Date: 18/07/25

Resistivity $(\rho) = \frac{RA}{L}$

metal / conductor :

$\rho \approx 10^{-2}$ to 10^{-8} Ωm

$\sigma \approx 10^{2}$ to 10^{8} $S m^{-1}$

Semiconductor :

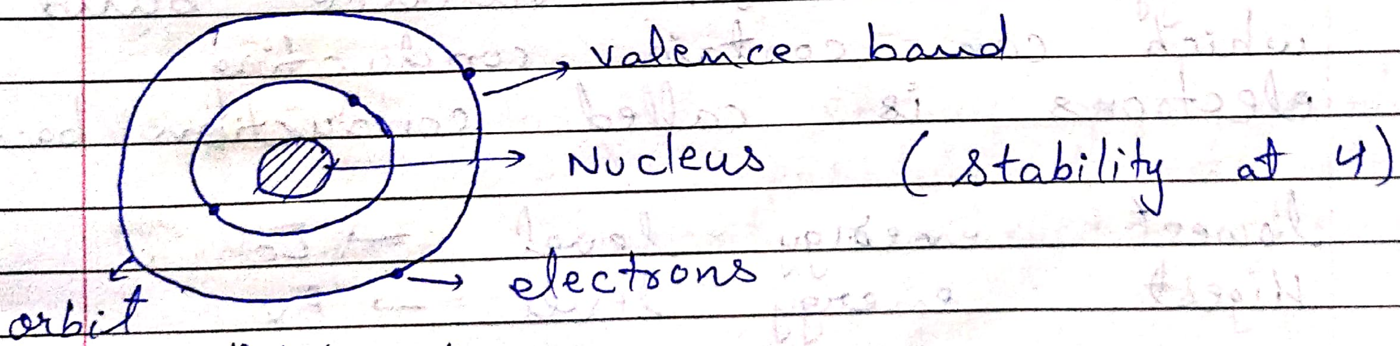
$\rho \approx 10^{-5}$ to 10^{6} Ωm

$\sigma \approx 10^{5}$ to 10^{-6} $S m^{-1}$

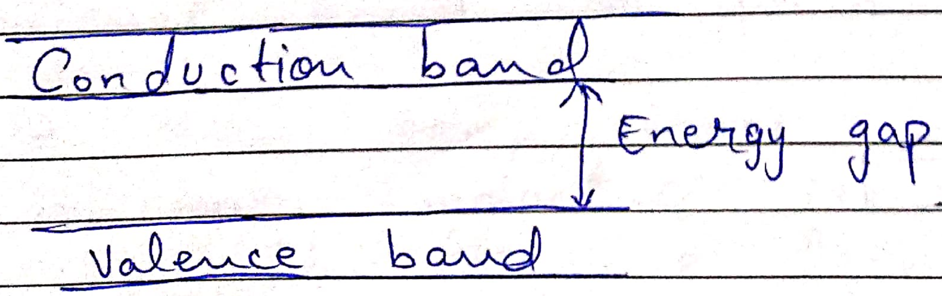
Insulator :

$\rho \approx 10^{11}$ to 10^{19} Ωm

$\sigma \approx 10^{-11}$ to 10^{-19} $S m^{-1}$



"Atom"



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Energy gap → minimum energy required to detach electrons from valence band to conduction band. It is a function of temperature and it decreases as temp. rises.

At temp T,

$$E_g = E_{go} - \beta T$$

T → Temp

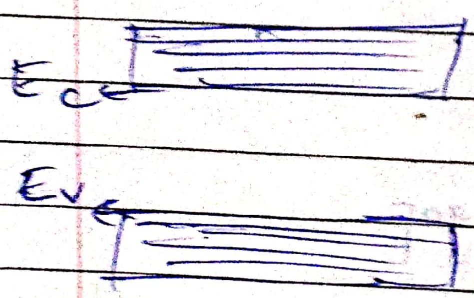
E_g → Band gap

E_{go} → Band gap at 0K

β → material constant

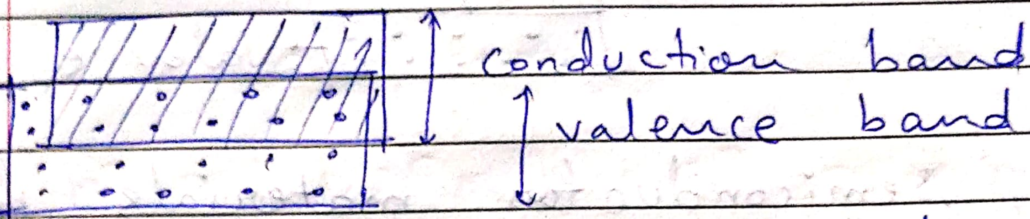
- Energy band which includes the energy levels of valence electrons is called valence band
- energy band above valence band which can contain conducting electrons is called conduction band

lowest energy level → E_c
Higest energy levll → E_v



Date ___/___/___

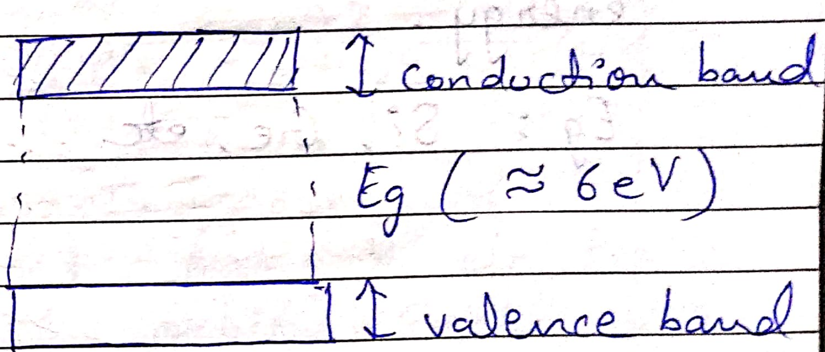
• metals / Conductors :→



no forbidden gaps between valence and conduction band. without any additional energy it contains a large number of free electrons and that is why it is a good conductor.

Eg → Al, Cu, Fe, etc...

• Insulators :→

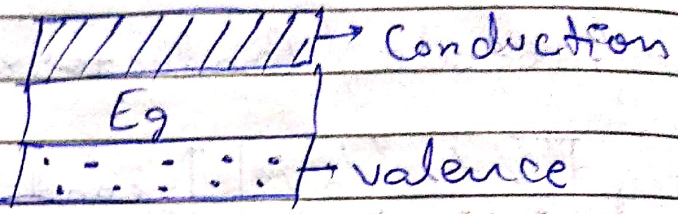


Very wide forbidden energy gap (nearly equal to 6 ev) separating filled valence band from vacant conduction band.

So It is impossible for an el^- in valence band to jump the gap.

At room temp. there is no conduction. It may conduct if its temp. is very high this is termed as Breakdown of insulator.

• Semiconductors :



At 0K, semiconductor materials have same structure as insulators except the difference in size of Band gap which is much smaller in semiconductors. Relatively small gaps allow for excitation of el^- from lower band to upper band by reasonable amount of thermal energy.

Eg : Si, Ge, etc ...

Date 18/07/25

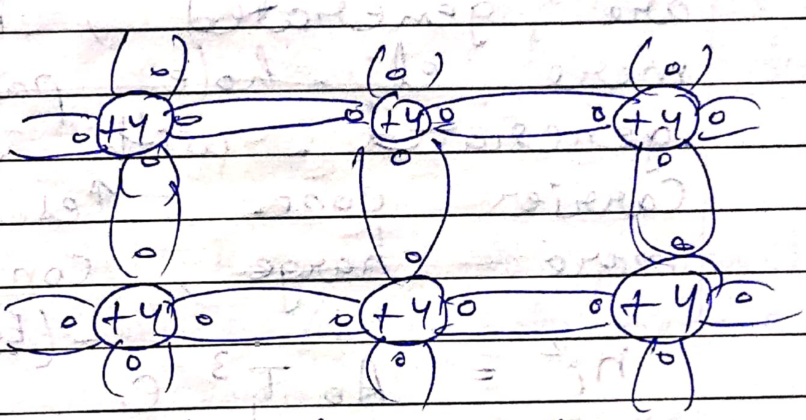
→ Types of semiconductor materials

1) Elemental / Intrinsic → Si, Ge

11) Compound / Extrinsic → ZnO, Cds
- → p - type (tri-Valent)
- → n - type (pentavalant)

(I) Intrinsic:→

Absolute Zero temp. (−273K)



- It is the purest form of semiconductor. it has 4 electrons in the outermost orbit. Each atom attempts to accquire 8 el⁻ in outermost shell. Sharing of 1 el⁻ from each of 4 neighbouring atoms this sharing is known as covalent bonding.

- At absolute zero, all valence el⁻ are tightly bound to parent atom. no free electrons are available for conduction. at room temp. sufficient thermal energy is supplied to break the covalant

Date: / /

bond generating e^- - hole pairs.

- Conc. of free e^- (n), and holes (p) will always be equal

$n = p = n_i$ (intrensic carrier conc.)

- At room temp., some e^- - hole pair are generated, if temp. rises more e^- - hole pair will be generated. with Increase in temp Carrier conc. ↑es. As there is more charge, conductivity will ↑es

$$n_i^2 = \underset{\text{material constant}}{A_0}\ \underset{\text{Temp.}}{T}^3\ e^{-\left(\frac{E_{g0}}{kT}\right)}$$

E_{g0} → Band gap at 0K

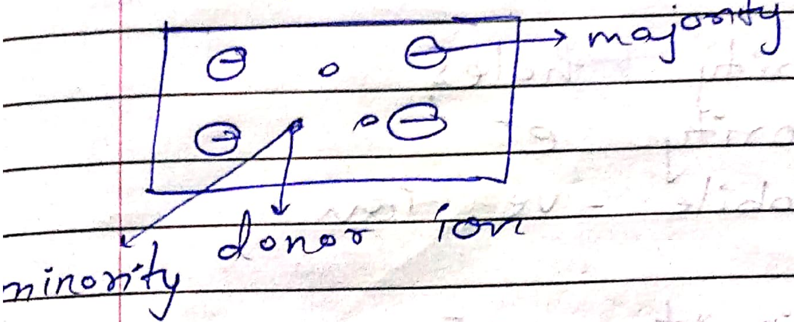
k → Boltzmann constant

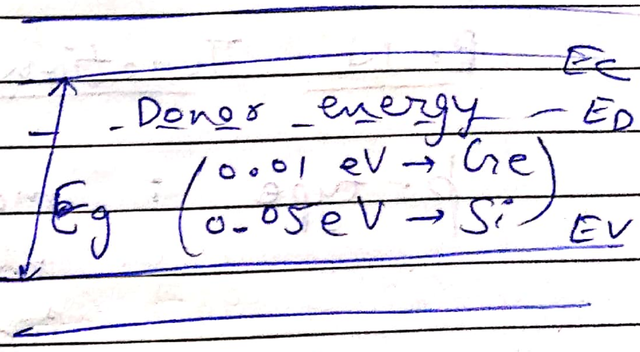
(II) Extrinsic :→

Doping is done to Vary the conductivity by doping crystal has pre-dominance of either e^- or holes.

(i) n-type (ii) p-type

① n-type :-





- pentavalent impurity is added to intrinsic silicon such impurities donate excess el⁻ and refer to as donor or n-type.

- excess el⁻ losely bound to parent atom is relatively free to move within n-type material.
when impurities are added, additional energy levels are added in energy band structure. extra energy level is called Donar energy level (E_D) and it does not depend on temp.

- When doped with n-type impurity not only no. of el⁻ rises but the no. of holes les below that which could be available in intrinsic semiconductor.

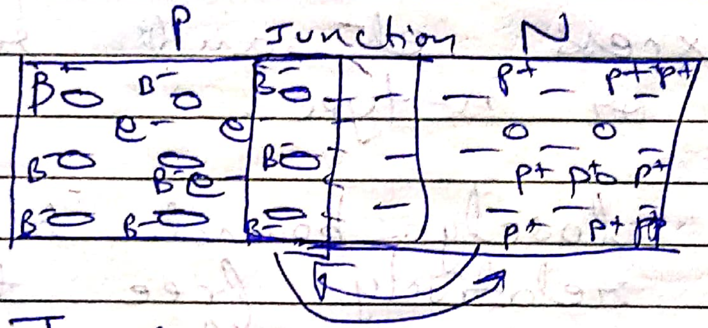
(opposite for p-type)

Date : 21/07/25

P-N Junction:

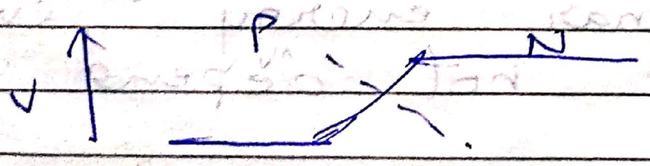
p-type : majority holes
minority e^-
immobile -ve ion

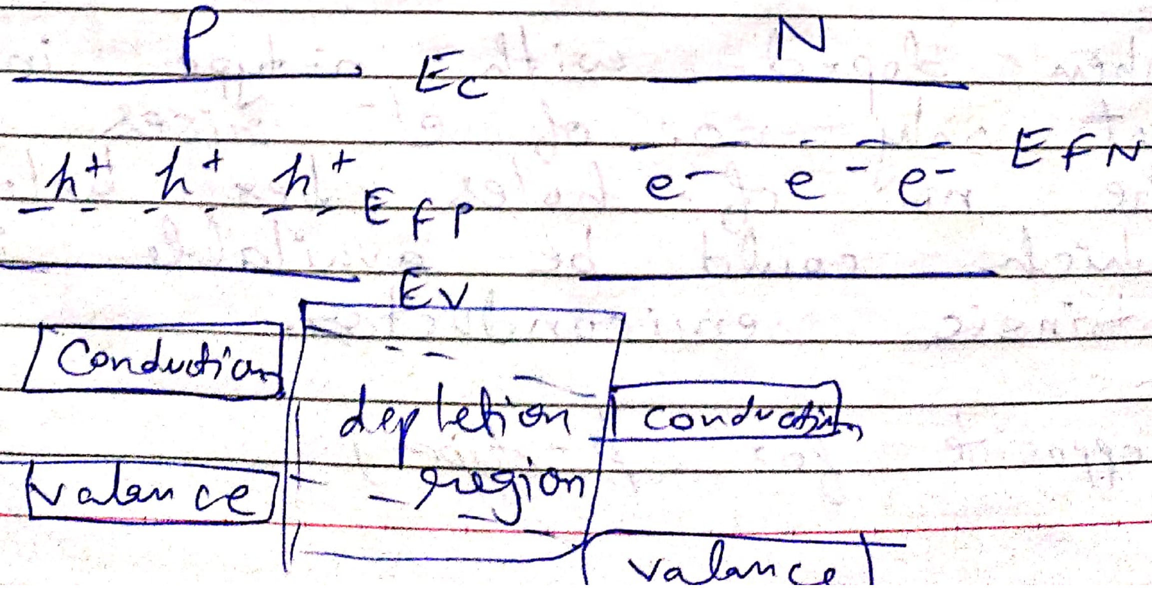
n-type : majority e^-
minority holes
immobile +ve ion



$$\overrightarrow{I_{diff}} = \overleftarrow{I_{drift}} = 0$$

V = P.E of +1C charge





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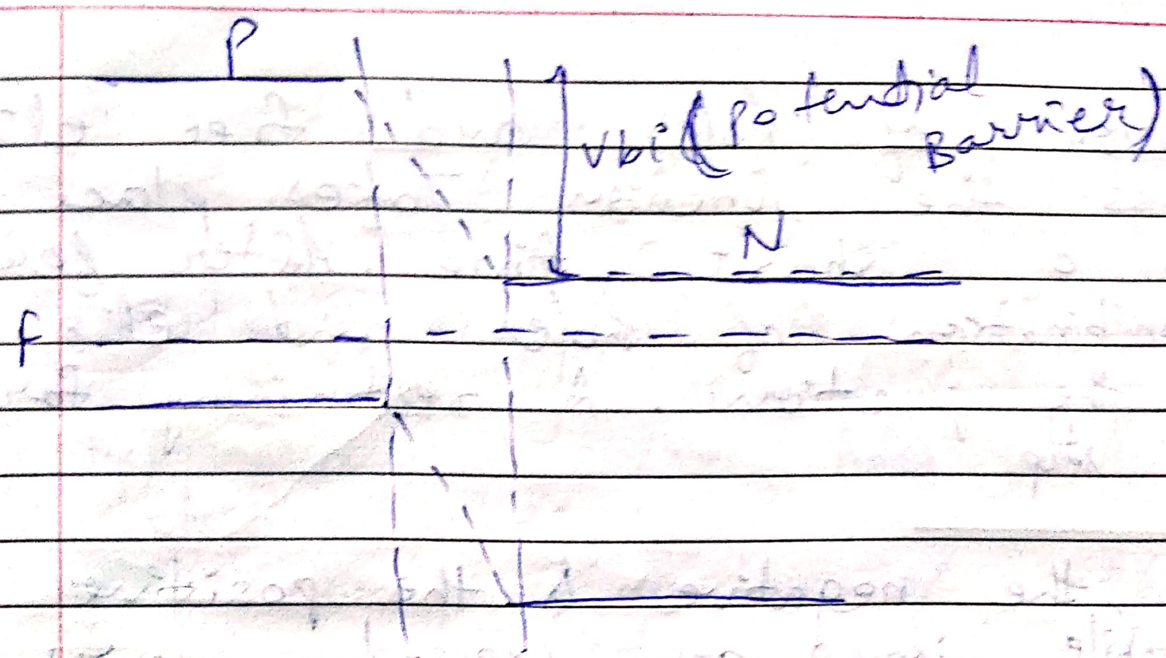

25/07/25

Formation of P-N Junction :-

holes from p-side diffuse to n-side where they combine with free el⁻.

free el⁻s from n-side diffuse to p-side, where they combine with holes.

Diffusion of holes from 'p' to 'n' and free el⁻ from 'n' to 'p' takes place due to difference in concentration in two regions. this difference creates concentration gradient across the Junction and Results in diffusion of mobile charge carriers across the junction.

Date : ___/___/______

diffusion of holes and free el's across the junction Takes place for a short time. After few recombination of holes and el's at the junction. A restraining force is setup.

Here, the negative & the positive immobile ions are exposed. more holes trying to diffuse from p to n gets repelled by the positive ions. Similarly the electrons trying to diffuse from n to p gets repelled by the negative ions. So, the ions act as a barrier for diffusion. Some might be energetic enough that they can diffuse even after Repulsion. So, there is more diffusion, more ions are exposed and thus, the diffusion becomes hard.

The minority carrier at p enter at Junction region because of +ve charge and it attracts the electrons which gets suck into the n type this second motion happens in the opposite direction of diffusion. As time passes diffusion decreases

Date : ___/___/___

and the second motion (Drift) in the opposite dir^n Tes.

Eventually, a point is ~~whi~~ reached where every el⁻ diffusing to n type and every holes will be sucked back.

on average, number of charge carriers on the p-side & n-side remains same. this ~~is~~ equilibrium

★ Band Diagram of P-N Junction:-

free el⁻ in n region occupy upper part of conduction band. holes in p-region occupy bottom part of valence band. now these free el-s from n-region diffuse over the junction and moves to the lower part of p-region

After crossing the junction, the el's lose energy & falls into the holes of p-region valance band

At equilibrium.

★

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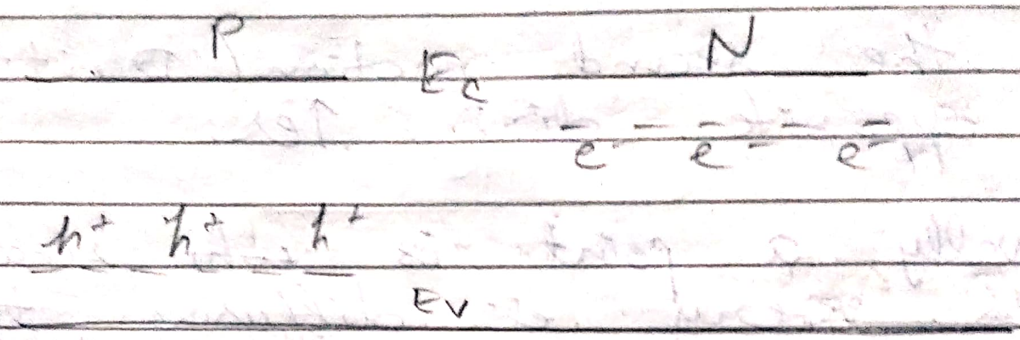

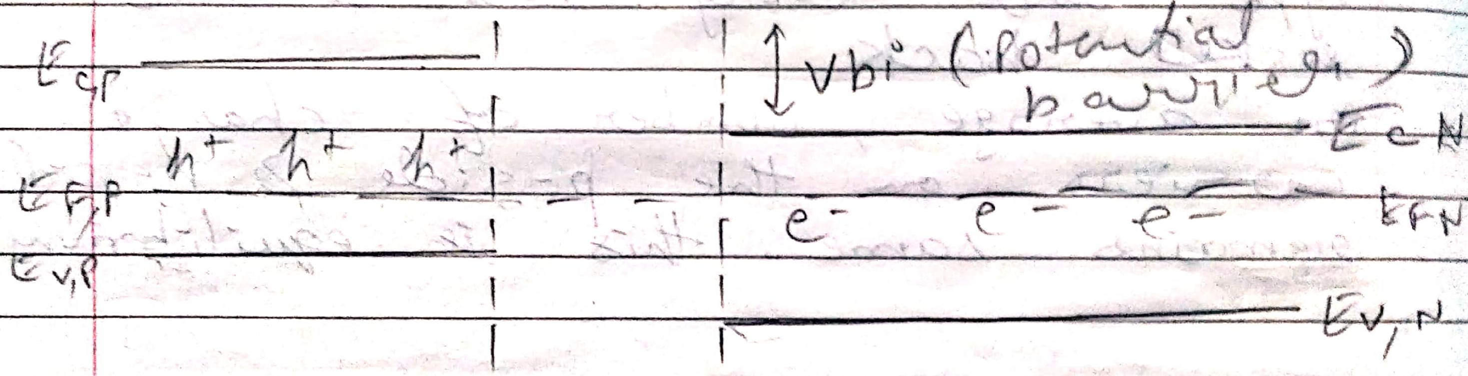

As diffusion continues Depletion region forms and the energy levels at n-side of conduction band. the les in conduction band of n-side is due to loss of higher energy el$\bar{s}$ that has already diffused across the junction to p-side. thus, the top of n-side conduction band gets ~~a line~~ to align to bottom of p-side conduction band. this is in equilibrium state.

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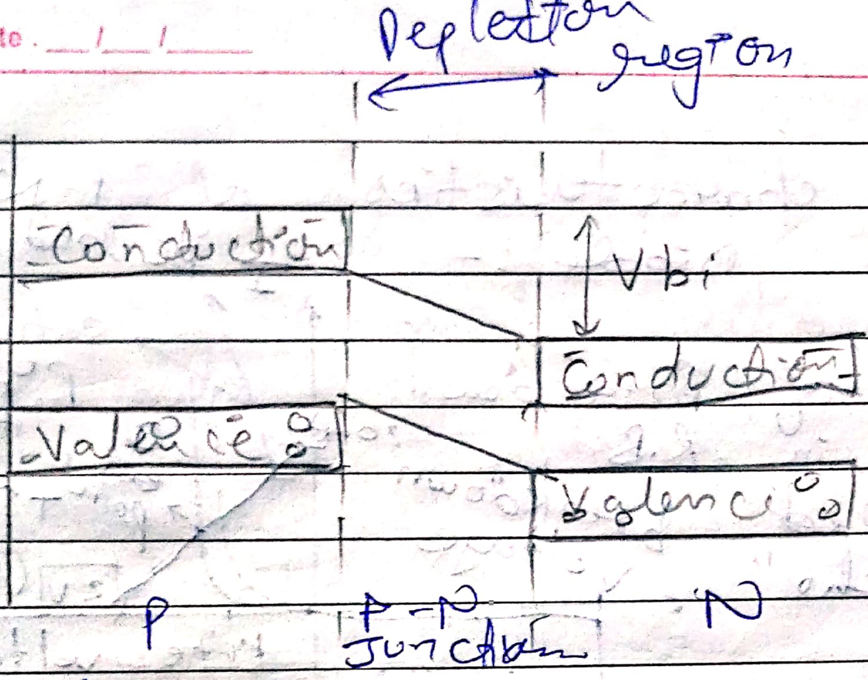
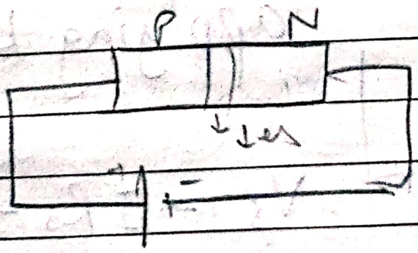
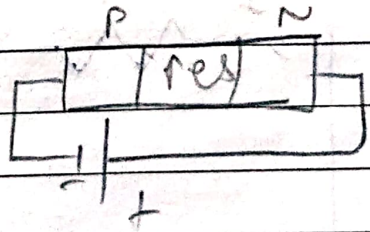
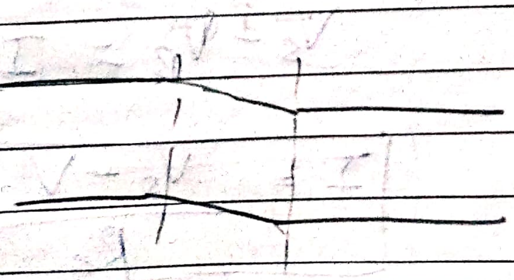


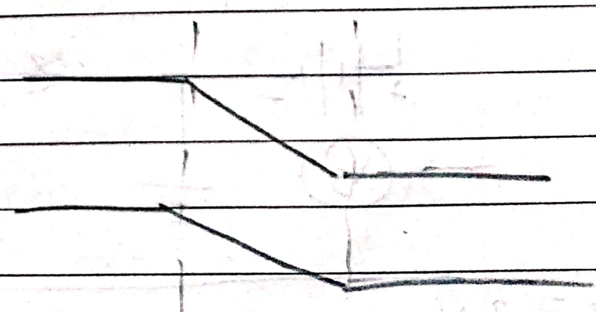
depletion region is complete as diffusion has stop. thus we have ~~add~~ an energy gradient across the junction the n-region els now needs to climb the hill towards the p-side but as conduction band has shifted down simultaneously. Valence band has also shifted; the energy gap between Valence band & Ec remains same.

→ forward biased → ; Reverse biased





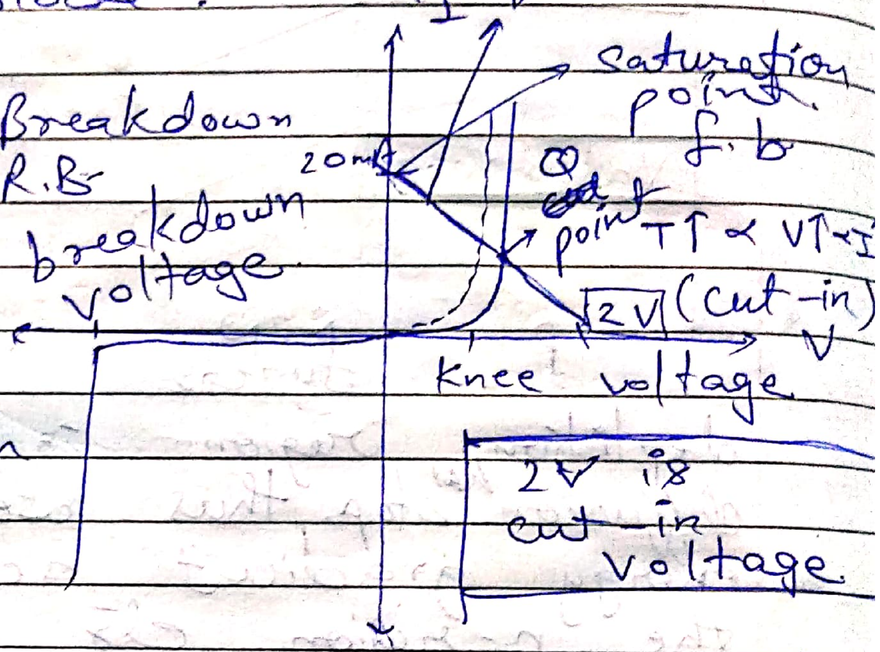




Q - point = operating point

Date 28/7/25

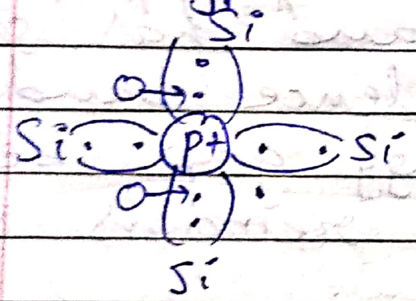
Transfer characteristics of P-N Junction Diode :-



Process of Breakdown voltage in R.B is called "Avalanche"
or
process by which free e^- are formed.

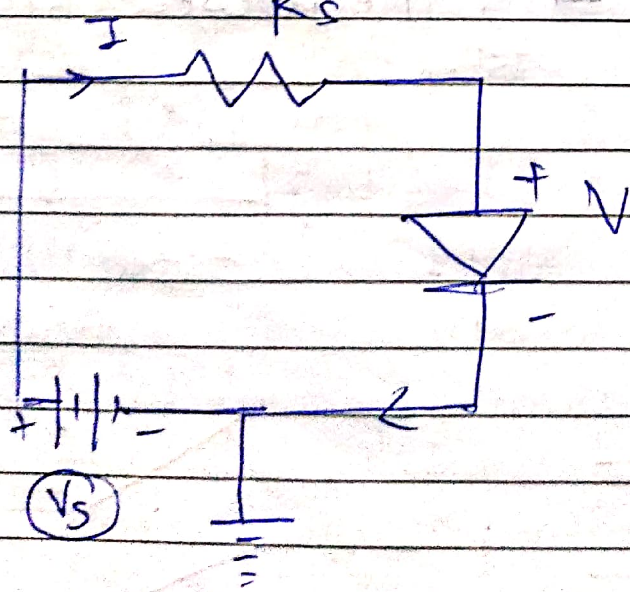
$\boxed{\text{2V is cut-in voltage.}}$

n-type :-



P —▷|— N closed / on

+ve —|◁— -ve open / off



applying KVL,

$$V_s - IR_s - V_B = 0$$

$$V_s - V_B = IR_s$$

$$\boxed{I = \frac{V_s - V_B}{R_s}}$$

$V_s = 2V$

$R_s = 100\,\Omega$

$V_B = 0$

$$I = \frac{2-0}{100} = \boxed{0.02\,A}$$

$$\Rightarrow \boxed{20\,mA}$$

Date: 31, 7, 25

★ Mass - Action law:

under thermal equilibrium, product of e^- and holes concentration is always constant and is equal to the square of intrinsic carrier concentration.

$$\cancel{n_i^2 = n_e h} \boxed{n_i^2 = np} = \text{constant}$$

n = e^- conc.
p = hole conc.
n_i = intrinsic conc.

this law mainly finds concentration of minority carriers

p-type $\rightarrow$ $n_p = \frac{n_i^2}{p_p}$

n-type $\rightarrow$ $p_n = \frac{n_i^2}{n_n}$

$$\text{minority carrier conc.} = \frac{n_i^2}{\text{majority carrier conc.}}$$

but majority carrier conc. is directly proportional to doping.

→ maj. conc. $\propto$ doping

→ min. conc. $\propto \frac{1}{\text{doping}}$

Date : __ / __ / ____

product of majority and minority conc is constant.

Q→ In p-type silicone sample, hole conc is $2.5 \times 10^{15}\ cm^{-3}$ if the intrensic carrier conc is $1.5 \times 10^{10}\ cm^{-3}$, then find the el⁻ conc. in p-type silicone sample

⇒ $n_i^2 = np$

$(1.5\times10^{10})^2 = n \times 2.5 \times 10^{15}$

$\frac{15}{10} \times \frac{15}{10} \times 10^{20} = n \times \frac{25}{10} \times 10^{15}$

$\frac{15 \times 15 \times 10^{20} \times 10^{-15}}{10 \times 25} = n$

$\boxed{n = 9 \times 10^{4}\ cm^{-3}}$

→ **Charge neutrality equation :→**

Total +ve charge = Total −ve charge

$(p^+) + N_D = (n) + N_A$

n = el⁻ conc.

p^+ = holes

N_D = donor ion

N_A = Acceptor ion.

Date ___/___/___

n-type $\rightarrow$ $p + N_D = n + N_A$

$n > p$ $N_A = 0$

$$\frac{n_i^2}{n} + N_D = n \quad \left(p = \frac{n_i^2}{n}\right)$$

$$N_D = n - \frac{n_i^2}{n}$$

$$N_D = \frac{n^2 - n_i^2}{n}$$

$$n N_D = n^2 - n_i^2$$

$$n_i^2 - n^2 + n N_D = 0$$

$$n = \frac{N_D}{2} + \sqrt{\left(\frac{N_D}{2}\right)^2 + n^2}$$

$$\boxed{N_D >>> n_i^2}$$

$$\boxed{n \approx N_D}$$

for p-type $\longrightarrow$ $\boxed{p \approx N_A}$

$\Rightarrow$ Temperature & Conductivity relation :-

effect of Temp on conductivity in intrinsic semiconductor :

$$\sigma = n_i q (\mu_n + \mu_p)$$

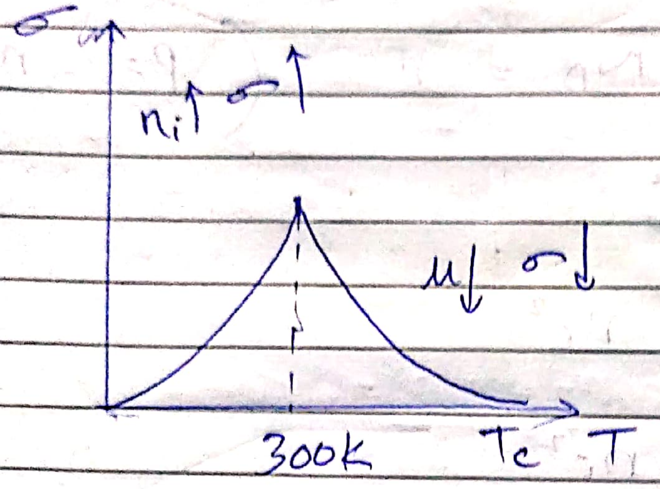
$\sigma \downarrow$ Conductivity

$\mu_n \downarrow$ mobility of e^-.

$\mu_p \rightarrow$ mobility of holes.

Date : __ / __ / __

effect of Temp. on conductivity in extrinsic semiconductor :



$0 < T < 300k$

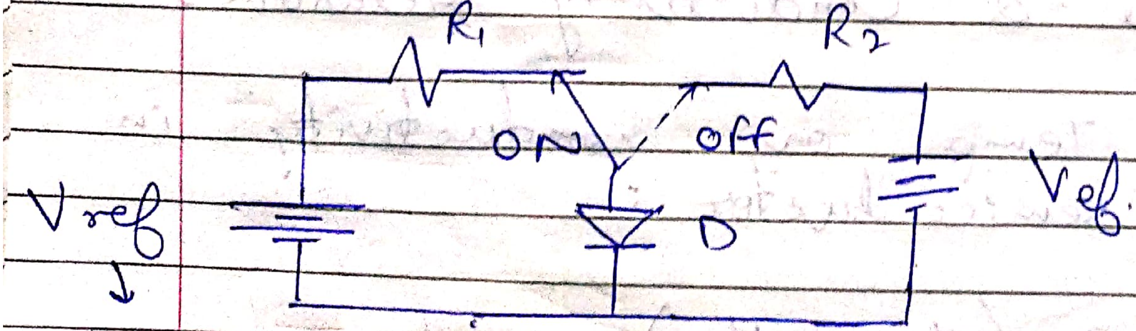
$300\,k < T < T_c$

$\boxed{T > T_c}$

1st August, 2025

- Application of Diode

1) as a switch
2.) As a rectifier
3.) As clipper & clamper

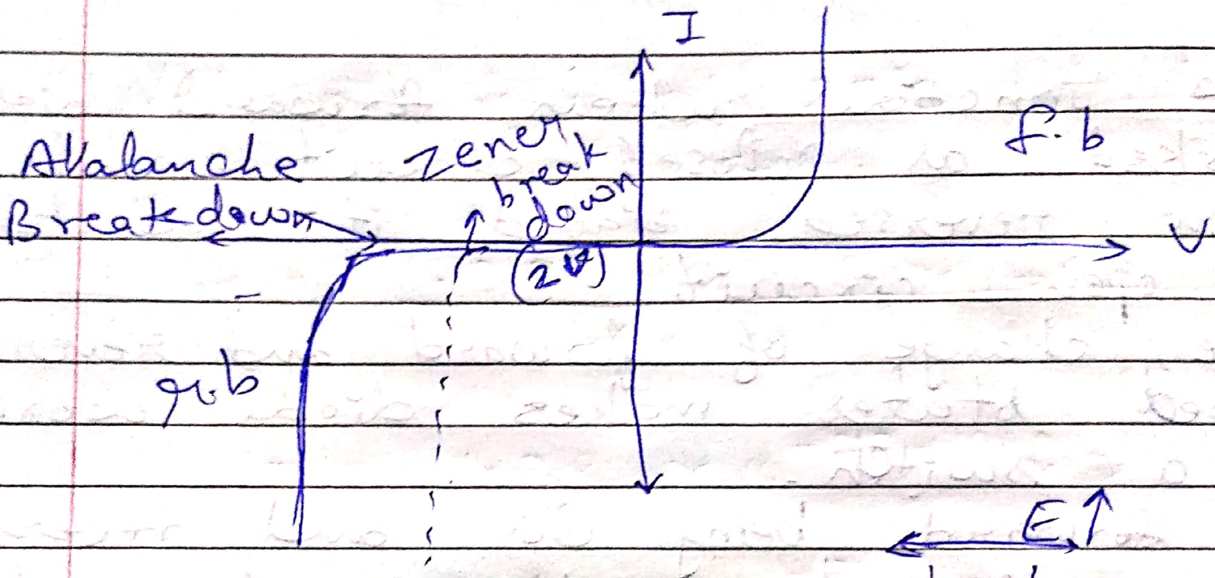


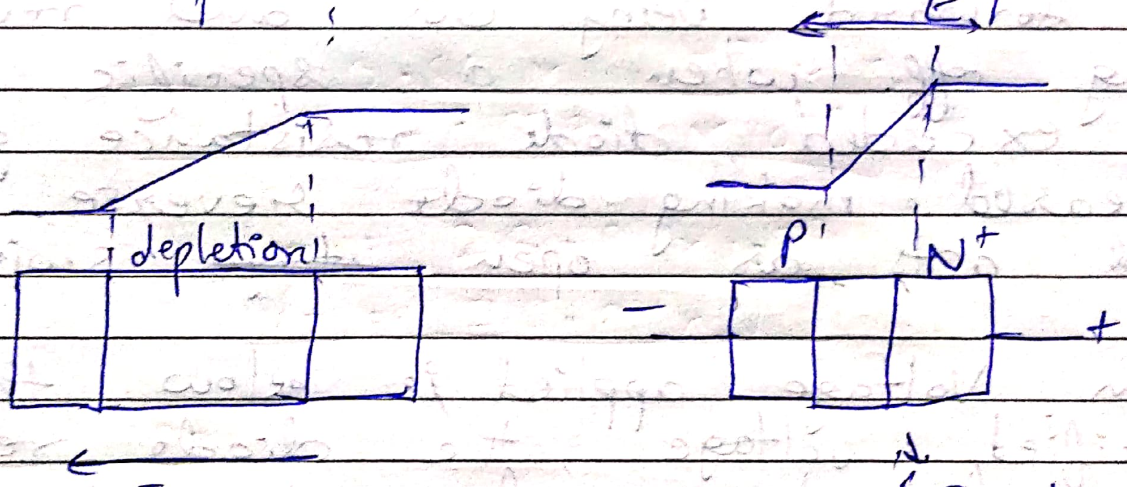
V ref → reference voltage.

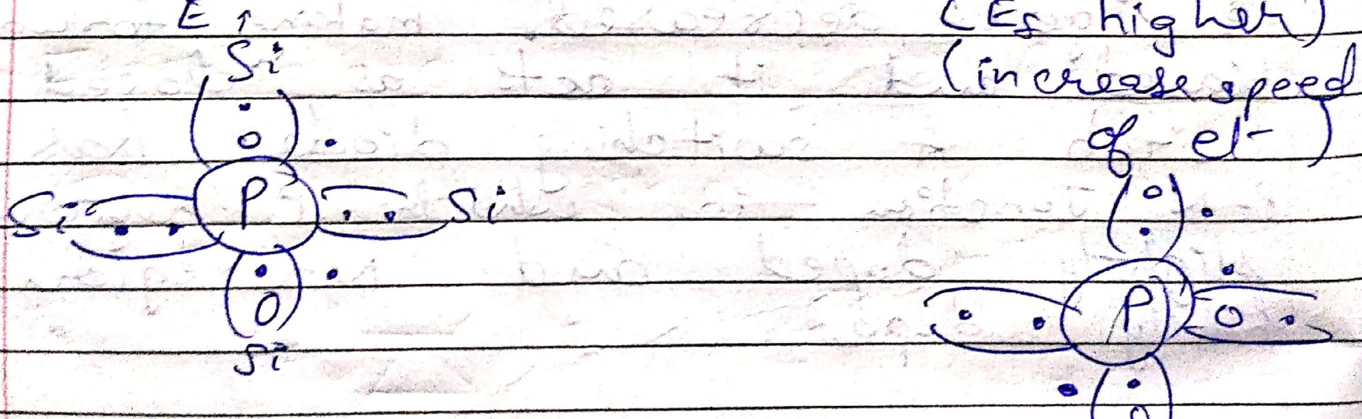
P-N Junction when forward biased worked as closed circuit and when reversed biased it works as open circuit.
Hence, change of forward and reverse biased states makes diode work as a switch.
The forward being on and reverse being off. When a specific voltage is exceeded, diode resistance gets increased making diode reverse biased and acts as open ~~stage~~ switch.

When Voltage applied is below the specified voltage, the diode resistance gets decreased making forward biased and it acts as closed switch. A switching diode has P-N Junction in which P-region is slightly doped and N-region is havily doped.

Date : 4th Aug 2025

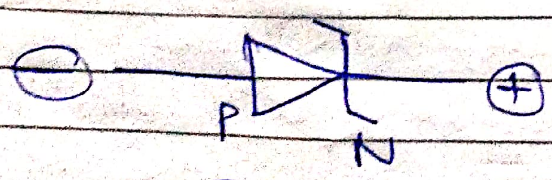




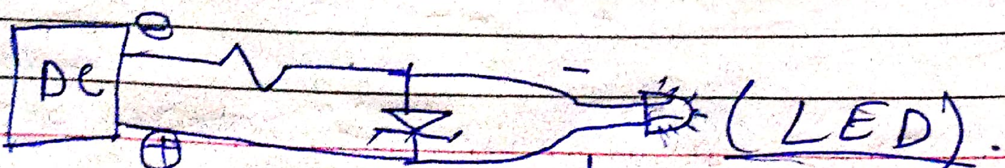


Zener diode :-

(use as a voltage regulator)



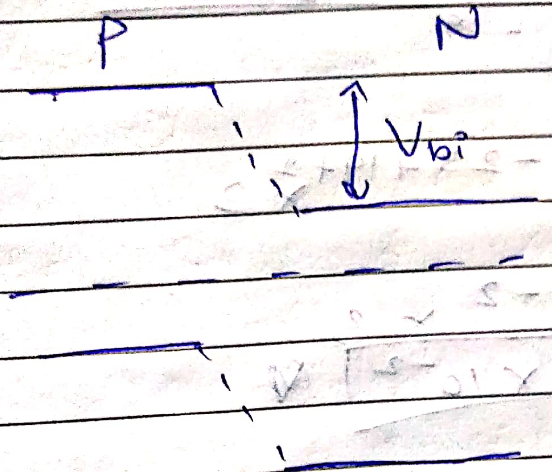
← symbol.



Date . __/__/__

★ Built in potential Voltage :

V_{bi} = potential Barrier.



$$\boxed{V_{bi} = \frac{KT}{q} \ln\left(\frac{N_A \cdot N_D}{n_i^2}\right)}$$

It is the potential difference across the depletion region of a diode even when no external voltage is applied.

Diode Current Eq^n :-

$$I_D = I_S \left(e^{V_D/nV_T} - 1\right)$$

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

(I_D = reverse Saturation Current)

(V_D = Applied voltage)
(n = ideality factor)
(V_T = thermal voltage)
$q = 1.6 \times 10^{-19}$ C
k = Boltzman constant $= 1.38 \times 10^{-23}$ J/K
T_K = absolute temp. = 273 + temp. in °C

Date : __/__/____

Q. At a temp. of 27°C, find out the thermal voltage.

$$\Rightarrow \quad V_T = \frac{1.38 \times 10^{-23} \times 300}{1.6 \times 10^{-19}}$$

$$V_T = \frac{1.38}{1.6} \times 10^{-23+19+2} \times 3$$

$$0.86 \times 10^{-2} \times 3$$

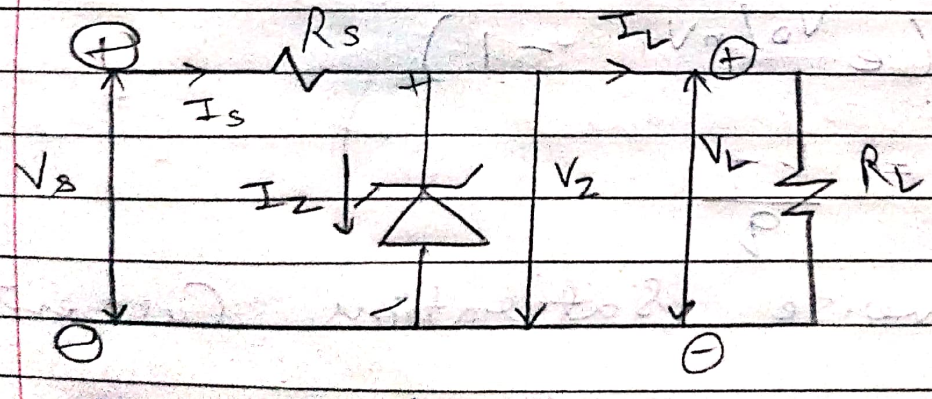
$$\boxed{V_T = 2.578 \times 10^{-2}}$$

$$V_T = 25.8 \times 10^{-3}$$

$$\boxed{V_T = 25.8\ mV}$$

8th August, 25

:→ Zener diode as Voltage Regulator:



V_s = Input dc voltage

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

V_z = Zener Voltage

Voltage drop across V_z $= I_z \cdot r_z$

r_z = reverse resistance

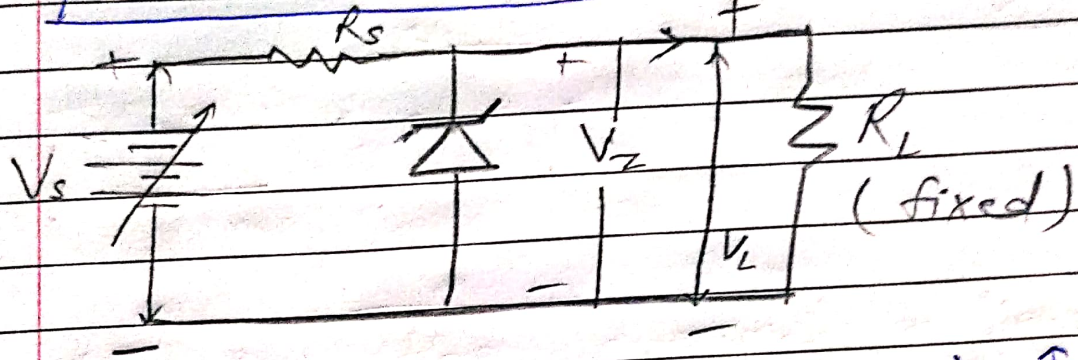
Voltage across terminal $(V_L) = V_z + I_z r_z$

if r_z is negligible.

$$V_L = V_Z$$

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

$$\boxed{I_Z = I_S - I_L}$$



1) Varying input voltage: $V_s \uparrow$, $I_s \uparrow$

I_L = constant

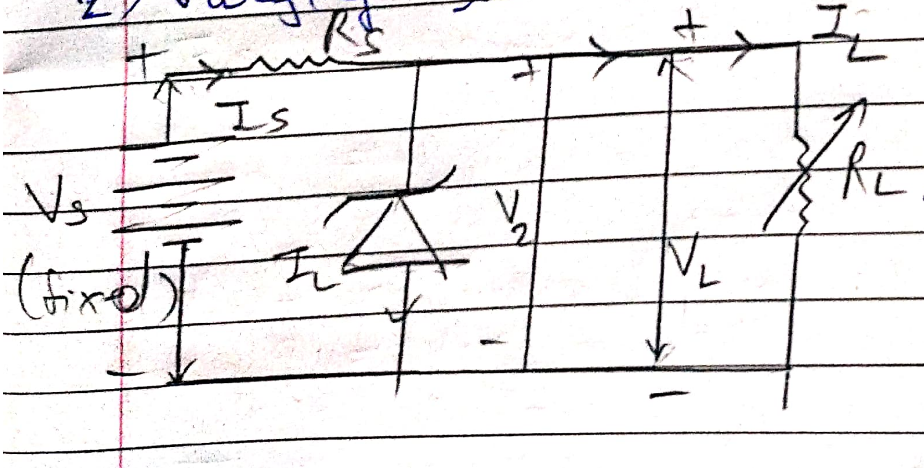
$V_s \uparrow$, voltage drop $\uparrow$

$R_s \uparrow$, V_L = const.

$V_s \downarrow$, $I_s \downarrow$, voltage drop $\downarrow$, $R_s \downarrow$,

I_L, V_L = constant.

2) Varying load Resistance: $R_L \downarrow$, $I_L \uparrow$,



so, $I_Z \downarrow$, ~~$I_s R_s$~~

$I_s R_s$ = constant.

V_L = constant.

$R_L \uparrow$, $I_L \downarrow$, $I_Z \uparrow$

$I_S R_S$ = constant , V_L = constant