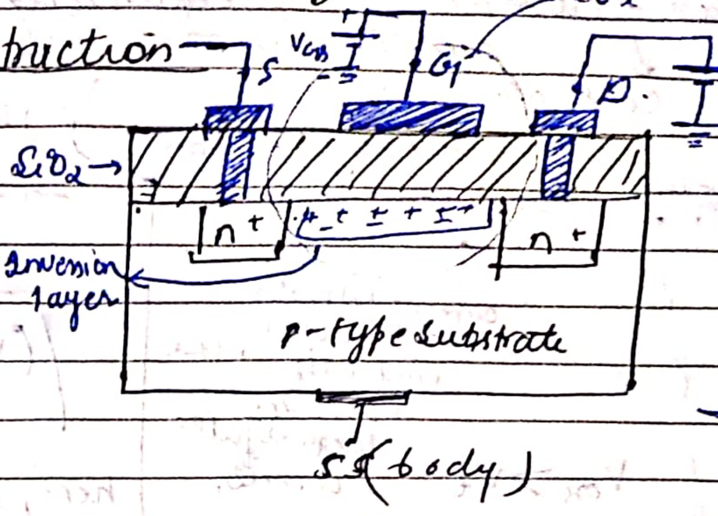
$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$.

Date: 1/12/22.

Enhancement only MOSFET –

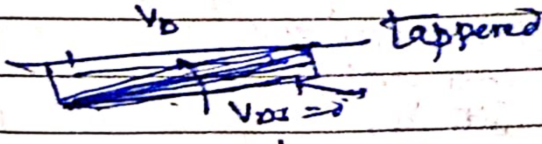
$C_{ox} \rightarrow$ oxide layer capacitive,

Construction –



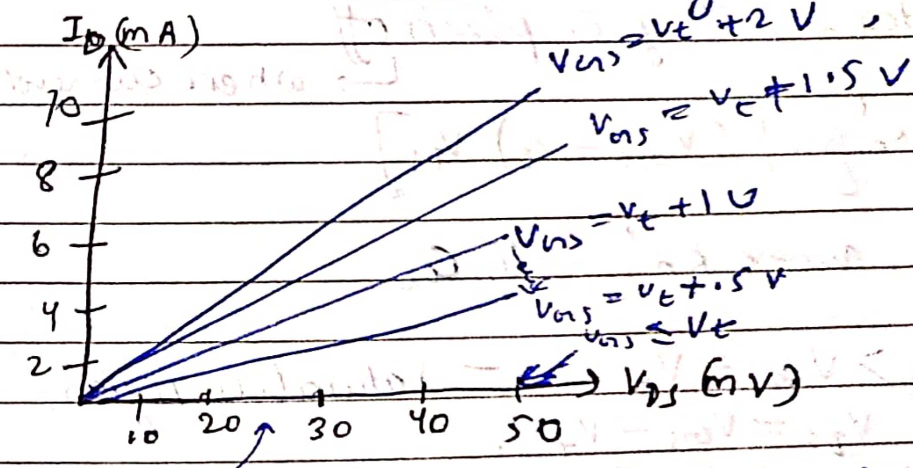
No channel is there in this.

Normally 'off' MOSFET.



At voltage,

The value of V_{GS} at which sufficient no. of electrons accumulate in the channel region to form a conducting channel is called Threshold Voltage, denoted by V_T.



channel resistance here become max.

→ If V_{GS} inc. then channel's ~~Resistance~~ resistance get dec.

& If smaller value of V_{DS} is provided then it doesn't pinchoff.

Now, V_{DS} is provided large here,

$\boxed{V_{GS} - V_{DS} = V_{GD}}$

$V_{GD} > V_t$

$V_{GS} - V_{DS} > V_t$.

$V_{DS} < V_{GS} - V_t$.

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(ii) $V_{DS} < V_{GS} - V_t$ region

$I_D =$

\# $V_{GS} - V_t = V_{OV}$ ↳ Override Voltage.

(i) $V_{GS} < V_t$ → Zero-current → no conducting channel will form. ($I_D = 0$)

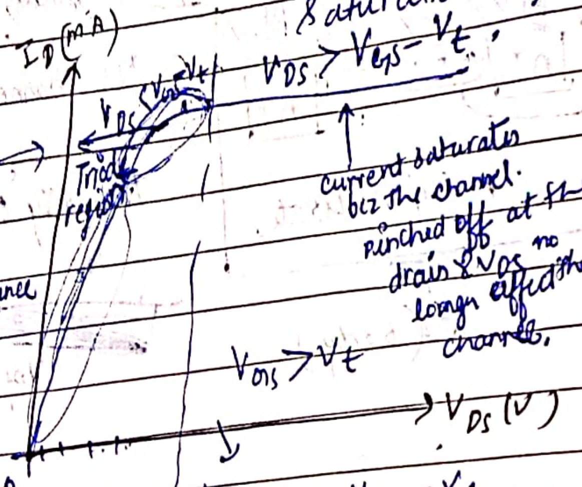
or $V_{GS} - V_t < 0$ ↓ cut-off condition.

Saturation Region

$V_{DS} > V_{GS} - V_t$.

(ii) Triode region

$$I_D = \frac{\mu_n C_{ox} \omega}{L} \left[(V_{GS} - V_t) V_{DS} - \frac{V_{DS}^2}{2} \right]$$



Curve bent because of channel resistance increase with V_{DS}

current saturates bcz the channel pinched off at the drain & V_{DS} no longer affect the channel.

almost st. line with slope proportional ← $V_{DS\,sat} = V_{GS} - V_t$.

here, μ_n mobility of e^-.

ω – width

L – length.

\# When $V_{DS} = 0$, the channel is maximum there. & gradually the V_{DS} got inc. in its value then at one instance, it gets pinch off.
↳ where current become constt.

(ii) $I_D = \frac{K_n' \omega}{L} \left[(V_{GS} - V_t) V_{DS} \right]$

where $K_n' = \mu_n C_{ox}$

(iii) $V_{DS} > V_{GS} - V_t$ – Saturation region,

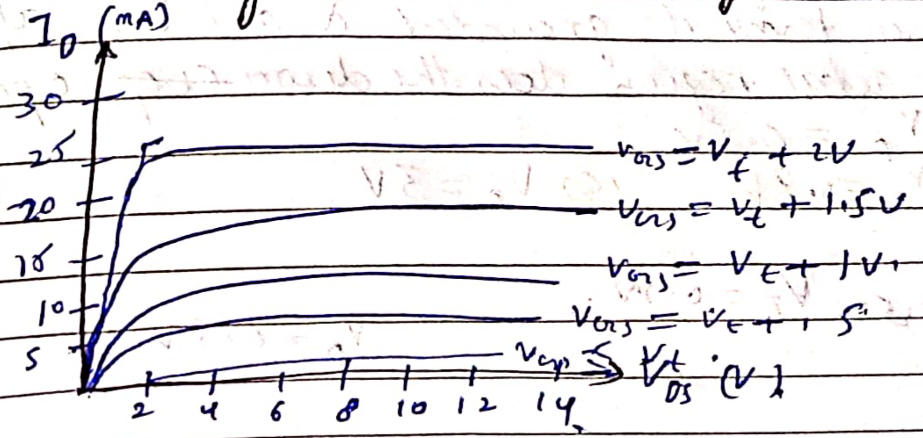
$V_{DS} = V_{GS} - V_t$,

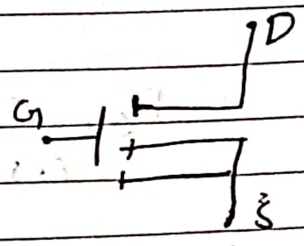
$$I_D = \frac{K_n' \omega}{L} \left[(V_{GS} - V_t)(V_{GS} - V_t) - \frac{(V_{GS} - V_t)^2}{2} \right]$$

$$= \frac{1}{2} \frac{K_n' \omega}{L} \left[(V_{GS} - V_t)^2 \right]$$

DATE 2/12/2022

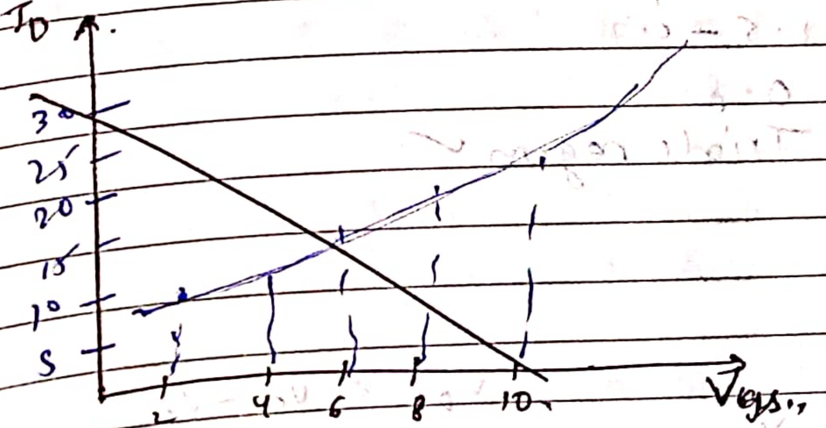
VI & transfer characteristics of E-MOSFET –



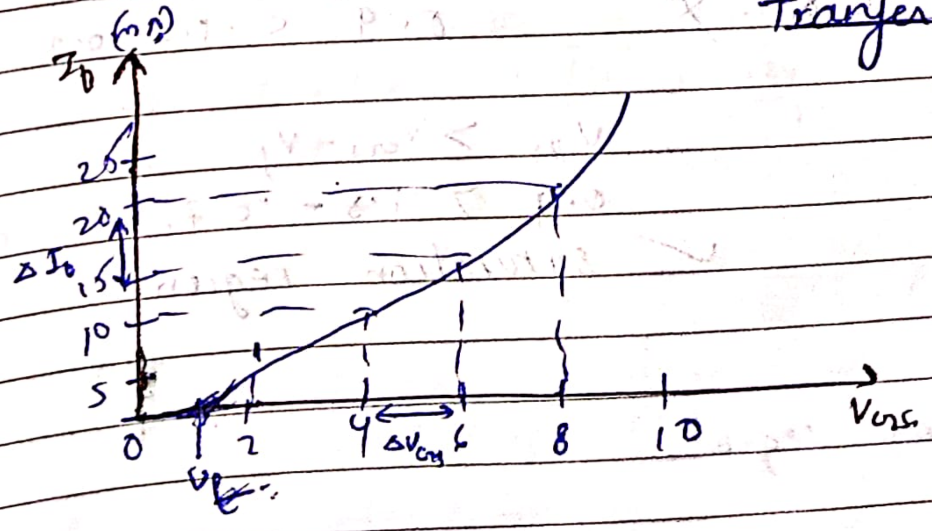


N – channel E-Mosfet
or
NMOS.

V_{GS} Vs I_D



Transfer characteristics



$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

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Ques. An Enhancement type N-MOS transistor with $V_T = 0.7V$ has its source terminal grounded & a 1.5 V applied to the gate. In what region does the device ~~coop~~ operate for
(a) $V_D = 0.5V$
(b) $V_D = 0.9V$ (c) $V_D = 3V$.

$V_{GS} = 1.5V$ $V_T = 0.7V$. $V_D = 0.5V$

(i) 1 $V_{GS} < V_t$
$1.5 < 0.7$.

2 $V_{DS} < V_{GS} - V_T$
$1.5 - 0.7$
$0.5 < 0.8$
Triode region ✓.

$\frac{1.5}{0.7}$

(ii) $V_D = 0.9V$.

$V_{GS} < V_t$.
$1.5 < 0.7$ ✗

$V_{DS} < V_{GS} - V_T$
$0.9 < 1.5 - 0.7$

$V_{DS} > V_{GS} - V_T$
$0.9 > 1.5 - 0.7$.
✓ saturation region.

(iii) saturation region

$V_{GS} - V_t \rightarrow V_{OV}$

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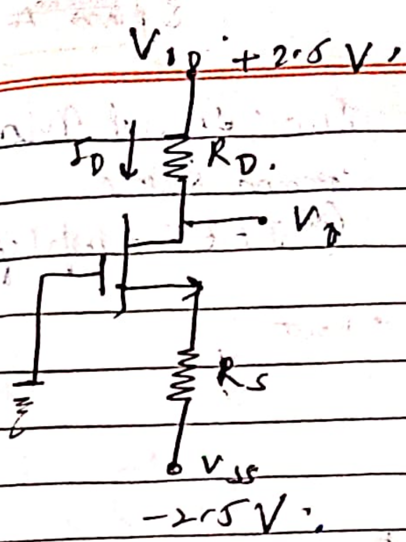


Design the ckt. as shown in fig. so that the transistor operates at $I_D = 0.4mA$; $V_D = +0.5V$.
The NMOS transistor has $V_t = 0.7V$.
$\mu_n C_{ox} = 100 \mu A/V^2$;
$L = 1 \mu m$ $W = 32 \mu m$.

$V_G = 0$; $I_D = 0.4mA$
$= 400 \mu A$,

$\Rightarrow I_D = \frac{1}{2} K_n \frac{W}{L} \left[(V_{GS} - V_t)^2 \right]$

$\frac{400 \times 2 \times 1}{100 \times 32} = (V_{GS} - V_t)^2$.

$(V_{GS} - V_t)^2 = 0.25$

$V_{GS} - 0.7 = \sqrt{0.25}$

$V_{GS} - 0.7 = 0.5$

$V_{GS} = 0.5 + 0.7$

$\boxed{V_{GS} = 1.2V}$

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

$R = \frac{V_S - V_{GS}}{I_D}$.

0.4×10^{-3}.

2) $R_S = \frac{-1.2 - (-2.5)}{0.4}$

$= \frac{-1.2 - (-2.5)}{0.4 \times 10^{-3}}$

$R_S = 3.2 \; K\Omega$

$R_D = \frac{V_{DD} - V_D}{I_D}$ $= \frac{2.5 - 0.5}{0.4 \times 10^{-3}}$.

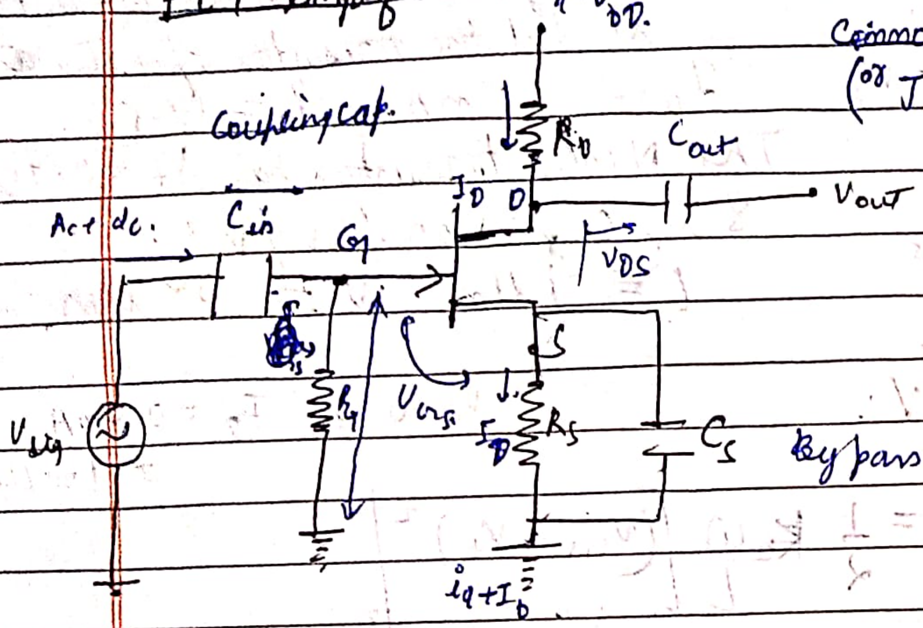
$\boxed{R_D = 5 K\Omega}$

→ Capacitor block DC & pass AC

7/12/22.

FET Amplifier -

Small signal Model
Common Source
(or JFET Amplifier)



By pass Capacitor

→ To avoid the drop of more current in R_S we use By pass capacitor here so as the amplified signal we'll get on output capacitor. [Capacitor then block DC & allow AC to pass].

C_{in} & C_{out} → Coupling capacitor,
C_S → By Pass Capacitor

① DC Analysis → capacitor acts as open ckt; All ac sources = 0.
② AC Analysis → capacitor act as short ckt, All dc source grounded

When DC Analysis -

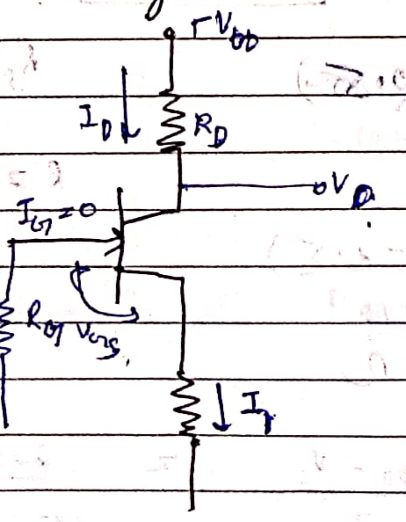
$V_{DD} - I_D R_D - V_{DS} - I_D R_S = 0$

$V_D = V_{DD} - I_D(R_D + R_S)$

$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$

V_P → $V_{GS\,off}$

I_{DSS} → max. ds itself



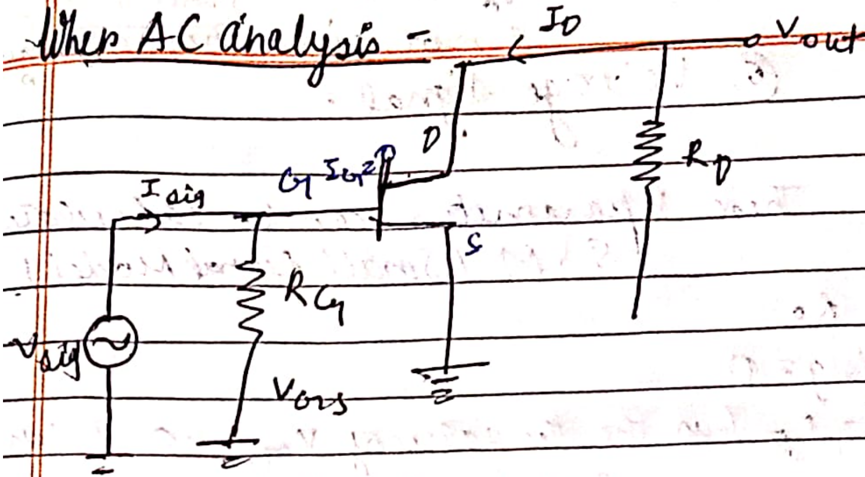
$G - V_{GS} - I_D R_S = 0$

$V_{GS} = -I_D R_S$

$V_{GS} = -I_D$

we can find these- using AC analysis- Input resistance, Output resistance, Voltage gain

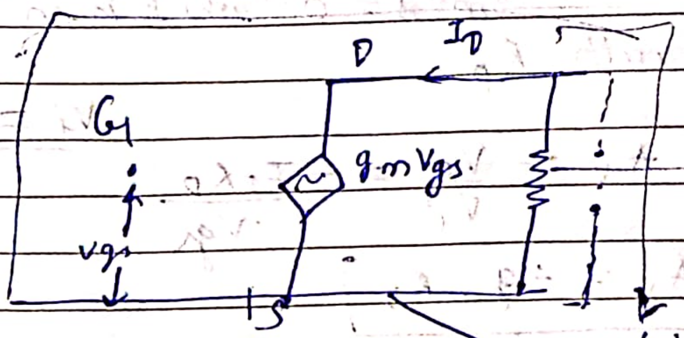
When AC analysis -



$$r_d = \frac{\Delta V_{DS}}{\Delta I_D}$$

$$g_m = \frac{I_D}{V_{GS}}$$

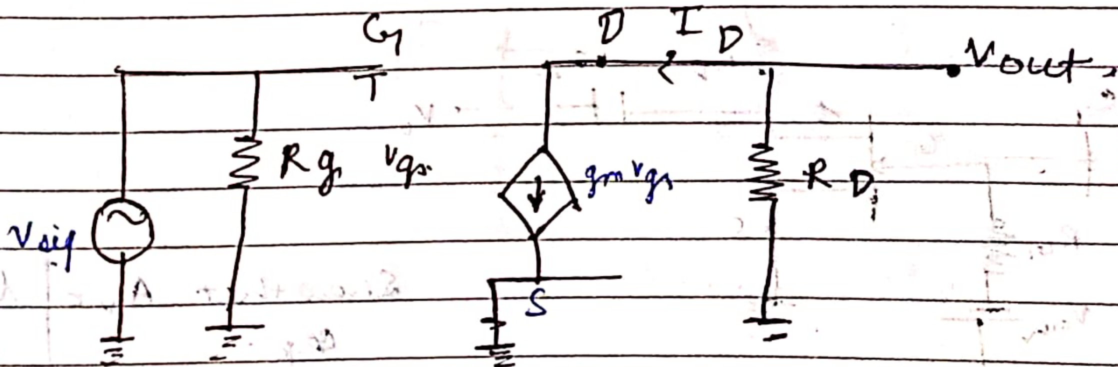
$$I_D = g_m V_{GS}.$$



This higher resistance represent as open ckt bcz no current is there.

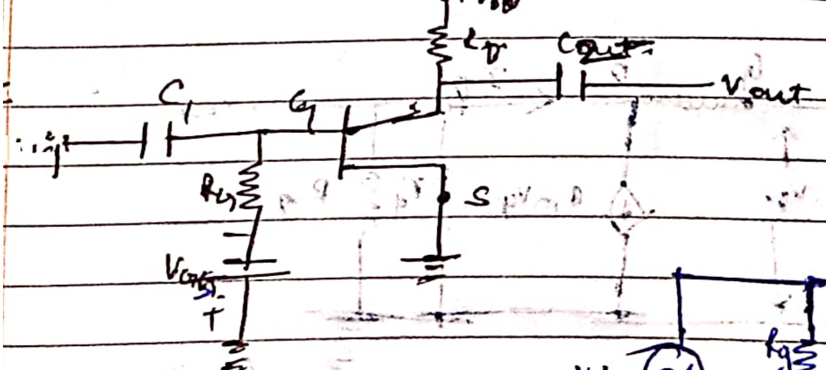
approximate model.

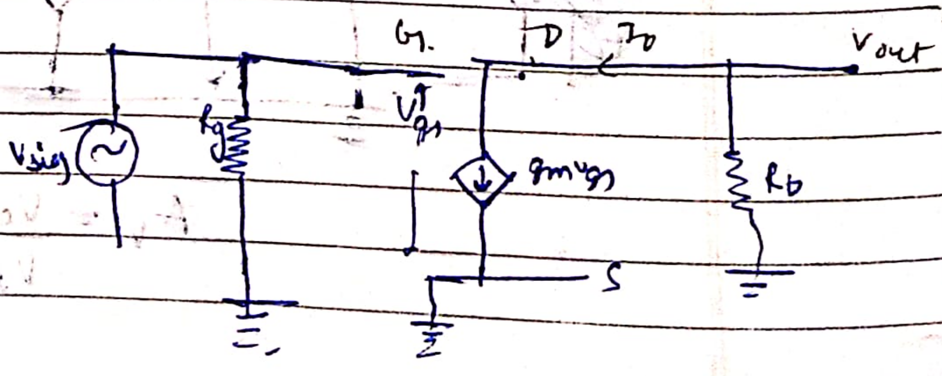
Exact model



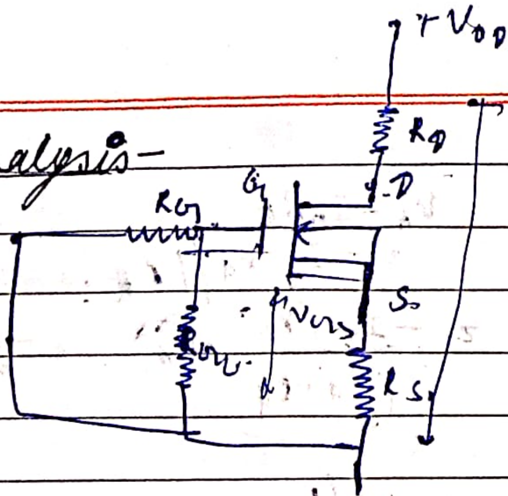
$R_i = R_G$ — (1).

Small signal model of FET



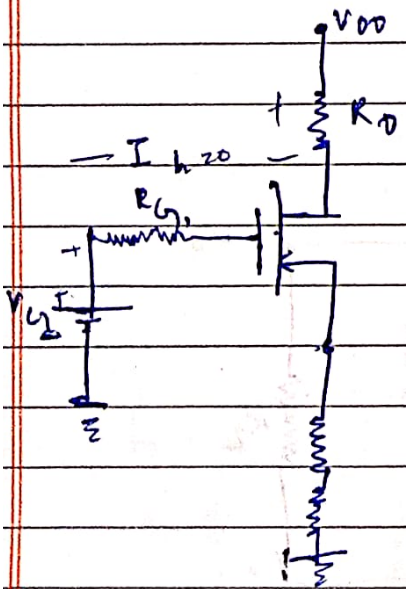


DC Analysis-



$$V_G = V_{TH} = \frac{R_{G2}}{R_{G1} + R_{G2}} \times V_{DD} \quad \text{—} \ (1)$$

$$R_G = R_{G_1} // R_{G_2} \quad \text{—} \ (2)$$



$$V_{GS} = V_G - V_S$$
$$= V_G - I_D R_S \quad (3)$$

$$V_{DD} - I_D R_D - V_{DS} - I_D R_S = 0$$

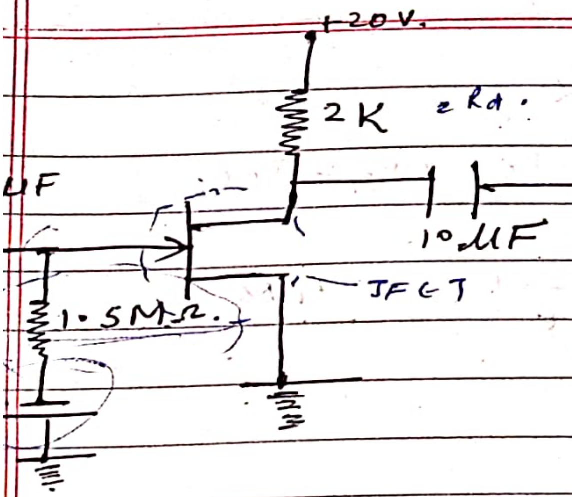
$$V_{DS} = V_{DD} - I_D (R_D + R_S) \quad \text{—} \ (4)$$

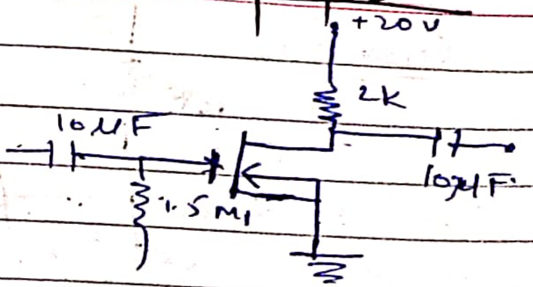
$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

$$= I_{DSS}\left[1 - \frac{V_G - I_D R_S}{V_P}\right]^2$$

Depletion type MOSFET = JFET.

20/12/22





both are same.

$I_{DQ} = 6 mA$, $V_{GQ} = -2V$

$I_{DSS} = 10 mA$, $V_p = -7V$, $Y_{DS} = 40 \mu S$.

Find out g_m, r_d, Z_i, Z_o & A_v.

$I_D = 6 mA$;

$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$

$$g_m = -\frac{2 I_{DSS}}{V_p}\left[1 - \frac{V_{GS}}{V_p}\right]$$

$$= -\frac{2 \times 10}{-7}\left[1 - \left(\frac{-2}{-7}\right)\right]$$

$$= \frac{20}{7}\left(1 - \frac{2}{7}\right)$$

$$\boxed{g_m = 2.04 \text{ mS or mA/V}}$$

$$r_d = \frac{1}{Y_{DS}} = \frac{1}{40} = \frac{1}{40 \times 10^{-6}} = 25000\Omega.$$

$$= 25 K\Omega.$$

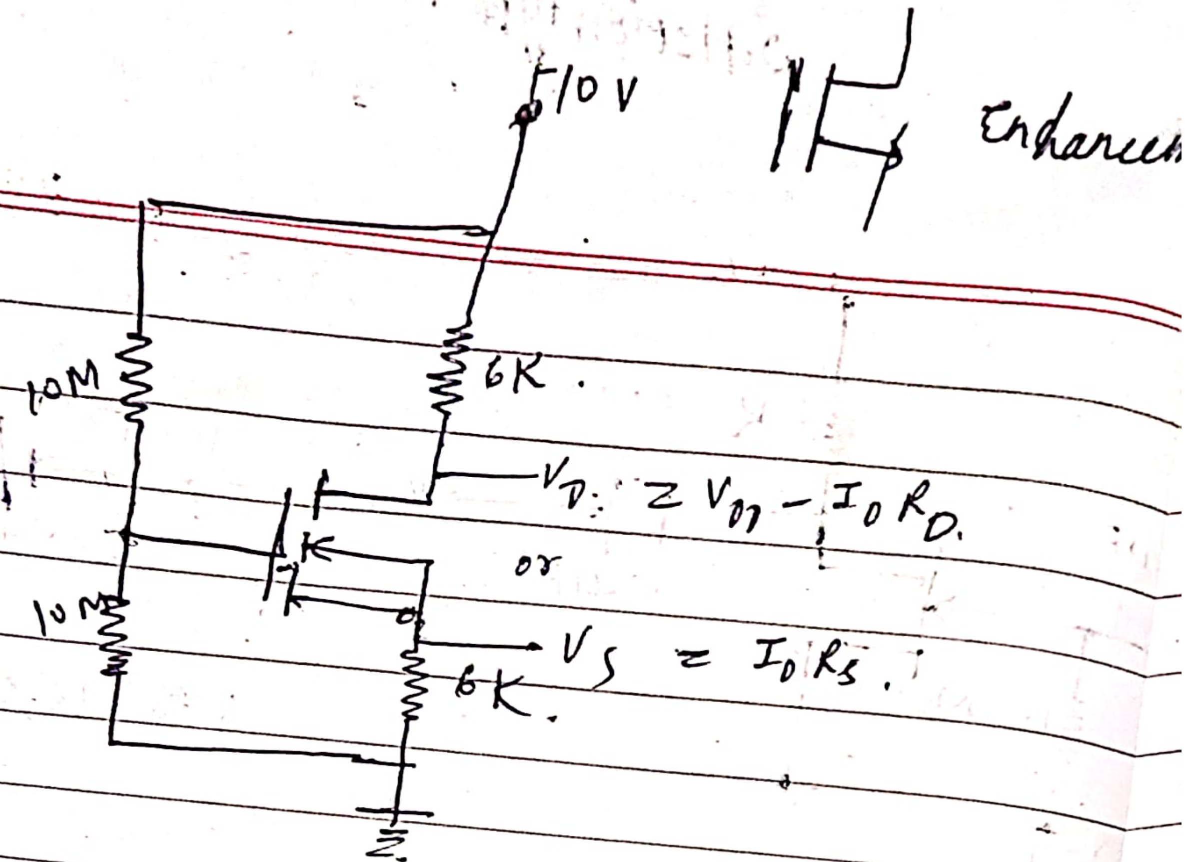
Z_i or $R_i = R_G = 1.5 M\Omega$.

R_o or $Z_o = r_d \| R_d$. $= \frac{25 \times 2}{25+2} = 1.85 k\Omega$.

$A_v = -g_m r_d \| R_d = 3.774$.

~~γ_b~~ = WLCox = Cox.

Ckt.



Analyse the ckt shown, Determine the voltage all nodes and the current through all branches
Given, $V_t = 1V$; & $K_n' \frac{W}{L} = 1 mA/V^2$

$$V_G = \frac{10}{10+10} \times 10$$
$$= 5V.$$

$V_{GS} > V_t$

Triode, $V_{DS} < V_{GS} - V_t$

Saturation.

$V_{DS} \geq V_{GS} - V_t$ =

$$\cancel{I_D = \frac{1}{2} K_n' \frac{W}{L} [V_{GS} - V_t]^2}$$
$$\cancel{= \frac{1}{2} \times 1 [5-1]^2}$$
$$\cancel{\frac{1}{2} \times 16 =}$$
$$\cancel{I_D = 8. A}$$

$V_S = I_D R_S$; $V_{GS} = V_G - V_S$

$V_S = 6 I_D$ $\quad = 5 - 6 I_D$

$I_D = \frac{1}{2} \times 1 \left[(5 - 6I_D) - 1\right]^2$

~~$I_D = \frac{1}{2}$~~

~~$2I_D = \left[5 - 6I_D - 1\right]^2$~~

~~$2I_D =$~~

$2I_D = (5 - 6I_D - 1)^2$

$2I_D = (4 - 6I_D)^2$

$2I_D = 16 + 36I_D^2 - 48I_D$

$36I_D^2 - 50I_D + 16 = 0$

$\boxed{I_D = 0.88\ mA}$ ✗ $\qquad \boxed{I_D = 0.5\ mA}$

$V_S = I_D R_S$
$= 0.88 \times 6$
$\boxed{V_S = 5.28\ V}$

$V_S = I_D \times R_S$
$= 0.5 \times 6$
$\boxed{V_S = 3\ V}$

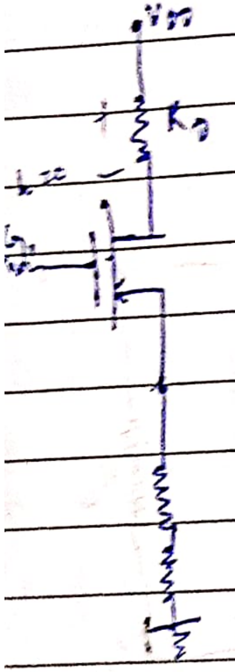
$V_{GS} = 5 - 6I_D$
$= 5 - 6 \times 0.88$
$= 5 - 5.28$
$\boxed{V_{GS} = -0.28\ V}$

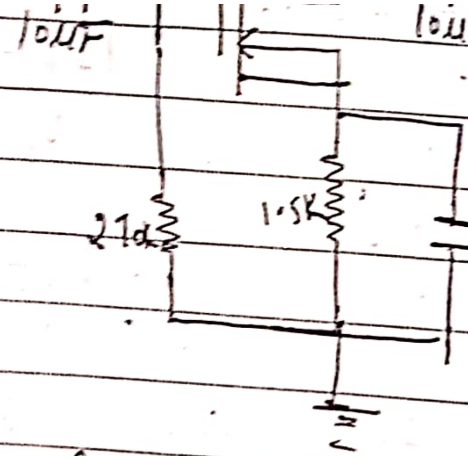
$V_{GS} = 5 - 6 \times 0.5$
$= 5 - 3$
$\boxed{V_{GS} = 2\ V}$

For Enhancement, V_{GS} value should be +ve so, we " take $I_D = 0.5\ mA$ for +ve value of V_{GS}.

$V_D = V_{DD} - I_D R_D$
$= 10 - 0.5 \times 6$
$= 10 - 3$

$\boxed{V_D = 7V}$

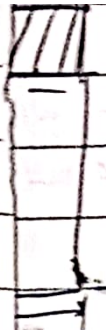




$I_{DSS} = 8\ mA$

$V_p = -4V$

Calculate I_{DQ}, V_{GSQ}, V_D, V_S, V_{GD} & V_{DS}.



$V_{GS} > V_t$.

$V_{DS} \le V_{GS} - V_t$

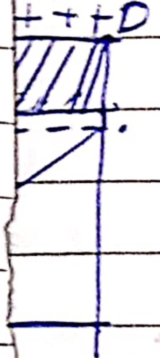
$C'_{ox} = C_{ox} \cdot A$

$= WL \cdot C_{ox}$.

$C_{gs} = C_{gd} = \frac{1}{2} C'_{ox} = \frac{1}{2} WL$

... region

...n =



$V_{GS} > V_t$

$V_{DS} \geq V_{GS} - V_t$

$C'_{ox} = \frac{2}{3} WL C_{ox}$

$C_{gd} = 0$, $C_{gb} = 0$

No channel. as at the source

$V_{GS} < V_t$

$C_{gd} = 0$

$C_{gb} = WL C_{ox} = C'_{ox}$.

$V_{DS} = V_D - V_S$

$= 7 - 3$

$\boxed{V_{DS} = 4V}$

Saturation

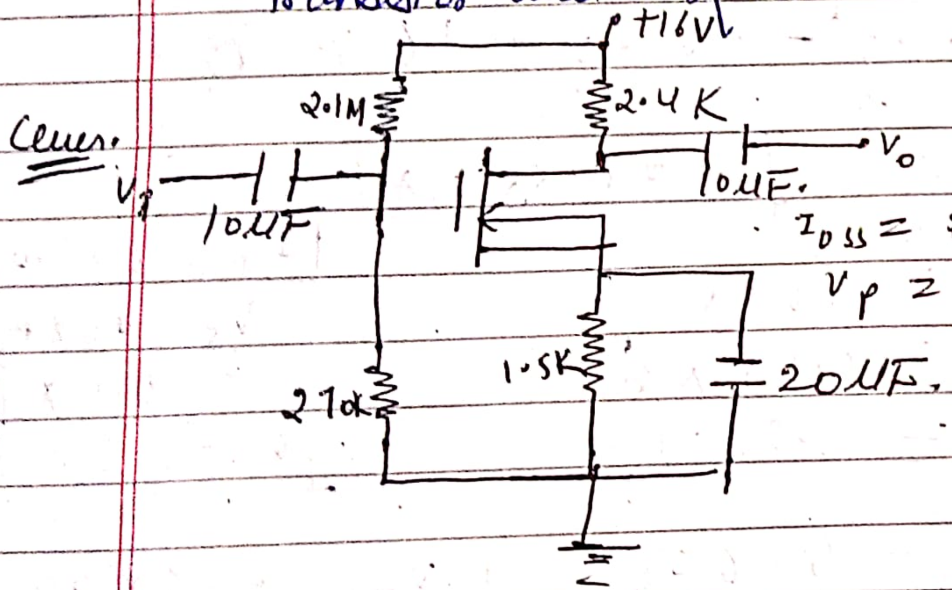
$V_{DS} > V_{GS} - V_t$

$4 > 2 - 1$

$\boxed{4 > 1}$

$\therefore$ condition ~~satisfied~~ satisfied hence, the transistor will work in saturation region.

Ques.



$I_{DSS} = 8\ mA$

$V_P = -4V$

Calculate I_{DQ}, V_{GSQ}, V_D, V_S, V_{GD} & V_{DS}.

Capacitor -

...itive effect:-

capacitor b/

b/w gate

b/w gat

...ion Regi

...n:-

No

V_{GS}

C_{gd}

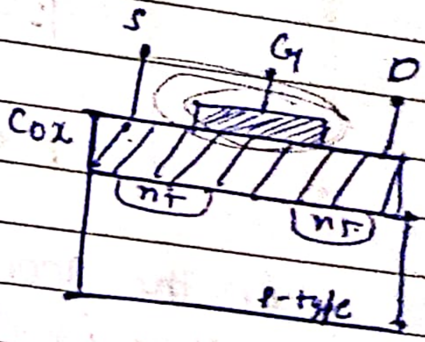
MOS Capacitor -

Capacitive effect :-

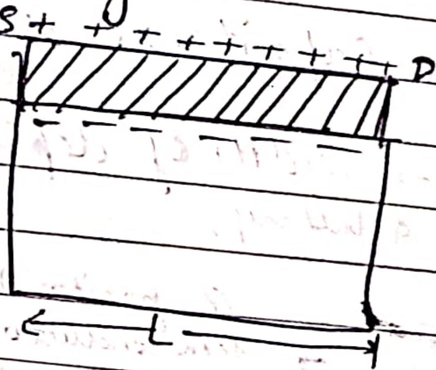
$C_{gd} \rightarrow$ capacitor b/w gate & drain

$C_{gs} \rightarrow$ b/w gate & source

$C_{gb} \rightarrow$ b/w gate & body.



Triode Region



$V_{GS} > V_t$.

$V_{DS} \leq V_{GS} - V_t$

$C'_{ox} = C_{ox} \cdot A$

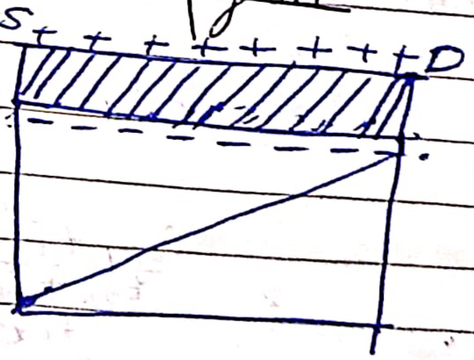
$= WL \cdot C_{ox}$.

$C_{gb} = 0$

when E MOSFET work as in saturation region.

$C_{gs} = C_{gd} = \frac{1}{2} C'_{ox} = \frac{1}{2} WL\, C_{ox}$

Saturation Region:-



$V_{GS} > V_t$

$V_{DS} \geq V_{GS} - V_t$

$C'_{ox} = \frac{2}{3} WL\, C_{ox} = C_{gs}$

$C_{gd} = 0$, $C_{gb} = 0$

Cut Off Region -

No channel. as at the source side $V_{GS} = 0$

$V_{GS} < V_t$

$C_{gs} = C_{gd} = 0$

$C_{gb} = WL C_{ox} = C'_{ox}$

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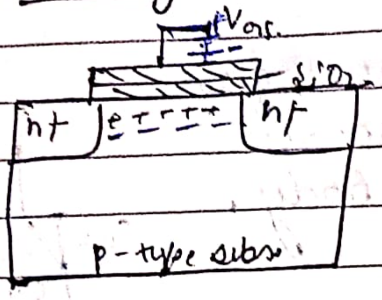
C-V Characteristics — (C-V Curve)

capacitance Vs Voltage characteristics



1. Accumulation
2. Depletion
3. Inversion

In the accumulation only one type of capacitor is there i.e. Oxide capacitor → $C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$,

In Depletion Condition, the Capacitance starts decreasing as the $C = \frac{\varepsilon_0 A}{d}$ → width of depletion.

charge — at boundary connect at +ve terminal of battery.

$$\frac{1}{\frac{1}{C_{other}}} = \frac{1}{C_{ox}} + \frac{1}{C_{sd}}$$ → (capacitor) semiconductor provided at the p-type.

$$C'_{dep} = \frac{C_{ox} C'_{sd}}{C_{ox} + C'_{sd}},$$

$$= \frac{C_{ox}}{1 + \frac{C_{ox}}{C_{sd}}}$$

$C'_{sd} = \frac{\varepsilon_s}{x_d}$ → width of depletion

$$C'_{dep} = \frac{\varepsilon_{ox}/t_{ox}}{1 + \frac{\varepsilon_{ox}/t_{ox}}{\varepsilon_s/x_d}} = \frac{\varepsilon_{ox}/t_{ox}}{\frac{t_{ox} + \varepsilon_{ox}}{t_{ox}}}$$
ε_s / x_d

$1 + \frac{\varepsilon_{ox}}{t_{ox}}$
$\frac{\varepsilon_s}{x_d}$

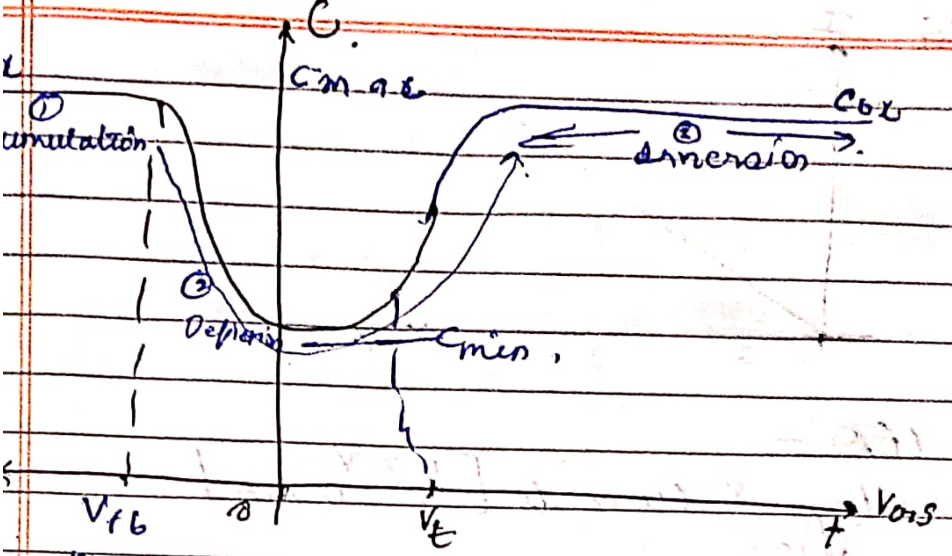
$$= \frac{\varepsilon_{ox}}{t_{ox} + \frac{\varepsilon_{ox}}{\varepsilon_s} x_d}$$

$\frac{t_{ox} + \varepsilon_{ox}}{t_{ox}}$

when
$V_{GS} = V_t$.
$x_d = x_{d\,T\,max}$

$$\boxed{C'_{min} = \frac{\varepsilon_{ox}}{t_{ox} + \frac{\varepsilon_{ox}}{\varepsilon_s} x_{dT}}}$$

$$\boxed{C'_{dep} = C'_{min}}$$



flat band voltage.

* C-V Curve *.

23/12/22

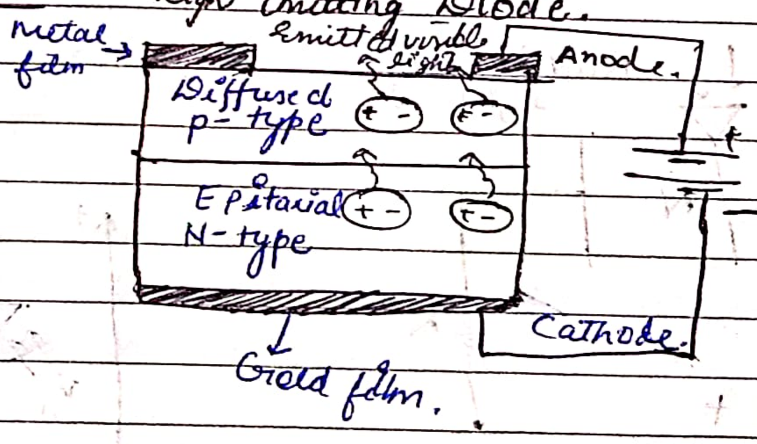
Opto Electronic Devices -

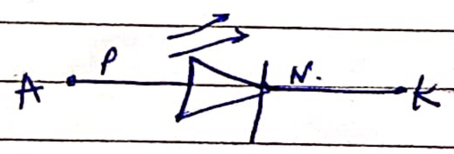
1) LED — Emitters

2) Photo Diode } sensors
3) Solar cell }

→ construction, characteristics VI
Applications, advantages, disadvantages.

LED - Light Emitting Diode.

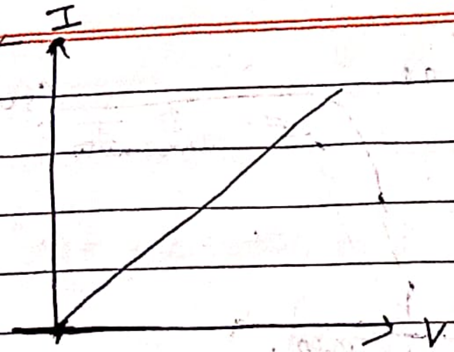




Symbol of LED Diode.

GaAs - Infrared light
GaAsP - Red or Yellow
GaP - Green.

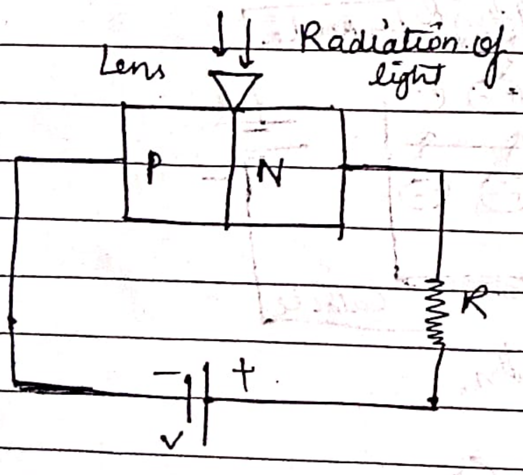
VI characteristic

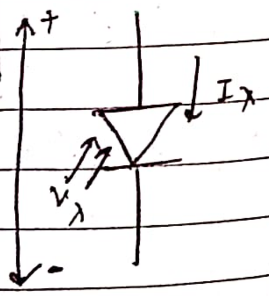


Advantages of LED -
1. Low working Voltage & currents [1-2 V. 5-20 mA]
2. Less power consumption
3. Very fast in action.
4. Small size & Weight.
5. Extremely long life if we provide the proper voltage
6. Higher Reliability.

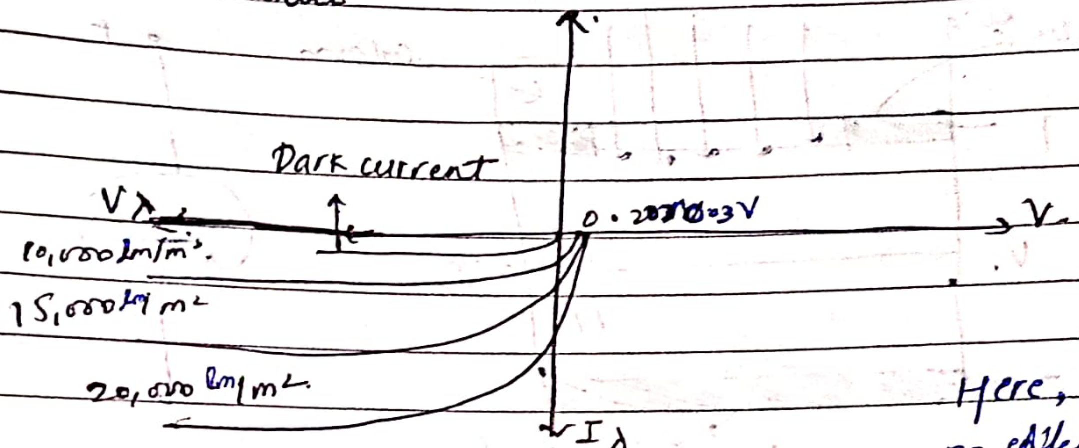
Disadvantage-
Sensitivity to Damage by Overvoltages & Current.

Photo Diode -





V.I Characteristic



Here, on current, there is no effect of applied Voltage

Current ∝ Light Intensity.

→ If the voltage tends to 0.2 to 0.3 V then the current becomes zero. as now no effect of Intensity on current.

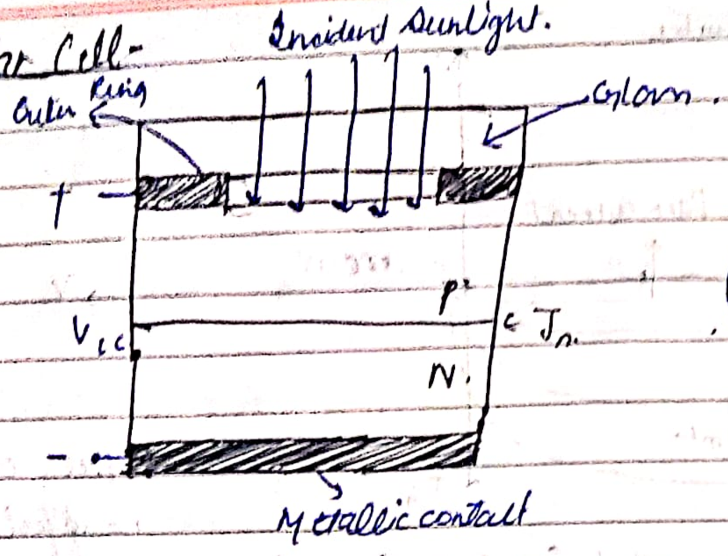
Dark current is defined as if no light is falling on p-n junction but due to reverse biasing very small current is there i.e. negligible.

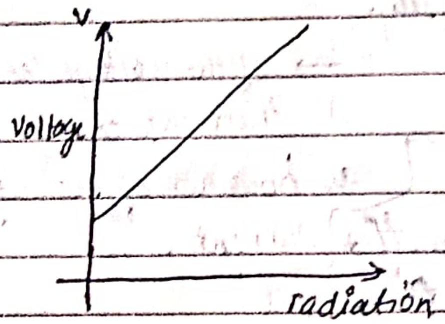
Advantages:-
Fast switching Time.
Better Frequency Response
Linearity is good.

Disadvantages:-
Dark current increases with temperature.
Small active area.

Application-
1. In switching application,
In Optical communication
In logic circuits that requires stability & high speed.

Solar Cell-





Advantages

(a) It is a Self-generating device.
(b) It is a pollution free energy conversion system.
(c) It can be operated over a wide Range of temperature.

Disadvantages / Limitations-

(a) It doesn't convert all solar Radiations into Electric Energy.
(b) Efficiency is low & It is Temperature Dependent.

Applications-

(a) In Space satellites (b) supplying power for street lights.
(c) Charging batteries.
(d) for generating power in Remote or Rural area (for lighting & water plant).

07/11/22.

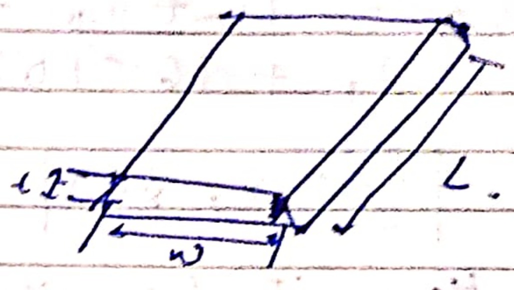
Sheet Resistance or surface Resistivity R_s.

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

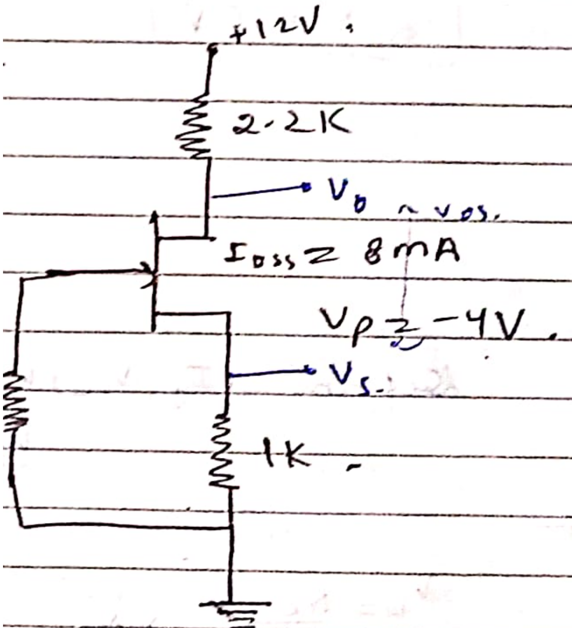
$$= \frac{\rho L}{Wt}$$

$$= \frac{\rho}{t} \frac{L}{W}.$$

$$R = R_s \frac{L}{W}.$$



Sheet Resistance is a measure of thin films that are uniform in thickness. It is commonly used to characterise materials made by semiconductor doping, Metal depositors, Resistive paste printing & glass coating.



find V_{GSQ}, I_{DQ}, V_{DS}, V_S & V_D

$$V_{GS} = V_G - V_S.$$

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

$$I_D = 8\left[1 - \frac{V_{GS}}{(-4)}\right]^2 \quad \text{--- (1)}$$

$$-I_D R_D - V_D = 0$$

$$V_D = V_{DD} - I_D R_D.$$

$$V_{GS} = V_G - V_S$$

$$= 0 - I_D R_S$$

$$V_{GS} = -I_D \cdot 1$$

now put V_{GS} in eq. (1)

$$I_D = 8\left[1 + \left(\frac{-I_D}{4}\right)\right]^2$$

$$I_D = 8\left[1 - \frac{I_D}{4}\right]^2 \Rightarrow I_D = 8\left[\frac{4 - I_D}{4}\right]^2$$

-2

$16 I_D = 8[4 - I_D]^2$

$\frac{\cancel{16} I_D}{\cancel{8}} = 16 + I_D^2 - 8 I_D$

$2 I_D = 16 + I_D^2 - 8 I_D$

$I_D^2 + 16 - 10 I_D$

$\boxed{I_D = 8,\ 2\,mA}$ $\qquad I_D < I_{DSS} \rightarrow 8.$

Here, $I_D \neq 8$ should not be there

$\boxed{I_D = 2\,mA}$

$V_S = I_D R_S = 2 \times 1$

$\boxed{V_S = 2V}$

$V_{DS} = V_D - V_S$

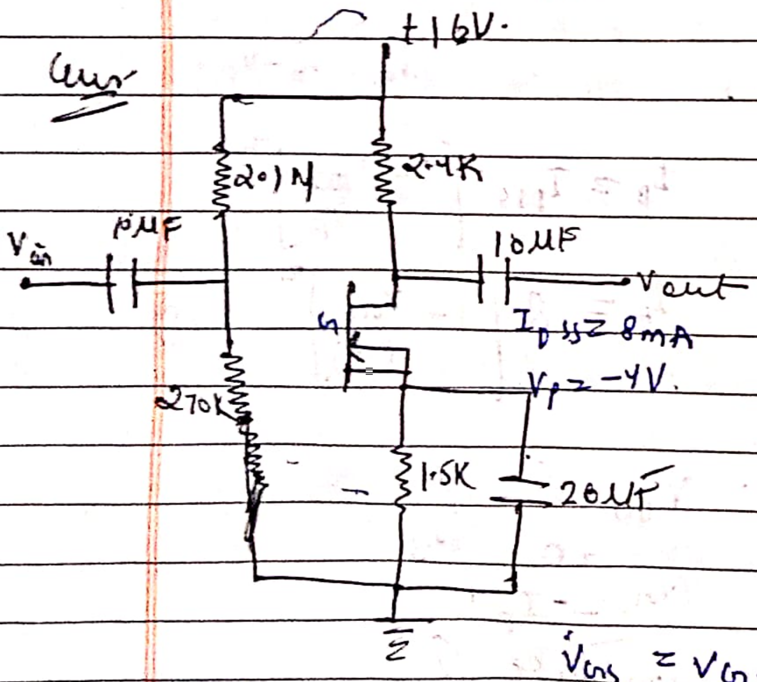
$= 7.6 - 2$

$\boxed{V_{DS} = 5.6\,V}$

$V_{GS} = -2 \times 1$

$= -2V.$

Ans



Determine I_D, V_{GS}, V_{DS}, V_D, V_S & V_{DG},

$V_G = \frac{R_{G2}}{R_{G1} + R_{G2}} \times V_{DD}$

$= \frac{270 \times 10^3}{270 \times 10^3 + 2.1 \times 10^6} \times 16$

$\boxed{V_G = 1.822\,V}$

$V_{GS} = V_G - V_S$

$= 1.822 - 1.5 I_D$

$V_S = I_D R_S$

17

$\mathcal{D}$ $x \log e$

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

$$I_D = 8\left[1 - \left[\frac{1.822 - 1.5 I_D}{-4}\right]\right]^2$$

$$I_D = 8\left[\frac{1}{1} + \left(\frac{1.822 - 1.5 I_D}{4}\right)\right]^2$$

$$\frac{I_D}{8} = \left(\frac{4 + 1.822 - 1.5 I_D}{4}\right)^2$$

$$\frac{I_D}{\cancel{8}} \times \cancel{16}^2 = (4 + 1.822 - 1.5 I_D)$$

$$2 I_D = (5.822 - 1.5 I_D)^2$$

$$2 I_D = 33.89 + 2.25 I_D^2 - 17.46 I_D$$

$$2.25 I_D^2 - 19.46 I_D + 33.89 = 0$$

$$\boxed{I_D = 6.23, \ 2.41 \text{ mA}}$$

$-V_G$ in n-type

ways to check value of I_D.

Compare value of I_D with I_{DSS}

Put value of I_D in eq^n $V_{GS} = V_G - V_S$.

the

$V_{DS} = V_{DD} - I_D R_D - I_D R_S$

$V_{DS} = V_D - V_G$

$= 6.601 - 1.82$

$\boxed{V_{DS} = 4.781 V}$

$V_{DS} = V_{DD} - I_D R_D - I_D R_S$

$= V_{DD} - I_D[R_D + R_S]$

$V_{DS} = 16 - 2.41(2.2 + 1)$

$V_{DS} = \cancel{6.768}$

for N channel, V_{DS} should be +ve

so $I_D = 2.41$

[redacted]

Qns. A Si sample with $10^{15}/cm^3$ donors is uniformly optically excited at room temp. such that 10^{19} EHPs are generated per sec. Find the separation of the quasi fermi level & change of conductivity upon shining the light. Electron & hole life times are $10\,\mu s$ & $D_p = 12\,cm^2/s$

n_i for Si $= 1.5\times10^{10}/cm^3$ & $\mu_e = 1300\,cm^2/V\text{-}s$

$\tau_p = 10\,\mu s$; $D_p = 12\,cm^2/s$

$$\delta n = \delta p = g_{op}\tau_e = 10^{19}\text{ EHPs}\times10\times10^{-6}$$

$n_0 = 10^{15}$

$$\boxed{\delta p = 10^{14}}$$

$n_0 p_0 = n_i^2$

$$p_0 = \frac{(1.5\times10^{10})^2}{10^{15}}$$

$$p_0 = 2.25\times10^{5}$$

$n = \delta n + n_0 = 10^{14} + 10^{15}$

$$\boxed{n = 1.1\times10^{15}}$$

$p = p_0 + \delta p$

$= 2.25\times10^{5} + 10^{14}$

$= 10^{14}$

$$E_{fn} - E_{fp} = kT\log\frac{np}{n_i^2}$$

$$= 0.026\log\frac{1.1\times10^{15}\times10^{14}}{(1.5\times10^{10})^2}$$

$= 0.225$

$= 0.51\,eV$

$$\Delta\sigma = q[\mu_e\delta n + \mu_p\delta p]$$

$$\frac{D_p}{\mu_p} = \frac{kT}{q}$$

$$\frac{12}{0.026} = \mu_p$$

$$\boxed{461.53 = \mu_p}$$

$$\frac{D_p}{\mu_p} = \cancel{0.026\times\mu_p}$$

$$\Delta\sigma = q[\mu_e\delta n + \mu_p\delta p]$$

$$= 1.6\times10^{-19}[1300\times10^{14} + 461.53\times10^{14}]$$

$$= 0.028\ \Omega^{-1}cm^{-1}$$