Date :
Page No. :

Intro. to Semi-Conductors

→ Difference between Metals, Semi-Conductors and Insulators

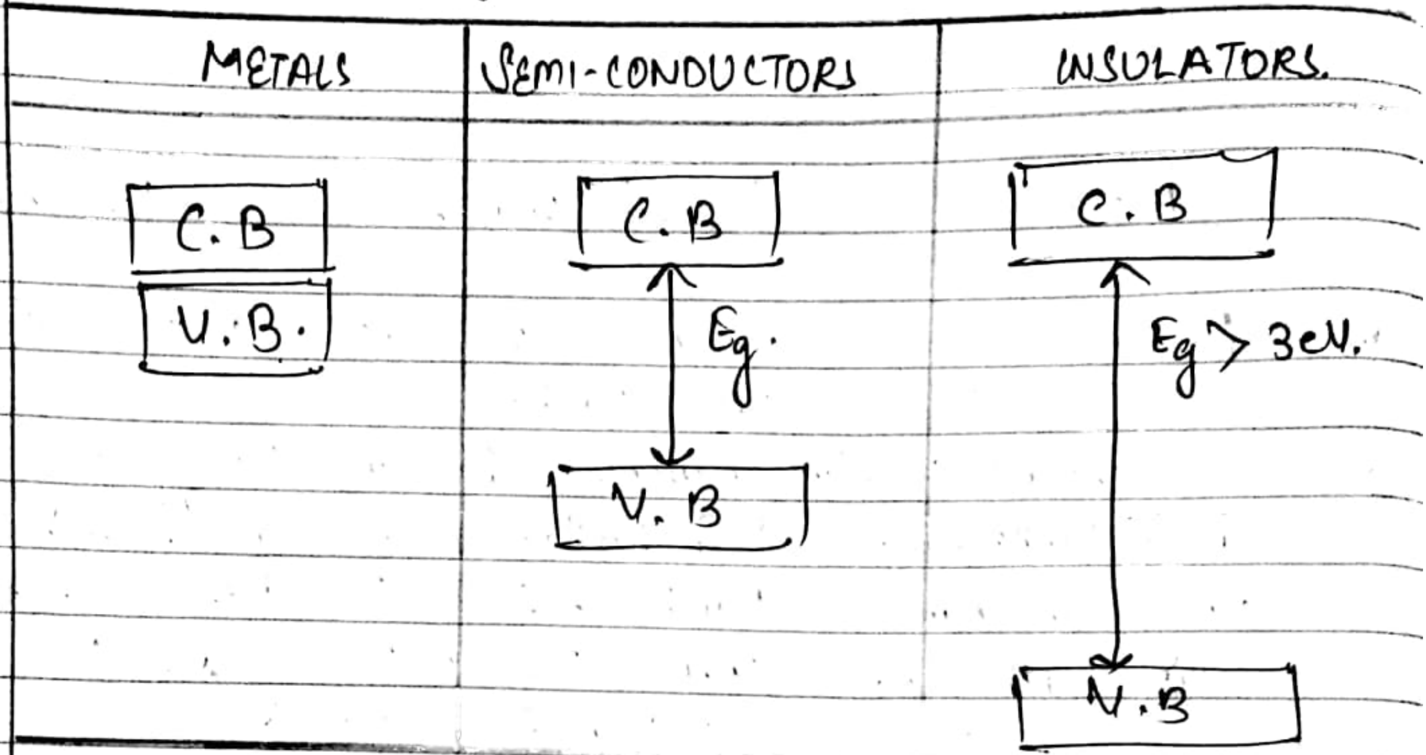
	Metals	Semi-Conductors	Insulators
1.	Free e's	e's becomes free at room temp.	No free e's
2.	Conductivity ↓ with ↑ in temperature	Conductivity ↑ with ↑ in temperature.	No effect of temp. on conductivity.
3.	They have almost zero band gap.	Band gap is greater than metals but less than insulators	Very high band gap.
4.	Cu, Fe, Ag, Al, Au etc.	Si, Ge, GaAs, etc.	wood, plastic, paper etc.

→ Energy bands : Every material is composed of atoms. Each atom has certain discrete energy levels. When the atoms come close to each other, these energy levels split and gives rise to ~~ov~~ overlapping energy levels which contains a range of energies. These are known as energy bands.

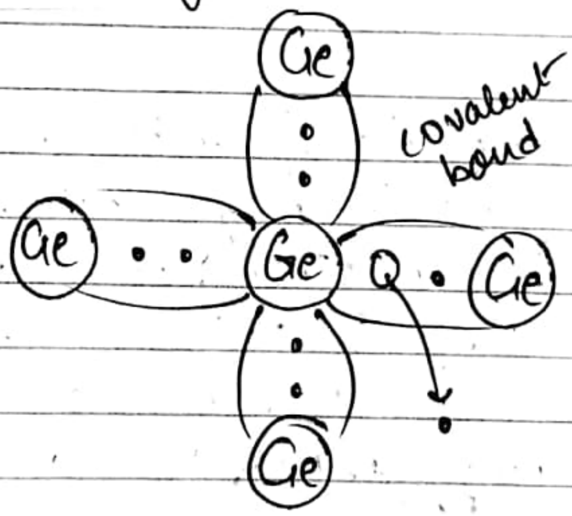
The completely filled band is known as Valence band and the partially filled band is known as Conduction band. Sometimes, there is gap between the conduction band and valence band which is known as Band Gap of that particular material.

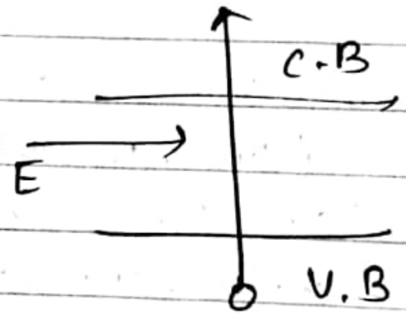
Scanned by CamScanner

Difference between Metals, Semi-conductors and insulators w. r. to. energy bands.



Concept of electrons and holes.



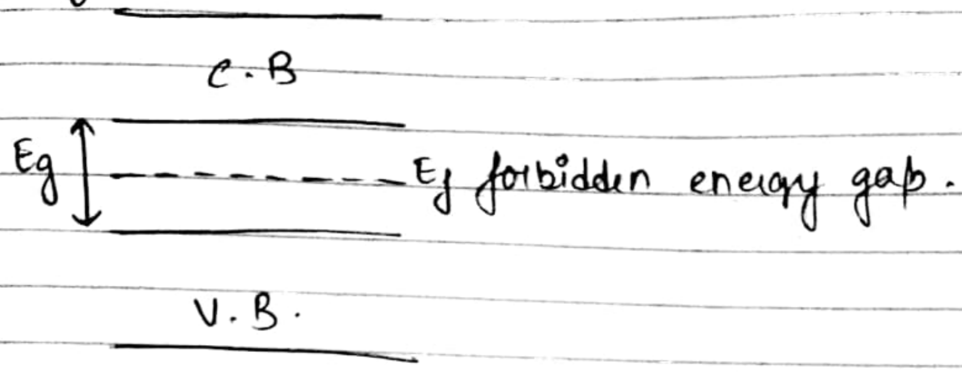


~~Doping~~ FERMI-ENERGY Fermi energy is the quantum mechanical concept & usually refer to the energy of the highest occupied quantum state in a system of fermi ~~atoms~~ ions at absolute temp.

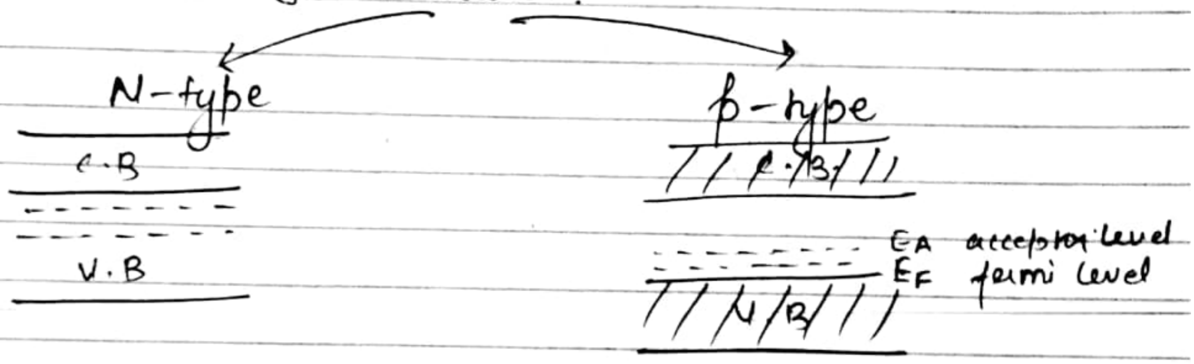
Fermi level is the max. energy which can be occupied by an electron at absolute 0K.

FERMI-ENERGY DIAGRAM

~~Law of Mass Action~~: (for Intrinsic Semiconductor):



for extrinsic semiconductor:



→ LAW OF MASS ACTION:

Under thermal equilibrium for any semiconductor, product of no. of holes and no. of $\bar{e}$s is constant and is independant of amount of doping. This relation is known as Mass-action law.

mathematical expression —

$$\boxed{np = n_i^2}$$

n → $\bar{e}$ concentration

p → hole concentration

n_i → Intrinsic concentration

LAW OF ELECTRICAL NEUTRALITY

Total positive charge density is equal to the total negative charge density

mathematical expression :-

$$\boxed{N_D + P = N_A + n}$$

where, N_D = concentration of donor atom

P = hole concentration

N_A = concentration of acceptor atom

n = electron concentration.

1. for n-type semiconductor;

$$N_A = 0, \quad n >> P$$

$$\therefore N_D + P = N_A + n$$

$$\therefore \boxed{N_D = n \text{ for n-type semiconductor}}$$

Also, $\boxed{p = \frac{n_i^2}{n} = \frac{n_i^2}{N_D}}$

2. for p-type semiconductor;

$$N_D = 0 \quad p >> n$$

$$\therefore N_D + P = N_A + n$$

$$\therefore \boxed{N_A = P \text{ for p-type semiconductor}}$$

$$\boxed{n = \frac{n_i^2}{p} = \frac{n_i^2}{N_A}}$$

NOTE : $J = \frac{I}{A} = neV_d$

$V_d = \underbrace{\mu}_{\text{mobility}} E \quad \therefore \boxed{J = ne\mu E}$

$J_e + J_p \longrightarrow p e \mu_p E$

current density $\longleftarrow J = \sigma E$ microscopic form of ohm's law

conductivity $\longleftarrow$ $\boxed{\sigma = ne\mu}$

$F = qE \quad \therefore \quad a = \frac{F}{m} = \frac{qE}{m}$

$\because \; v = at = \frac{qE}{m} t \longrightarrow$ relaxation time

$= \mu E$

$\boxed{\mu = \frac{qt}{m}}$

N = No. of free e⁻s distributed in the conductor
L = length of the conductor
A = cross-section of the conductor

$I = q \cdot \frac{N}{T}$

$\therefore \; I = q \cdot \frac{N}{T} \times \frac{L}{L}$

$\therefore \; \frac{I}{A} = q \frac{N.v}{L.A} = J$

$\because \; n = \frac{N}{V}$

$\therefore \; \frac{I}{A} = \frac{q.Nv}{V} = J$

$\boxed{J = q n v} \longrightarrow$ drift velocity

$V \longrightarrow$ volume

$\therefore \; \boxed{J = q n \mu E}$

$\therefore J_p = q p \mu_p E \qquad J_n = -qn(-\mu_n E)$

intrinsic semi-conductor

$J_{total} = J_p + J_n$

$J_{total} = qE(p\mu_p + n\mu_n)$

$\therefore \sigma_{total} = q(p\mu_p + n\mu_n)$

n-type $\rightarrow \sigma = qn\mu_n \quad , n >> p$

p-type $\rightarrow \sigma = qp\mu_p \quad , p >> n$

Q/ A Cu wire of 2mm diameter with conductivity $5.8 \times 10^7 \Omega m$ and e^- mobility $0.0032 m^2/V\text{-}s$. is subjected to electric field $20 mV/m$. Find —

(i) Density of free e^- (n)
(ii) Current density (J)
(iii) Current flow in the wire (I)
(iv) Drift velocity. (V_d)

$d = 2mm$

$\sigma = 5.8 \times 10^7 \Omega m$

$\mu = 0.0032 \; m^2/V.s.$

$E = 20 mV/m.$

$\sigma = ne\mu.$

$5.8 \times 10^7 \Omega m = n \times 1.6 \times 10^{-19} C \times 0.0032 m^2/V.s$

$\frac{5.8 \times 10^7 \times 10^4}{1.6 \times 10^{-19} \times 32} = n$

$n = \frac{58 \times 10^{30}}{16 \times 32}$

TRANSPORT PHENOMENON

$$J = J_{drift} + J_{diffusion}$$

$$J_{drift} = neV$$

$$V = \mu E$$

$$J_{drift} = J_{n,drift} + J_{p,drift}$$

$$= ne\mu_n E + pe\mu_p E$$

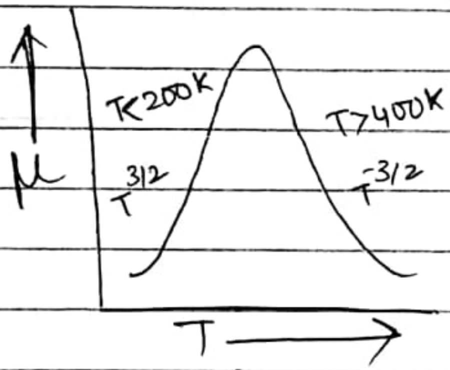
$$= eE(n\mu_n + p\mu_p)$$

$$J = \sigma E$$

$$\sigma_{drift} = e(n\mu_n + p\mu_p)$$

$$\boxed{\sigma = ne\mu}$$

Temperature variation of Conductivity.



T < 200K impurity scattering
T > 400K lattice scattering.

$\boxed{J_{diffusion}}$: flow of charge carriers due to concentration gradient.

$$-\frac{dn}{dx}$$

$J_{n,diffusion}$ = diffusion current due to electrons

$$J_{n,diffusion} = eD_n \cdot \frac{dn}{dx}$$ ⟶ diffusion coefficient

$$J_{p,diffusion} = -eD_p \cdot \frac{dp}{dx}$$

$$J_{diffusion} = J_{n,diff.} + J_{p,diff.}$$

$$= eD_n \frac{dn}{dx} - eD_p \frac{dp}{dx}$$

Page No. :

PN Junction Diode

NOTE: Points to remember :- formation of depletion, Built in potential, potential barrier, forward bias, Reverse bias, Reverse saturation current, Breakdown voltage.

Q/ How depletion layer is formed ?

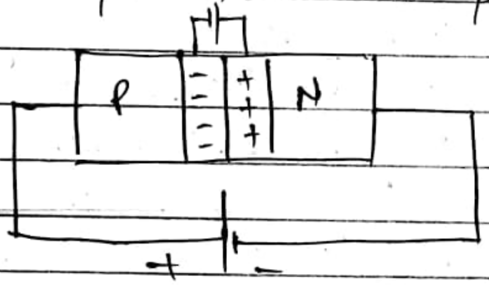
When PN Junction diode is formed, a concentration gradient exists across the junction as e's are majority charge carriers on n-side but minority charge carriers on p-side, similarly, holes are majority charge carriers on p-side but minority charge carriers on n-side. Due to this concentration gradient, diffusion of charge carriers occurs across the junction. Due to diffusion, e's on n-side leave the donor atoms and these donor atoms forms positive donor ions, similarly, on p-side when holes leave the acceptor impurities, acceptor impurities forms negative ions. Due to this process near the junction, a layer is formed which has positive immobile ions on n-side and negative immobile ions on p-side. This layer is depleted of mobile charge carriers and is known as Depletion layer.

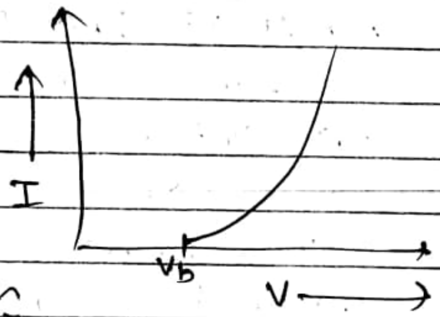
Q/ What is potential barrier ?

Inside the depletion layer, due to formation of positive charges on n-side and negative charges on p-side, a potential difference originates which is known as potential barrier. This potential barrier stops the further diffusion of charge carriers.

FORWARD BIASING

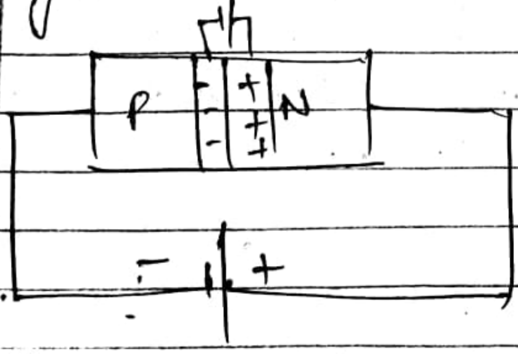
In p-n junction diode, the potential barrier stops the diffusion of carriers across the junction. In order to achieve conduction in a diode, it is necessary that charge carriers are able to cross the junction. This can only be done if we apply an external voltage to counter the potential barrier. This biasing of the diode is known as forward bias. Here, we connect p-side with positive terminal and n-side with negative terminal of the battery. Due to forward bias, the depletion layer becomes thinner and finally vanishes when the external voltage exceeds the potential barrier.

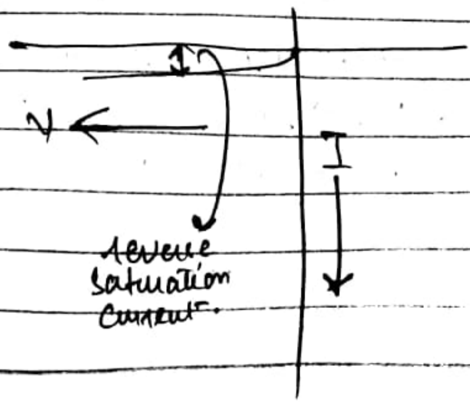




REVERSE BIASING

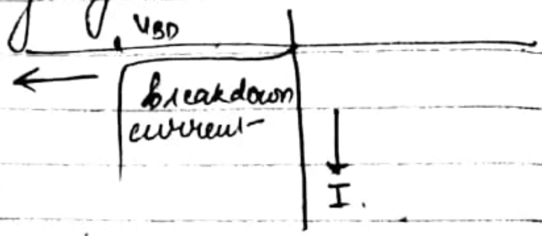
In reverse bias, p is connected to negative terminal and n is connected to positive terminal. This biasing adds to the potential barrier and depletion layer expands. In this case, minority charge carriers are able to cross the junction and we get a very small value of current which is known as reverse saturation current.





BREAK DOWN

Under reverse bias, we get a small value of current due to minority charge carriers but when the reverse voltage is increased beyond a threshold value, the current suddenly increases. This particular value of reverse voltage is known as Breakdown voltage and the phenomenon of sudden increase of reverse current is known as Breakdown.
Breakdown occurs due to breaking of covalent bonds and creation of new charge carriers.

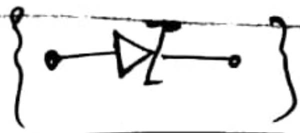


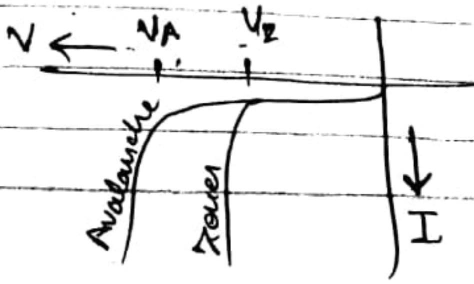
Breakdown is of two types :-

1. AVALANCHE BREAKDOWN: This breakdown occurs for a very high value of reverse voltage. So due to high value of the voltage, covalent bonds of the semiconductor are broken and charge carriers are generated. These charge carriers make collisions with neutral atoms and molecules and knockout many more charge carriers and this process continues till the diode completely burns. This is an uncontrolled process.

2. ZENER BREAKDOWN: Zener Breakdown occurs at sufficiently small values of reverse voltage because in this case, the diode is highly doped and it takes a small value of reverse voltage to break the covalent bonds.
Zener breakdown is similar to avalanche breakdown, the only difference is that in this case the diode is highly doped and by controlling the doping, we can control the breakdown voltage.

Difference b/w the two Breakdowns



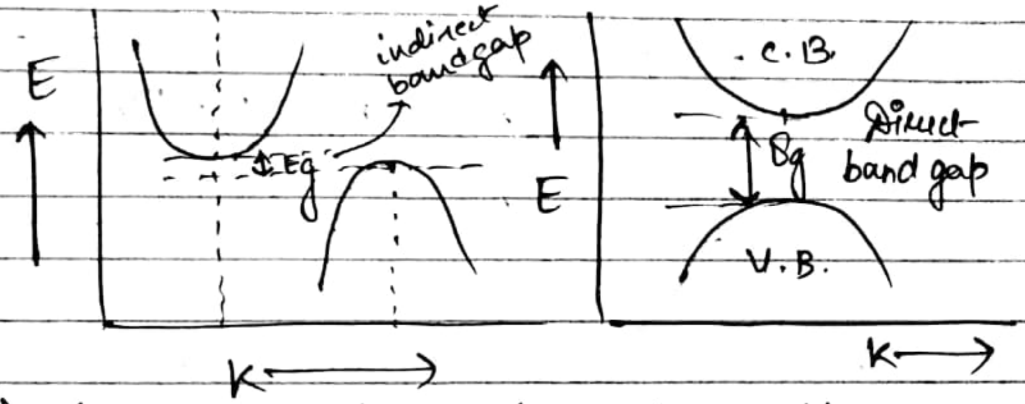


Diode Equation

Diode current ; $I = I_s\left(e^{qV/nKT} - 1\right)$

where, V = applied voltage
q = electronic charge
n = ideality factor
K = Boltzmann constant
T = temperature

$n = 1$ for indirect band gap semiconductors (Ge, Si)
$n = 2$ for direct band gap semiconductors (GaAs, InP)



$\frac{KT}{q}$ is known as thermal voltage, V_{TH}

for 300K, $\underline{V_{TH} = 25.9\,mV}$

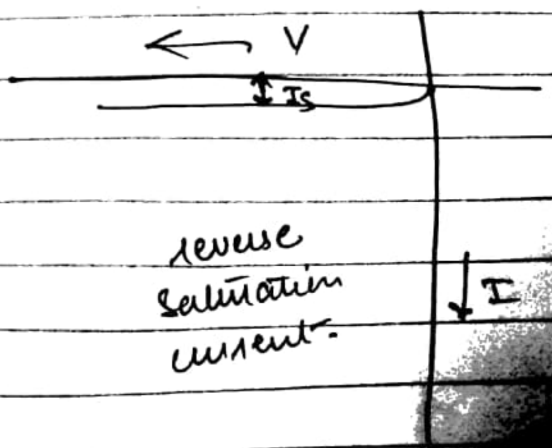
$$I = I_s\left(e^{V/nV_{TH}} - 1\right)$$

(1) for reverse bias, V is negative

$$I = I_s\left(e^{-V/nV_{TH}} - 1\right)$$

$$I = I_s\left(\frac{1}{e^{V/nV_{TH}}} - 1\right)$$

$$\therefore \boxed{I \simeq -I_s}$$

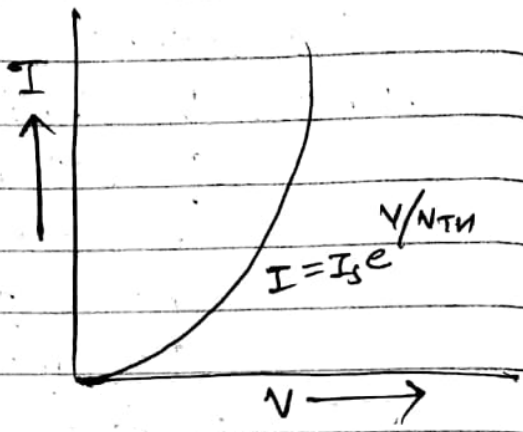


Date :
Page No. :

(2) for forward bias, V is positive

$$I = I_s\left(e^{V/nV_{TH}} - 1\right)$$

$$\boxed{I = I_s e^{V/nV_{TH}}}$$



<u>Built in potential.</u>

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

Q/ When a large reverse bias is applied, the current flowing through a diode at room temperature is 3×10^{-7} A. Calculate the current flowing the diode when 200mV forward bias is applied.

$I_s = 3\times10^{-7}$ A $\qquad n = 1$

~~$I = 3\times10^{-7}$ A~~

$$I = I_s\left(e^{V/nV_{TH}} - 1\right)$$

$$= 3\times10^{-7}\left(e^{200/25.9}\right)$$

$$= 3\times10^{-7}\, e^{7.78}$$

$$= 3\times10^{-7}\times$$

Q) A Ge Diode displays a forward voltage of 0.25V and 10mA current at room temperature. Estimate the reverse saturation current I_s. Assume diode ideality factor to be 1. Calculate the bias voltage needed for the diode currents of 1mA and 100mA. Estimate the value of I_s & also forward current at 0.25 V and at 30°C above R.T.

$$\cancel{I = I_s\left(\frac{1}{e^{V/\eta V_{TH}}} - 1\right)}$$

$$\cancel{I = I_s\left(e^{V/\eta V_{TH}} - 1\right)}$$

$$\cancel{10 = I_s\left(\frac{1}{e^{0.25\times10^{-3}/25.9}} - 1\right)}$$

$$\cancel{= I_s\left(\frac{1}{e^{5/6\times10^{-3}}} - 1\right)}$$

$$\cancel{= I}$$

(i) $I = I_s e^{V/\eta V_{TH}}$

$$10\times10^{-3}A = I_s \times e^{\frac{0.25\times10^{+3}mV}{25.9}}$$

$$= I_s \times e^{\frac{250}{30}}$$

$$10^{-2}A = I_s \times e^{10.8}$$

$$I_s = \frac{10^{-2}}{e^{10}} \simeq 7\times10^{-7}A$$

(ii)

$$1\times10^{-3}A = 7\times10^{-7}\left(e^{V/25.9\times10^{-3}}\right)$$

~~taking log on both sides~~

$$1 = 7\times10^{-4}\left(e^{V/25.9\times10^{-3}}\right)$$

$$e^{\frac{V}{25.9\times10^{-3}}} = \frac{1}{7}\times10^{4}$$

$$\frac{V}{25.9\times10^{-3}} = \ln 10^{4} - \ln 7$$

$N = (25.9 \times 10^{-3})(4\ln 10 - \ln 7)$

Q1 The following data is available for an intrinsic semi-conductor at 300k. $\mu_n = 0.39 m^2/V.s$ and $\mu_p = 0.19 m^2/V.s$ and $n = 2.4 \times 10^{19} m^{-3}$ Calculate the resistivity of the material

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

$n.p = n_i^2$

$n = p$

$n^2 = n_i^2$

$n = n_i$

$\sigma = 1.6 \times 10^{-19}(0.39 \times 2.4 \times 10^{19} + 0.19 \times 2.4 \times 10^{19})$

$= 1.6(0.39 + 0.19) \times 2.4$

$= 1.6 \times 2.4 (0.58)$

$\rho = \frac{1}{1.6 \times 2.4 \times 0.58} = 0.449 \Omega m$

Q2 Calculate the no. of atoms for an n-type semi-conductor whose resistivity is $0.449 \Omega m$; $\mu_n = 0.6 m^2/V.s$

$\frac{1}{0.449} = n \mu_n e$

$n = \frac{1}{0.449 \times 0.6 \times 1.6 \times 10^{-19}}$

$= 2.32 \times 10^{19}$

$N_D = 2.32 \times 10^{19}$

Q3 A pure Ge at 300k having density of charge carriers ~~at~~ as $2.25 \times 10^{19} m^{-3}$ is doped with impurity P atoms at 1 in 10^6. $\mu_n = 0.4 m^2/V.s$. $\mu_p = 0.2 m^2/V.s$. The no. of intrinsic atoms is 4×10^{28} atoms$/m^3$. If all the impurity atoms are ionised ~~fixed~~. Find the resistivity of n-type semi-conductor.

$$Total = 4 \times 10^{28}$$

$$N_D = \frac{4 \times 10^{28}}{10^6} = 4 \times 10^{22}$$

$$4 \times 10^{22} \times p = (2.25 \times 10^{19})^2$$

$$= 1.3 \times 10^{16}$$

$$\sigma = (4 \times 10^{22} \times 1.6 \times 10^{-19} \times 0.4) + (1.3 \times 10^{16} \times 1.6 \times 10^{-19} \times 0.2)$$

$$= 2560$$

$$\rho = 3.9 \times 10^{-4} \, \Omega m$$

(4) (1)

To an intrinsic Si crystal —

(i) Donor type impurity are added so as to have an n-type semi-conductor having $\rho = 10^{-4} \, \Omega m$.

(ii) Acceptor type impurities are added so as to have a p-type semiconductor having $\rho = 10^{-4} \, \Omega m$. Calculate the density of impurity atoms in each case give that $\mu_e = 0.36 \, m^2/Vs$ and $\mu_p = 0.18 \, m^2/Vs$

(i)
$$10^4 = n \times 0.36 \times 1.6 \times 10^{-19}$$

$$n = 1.7 \times 10^{23}$$

(ii)
$$10^4 = p \times 0.18 \times 1.6 \times 10^{-19}$$

$$p = \cancel{0.85 \times} \frac{1.7 \times 10^{23}}{2}$$

$$= 3.47 \times 10^{23}$$

Q(5)

At room temperature, the diode current is 0.5 mA at 0.45 V and 25 mA at 0.65 V. Determine n.

$$I = I_s (e^{V/nV_{TH}} - 1)$$

$$0.5 \, mA = I_s (e^{0.45/n.25.9} - 1) \quad \text{—— (1)}$$

$$25 \, mA = I_s (e^{0.65/n25.9} - 1) \quad \text{—— (2)}$$

dividing (2) by (1)

$$\frac{250}{0.5} = \frac{\cancel{I_s}}{\cancel{I_s}} \left\{ \frac{e^{0.65/n \cdot 25.9\times10^{-3}} - 1}{e^{0.45/n \cdot 25.9\times10^{-3}} - 1} \right\}$$

neglecting 1 as it is a very small value

$$\therefore \quad 50 = \frac{e^{0.65/n \cdot 25.9\times10^{-3}}}{e^{0.45/n \cdot 25.9\times10^{-3}}}$$

$$50 = e^{0.2/n \times 25.9\times10^{-3}}$$

$$\ln 50 = \frac{0.2}{n \times 25.9 \times 10^{-3}}$$

$$\frac{1.69}{100} = \frac{0.2 \times 1000}{n \times 25.9}$$

$$\therefore n \simeq 1.9$$

Q6. A silicon diode has reverse saturation current of $0.1 \mu A$ at $27^\circ C$. Find reverse saturation current at $37^\circ C$ and at $127^\circ C$

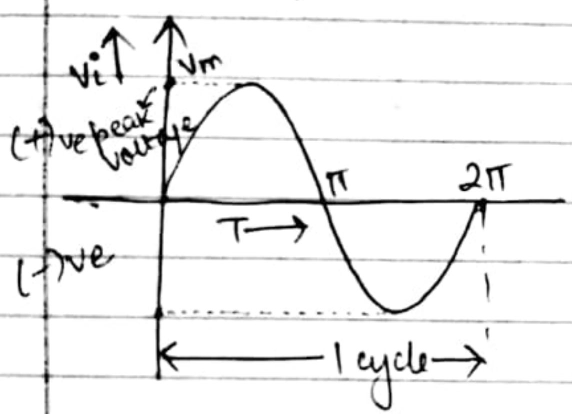
RECTIFIERS

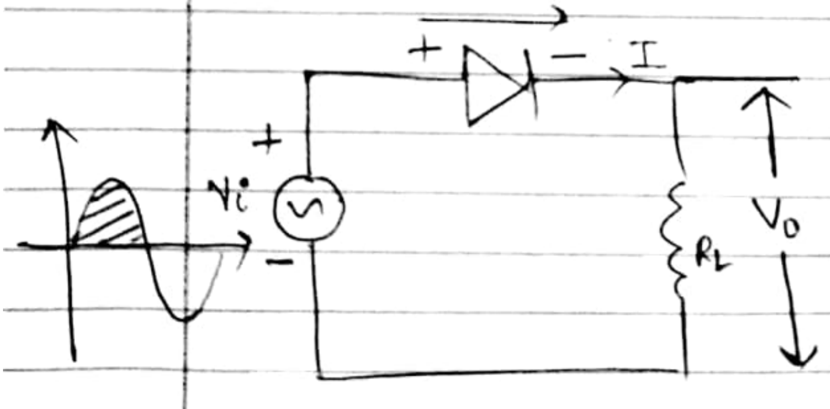
{minimizing the errors in a diode}

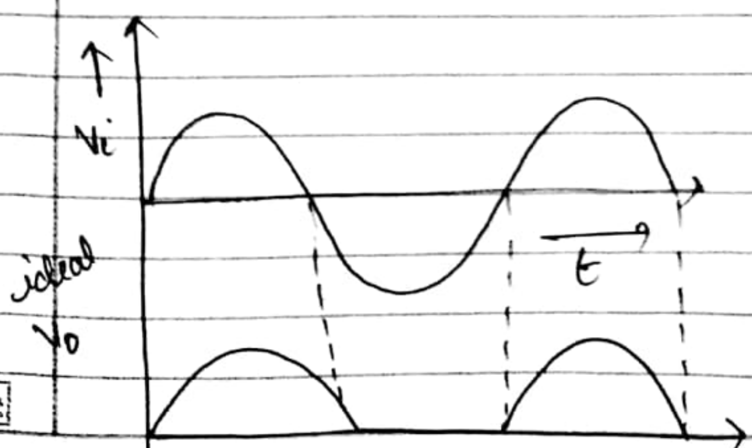
{An application of p-n junction diode. Use to convert from AC to DC.

Half wave rectifier | **Full wave rectifier**

Only one half of the a.c. voltage is rectified, for the other half we get zero voltage.





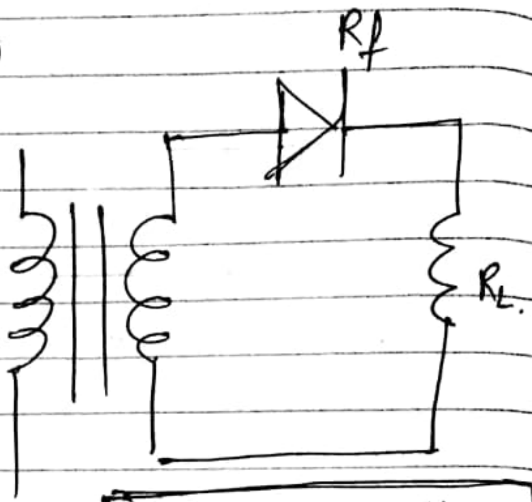


$v_i = V_m \sin \omega t$

FOR HALF-WAVE RECTIFIER

For average output (V_{av}) $= V_{dc}$

$$V_{avg.} = \int_0^{2\pi} V_0 \, d(\omega t) = \frac{1}{2\pi}\int_0^{2\pi} V_0 \, d(\omega t)$$



$\because V_i = V_m \sin\omega t$

$\therefore V_i = V_0 = V_m \sin\omega t \quad (0 \leq \omega t \leq \pi)$

$V_0 = 0 \quad (\pi \leq \omega t \leq 2\pi)$

$\boxed{\text{Peak inverse voltage} \quad PIV = V_m}$

$$\therefore V_{avg.} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin\omega t + \cancel{\int_{\pi}^{2\pi} V_m \sin\omega t}\right] d(\omega t)$$

$$= \frac{1}{2\pi}\int_0^{\pi} V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi}\int_0^{\pi} \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi}$$

$$= \frac{V_m}{2\pi}\left[-(-1-1)\right]$$

$$= \frac{V_m}{\cancel{2}\pi} \cdot \cancel{2}$$

$$\therefore \boxed{V_{avg.} = \frac{V_m}{\pi}}$$

$\therefore V_{avg.} = \frac{V_m}{\pi}$

$$\therefore I_{avg.} = \frac{V_{avg.}}{R_L} = \frac{V_m/\pi}{R_L}$$

$$= \frac{V_m}{R_L} \cdot \frac{1}{\pi}$$

$$= \frac{I_m}{\pi}$$

$$\therefore \boxed{I_{avg.} = \frac{I_m}{\pi}}$$

RMS load current and RMS load voltage.

RMS → Root mean square current.

$\because I = I_m \sin\omega t$

$$\therefore I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}\left(I^2 d(\omega t)\right)}$$

$$= \left[\frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}.$$

$$= \left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t) + \cancel{\int_{\pi}^{2\pi} I_m^2 \sin^2\omega t \, d(\omega t)}^{\,0}\right]^{1/2}$$

$$= \left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi}\int_0^{\pi} \sin^2\omega t \, d(\omega t)\right]^{1/2}.$$

$$= \left[\frac{I_m^2}{2\pi}\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)\right]^{1/2}$$

$= \frac{I_m}{2}$.

$\therefore \boxed{I_{rms} = \frac{I_m}{2}}$ $\boxed{I_{dc} = \frac{I_m}{\pi}}$

Form factor:

$F = \frac{I_{rms}}{I_{Dc}} = \frac{\pi}{2} = 1.57$.

$\therefore V_{rms} = I_{rms} \cdot R_L$

$= \frac{I_m}{2} \cdot R_L$

$\boxed{V_{rms} = \frac{V_m}{2}}$

$I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}$

$I_{rms}^2 = I_{ac}^2 + I_{dc}^2$.

FOR HALF-WAVE RECTIFIER

$\boxed{V_{avg.} = \frac{V_m}{\pi}}$

$\boxed{I_{avg.} = \frac{I_m}{\pi}}$

$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}}$

$\boxed{I_{rms} = \frac{I_m}{2}}$

Ripple factor $= \gamma$

$\gamma = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$

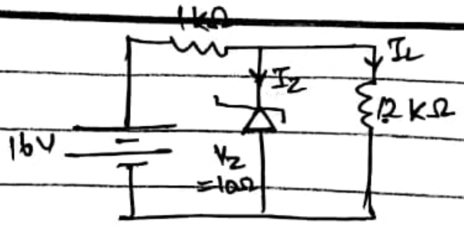
$= \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$

$\gamma = \sqrt{F^2 - 1} = 1.22$.

Rectification efficiency $= \eta$

$\eta = \frac{P_{dc}}{P_i} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_f + R_L)} = \frac{4}{\pi^2} \left(\frac{1}{\frac{R_f}{R_L} + 1}\right)$

Page No. :



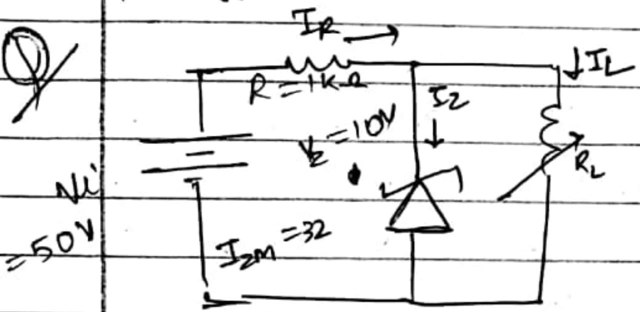
$$V = \frac{V_i R_L}{R + R_L} = \frac{16 \times 1.2}{1 + 1.2} = \frac{16.12/10}{22/10} = \frac{16.12}{22} = \frac{96}{11} = 8.7$$

$I_Z = I_R - I_L.$

$\therefore$ OFF state

$\because$ $V < V_Z$

{In off state, power will be 0.}



$$I_{L_{max}} = \frac{V_L}{R_{L_{min}}} = \frac{V_Z}{R_{L_{min}}}$$

$$R_{L_{min}} = \frac{V_Z R}{V_i - V_Z}$$

$$= \frac{10 \times 1}{50 - 10} = \frac{10}{40} = \frac{1}{4}$$

$$R_{L_{min}} = \frac{1}{4} = 0.25$$

$$R_{L_{max}} = \frac{V_Z}{I_{L_{min}}} = \frac{V_Z}{I_R - I_{ZM}} = \frac{10}{40 - 32} = \frac{10}{8} = 1.2$$

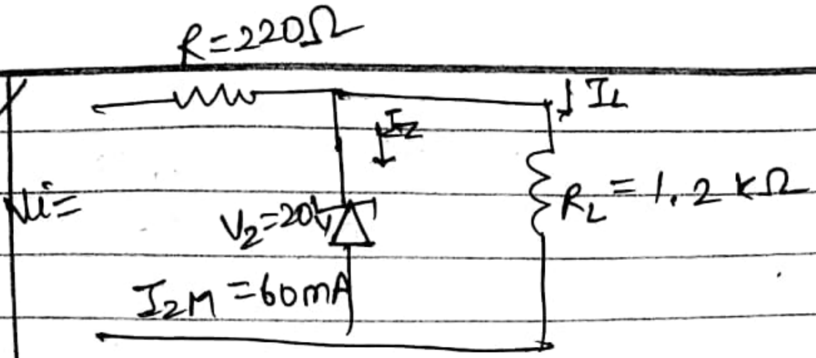
$$I_{L_{max}} = \frac{V_Z}{R_{min}} = \frac{\cancel{1000}\ 40}{0.\cancel{25}} = 40$$

$$I_R = \frac{V_i - V_Z}{R} = \frac{50 - 10}{1} = 40.$$

Date :

Page No. :

Q)



$$Vi_{min} = \frac{V_Z(R+R_L)}{R_L}$$

$$= \frac{20(220+1.2)}{1.2}$$

$$= 20($$

Q)

A diode has a resistance of 10Ω and supplies power to a load of 100Ω. The secondary of the Transformer supplies a voltage of 50V. (RMS). Calculate

i. The peak current V_m $\quad I_m = \frac{V_m}{R_f + R_L}$

ii. The DC load current

iii. RMS current

iv. DC voltage

v. The total AC input power.

vi Rectification efficiency.

$R_f = 10\Omega$

$R_L = 100\Omega$

$V_{rms} = 50V$

$V_{rms} = \frac{V_m}{\sqrt{2}}$

$50 \times \sqrt{2} = V_m$

(i) $V_m = 70.7$ V

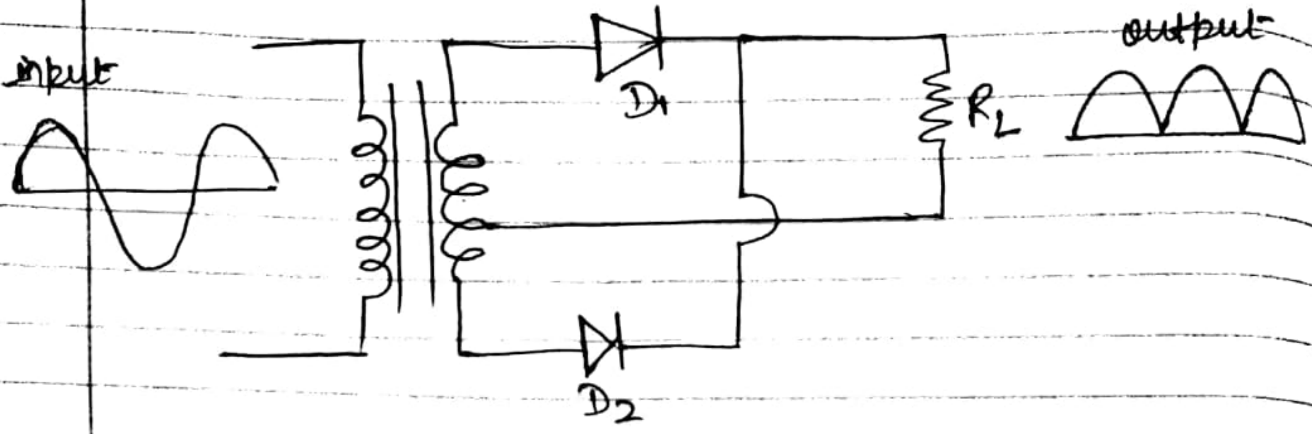
$$I_m = \frac{V_m}{R_f + R_L}$$

$$= \frac{70.7}{10+100}$$

$$= \frac{707}{1100}$$

$$= 0.64 \text{ A}$$

Full wave Rectifier (CENTRE TAP)



$$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

$$\boxed{PIV = 2V_m}$$

$$\boxed{I_{dc} = \frac{2I_m}{\pi}}$$

$$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

$$\boxed{I_{ac} = \sqrt{I_{rms}^2 - I_{DC}^2}}$$

Form factor = $F = \frac{I_{rms}}{I_{dc}} = \frac{I_m}{\sqrt{2}} \times \frac{\pi}{2I_m}$.

$\therefore \boxed{F = \frac{\pi}{2\sqrt{2}}} = 1.11$

Ripple factor = $\gamma = \frac{I_{ac}}{I_{dc}} = \sqrt{F^2 - 1}$

$\boxed{\gamma = \sqrt{F^2-1}} = 0.48$

Rectification efficiency = η

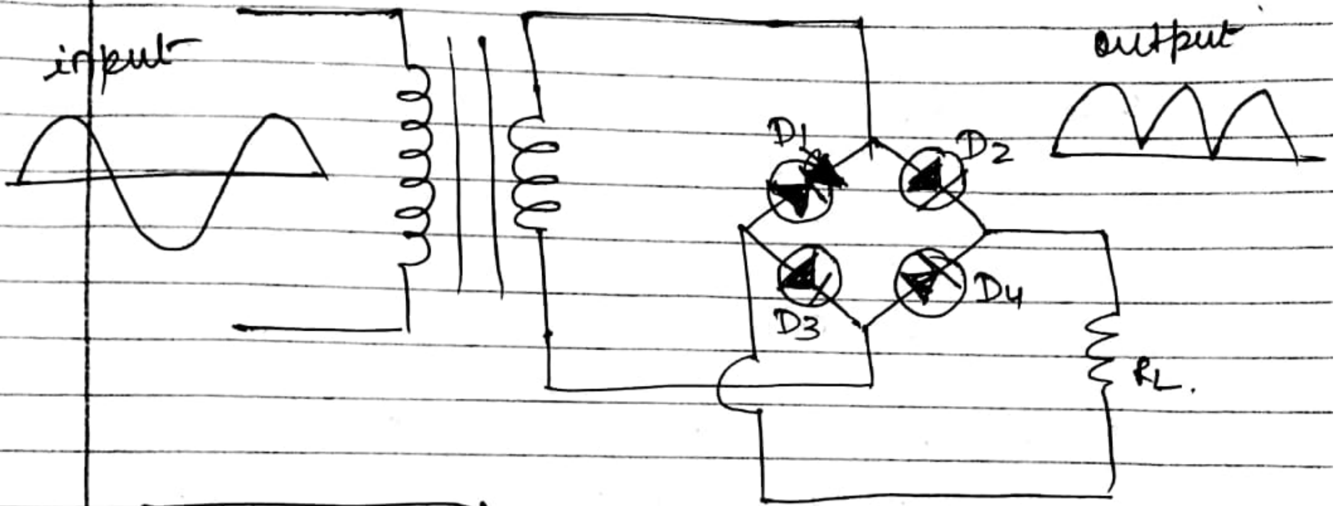
$\eta = \frac{P_{dc}}{P_i}$

$P_{dc} = I^2_{dc} \cdot R_L$

$P_i = I^2_{rms}(R_f + R_L)$

$\therefore \boxed{\eta = \frac{8}{\pi^2} \frac{1}{(R_f/R_L + 1)}}$

Full wave Rectifier (BRIDGE RECTIFIER)



$$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}}$$

$$\boxed{I_{dc} = \frac{2I_m}{\pi}}$$

$$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

$$\boxed{I_{ac} = \sqrt{I_{rms}^2 - I_{DC}^2}}$$

Form factor = F

$$F = \frac{I_{rms}}{I_{DC}} = \frac{I_m}{\sqrt{2}} \times \frac{\pi}{2I_m} = \frac{\pi}{2\sqrt{2}} = 1.11$$

$$\boxed{F = \frac{\pi}{2\sqrt{2}}}$$

Ripple factor = $\gamma = \frac{I_{ac}}{I_{dc}} = \sqrt{F^2 - 1} = 0.48$

$$\boxed{\gamma = \sqrt{F^2 - 1}}$$

Rectification efficiency = $\eta = \frac{P_{dc}}{P_i} = \frac{I_{dc}^2 R_L}{I_{rms}^2 (2R_f + R_L)}$

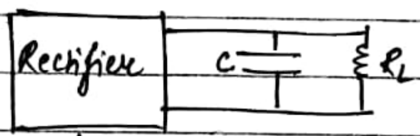
$$\boxed{\eta = \frac{8}{\pi^2}\left(\frac{1}{\frac{2R_f}{R_L} + 1}\right)}$$

Filter Circuits

The quality of rectification can be improved by smoothing the output wave forms from the rectifier. This is achieved by using filter circuits.

Filter circuits are such circuits which oppose the variations in a voltage. They are of different types—

(1.) Shunt Capacitor filter



The reactance of capacitor → X_C

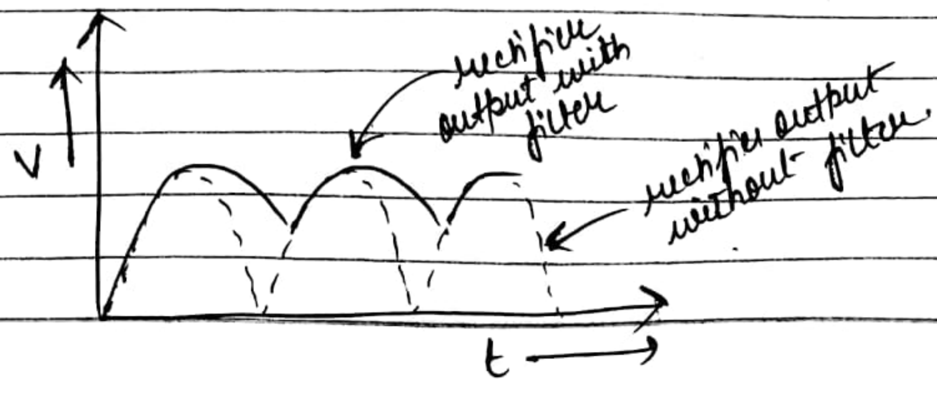
$$\therefore X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C}$$

$\therefore$ For $\underline{DC}$, $X_C = \infty$

For $\overline{AC}$, X_C is small.

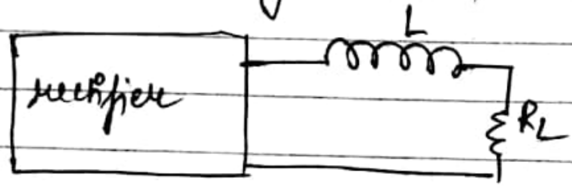
The capacitor offers infinite resistance to DC and very small resistance to AC. When it is connected in parallel with the load resistance in the output circuit of a rectifier, it bypasses the AC and only DC appears across the load.

Alternatively;



When the voltage across R_L increases, the capacitor gets charged. When the voltage falls, the capacitor discharges sending an additional current through R_L and hence it tends to maintain a constant voltage across R_L and variations in the output voltage are reduced. For a given value of R_L, larger the capacitance C, smaller will be its impedence which will result in better bypassing of AC component. i. e; smaller ripple factor

2. **Series Inductance filter**



Inductance reactance = ωL

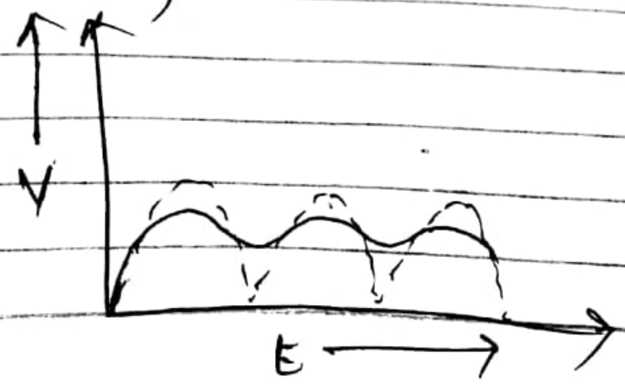
$\therefore \omega_L = 2\pi f L$

for DC, $X_L = 0$

for AC, X_L is high

The inductance offers a high resistance to AC and zero resistance to DC. It prevents AC to reach R_L and allows DC to appear across R_L. In this way Ripples are reduced in the rectifier output.

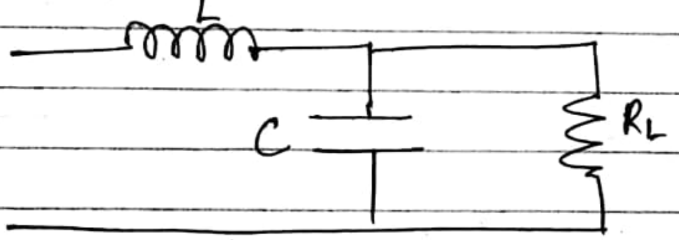
Alternatively;



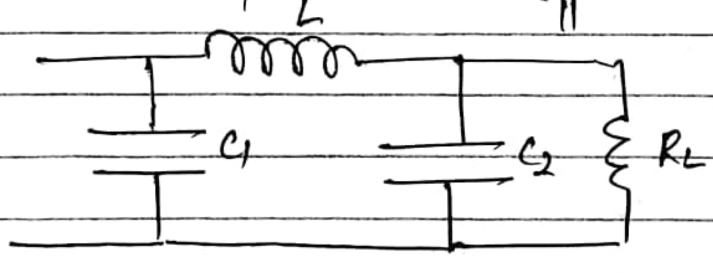
Date :
Page No. :

When the load current increases, the induced voltage across the inductor opposes the increase because its polarity is such that it sends an induced current in opposite direction. Similarly, when the load current decreases, the polarity of the induced voltage is reversed so that induced current flows in the same direction as the load current and boosts it up. The variations in the load current are thus minimized.

3. L-Section filter

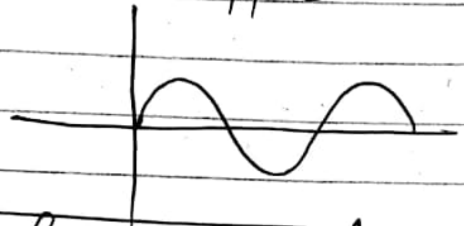


4. Π-Section filter



CLIPPERS

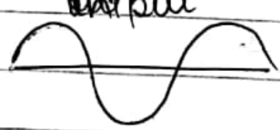
Diode networks that have ability to clip off a portion of input signal without distorting the remaining part of the alternating wave form are known as clippers.

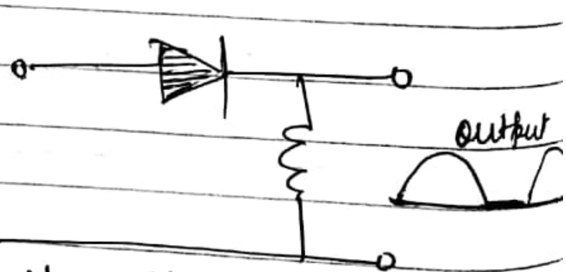


- SERIES CLIPPERS
  - unbiased
    - (+)ve
    - (-)ve
  - biased
    - (+)ve
    - (-)ve
- PARALLEL CLIPPERS
  - unbiased
    - (+)ve
    - (-)ve
  - biased
    - (+)ve
    - (-)ve

I. SERIES CLIPPERS (Unbiased)

(−)ve



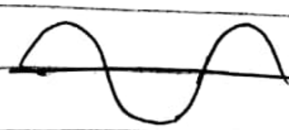


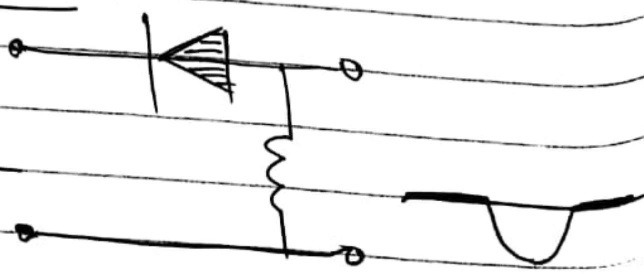
For half-wave rectifier, $V_i > 0V$, $V_o = V_i$

$V_i < 0V$, $V_o = 0$.

II. SERIES CLIPPERS (Unbiased)

(+)ve.





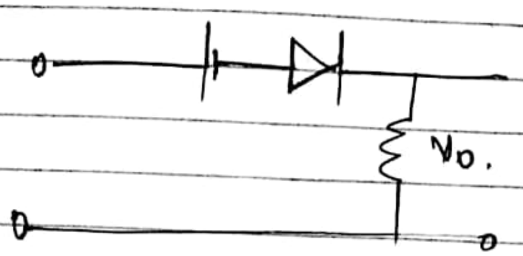
$V_i > 0V$, $V_o = 0$

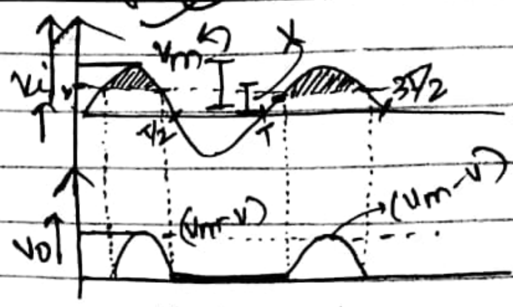
$V_i < 0V$, $V_o = -V_i$

Date :
Page No :

(III) SERIES CLIPPERS (Biased)

(−)ve





output waveform.

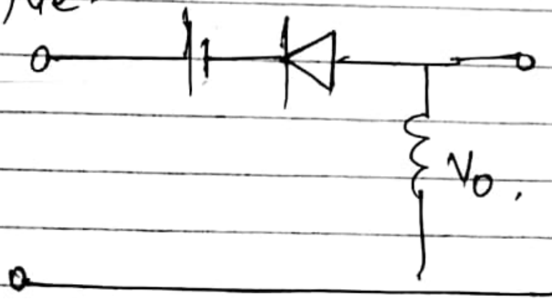
(just starts to conduct) $V_i = V$, $V_0 = 0$

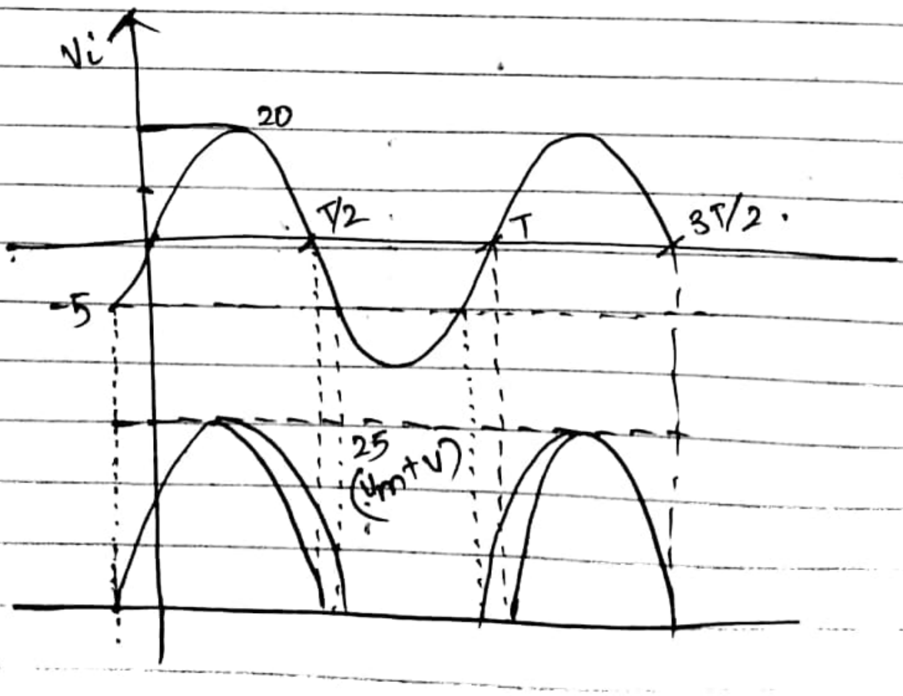
(open circuit, reverse bias) $V_i > V$, $V_0 = V_i - V$ (forward bias)

$V_i < V$, $V_0 = 0$.

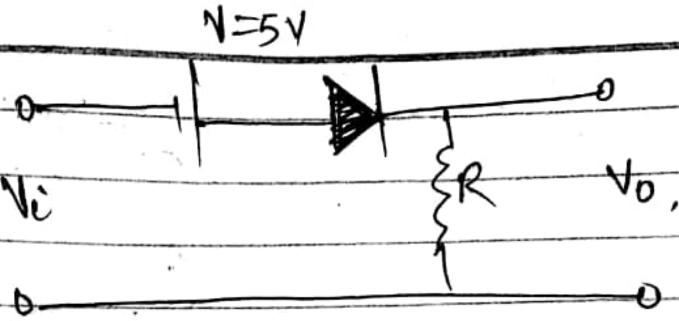
(IV) SERIES CLIPPERS (Biased)

(+)ve.





Eg.



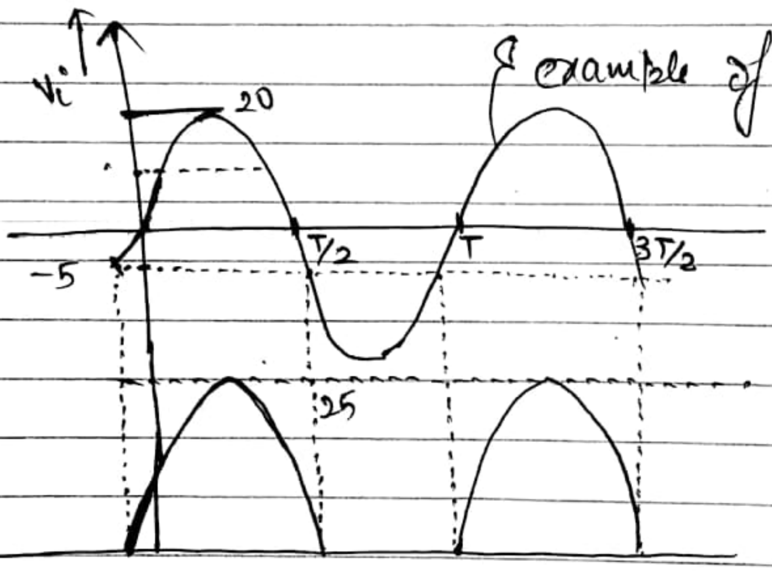
If $V_i = -5V$, $\underline{V_0 = 0.}$

If $V_i < -5V$, $\underline{V_0 = 0.}$

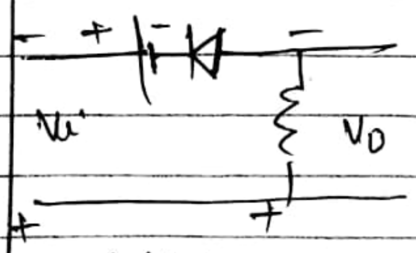
If $V_i > -5V$, $\underline{V_0 = V_i - (-5)}$

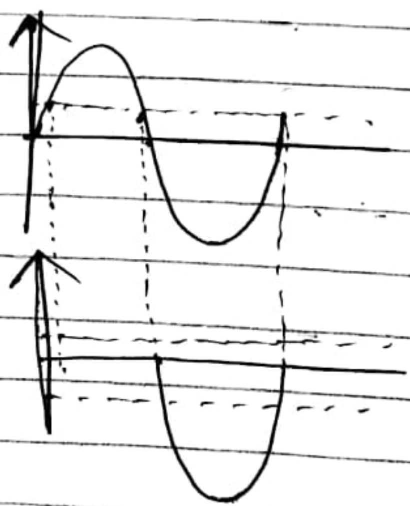
$= \underline{V_i + 5}$.

Q.



{example of series clippers for biased (+)ve half cycle}





$V_i < V$

$V_i - V_0 - V = 0$

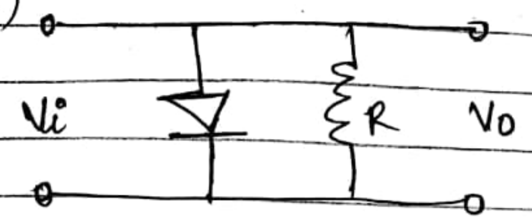
$V_0 = V_i - V$

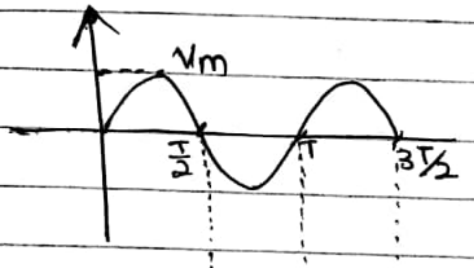
$V_i - V_0 + V = 0$

$V_0 = V_i + V$

PARALLEL CLIPPERS (+)ve (diode in forward biased condition)

(Biased)



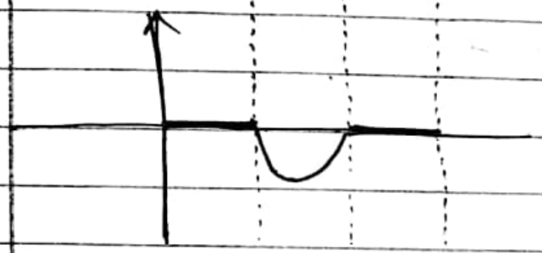


$V_i > 0\ V$ (diode in forward biased)

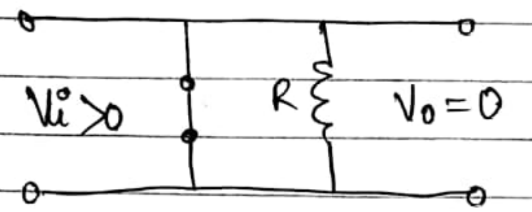
$V_o = 0$

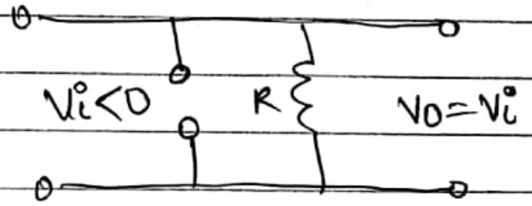
$V_i < 0\ V$

$V_o = V_i$

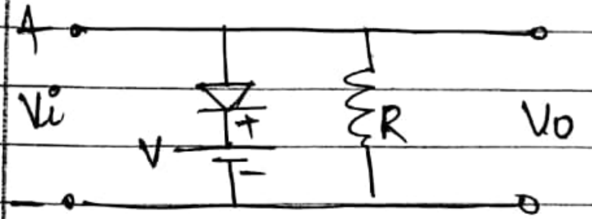


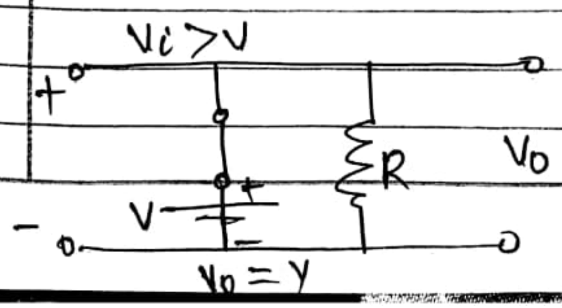
OR

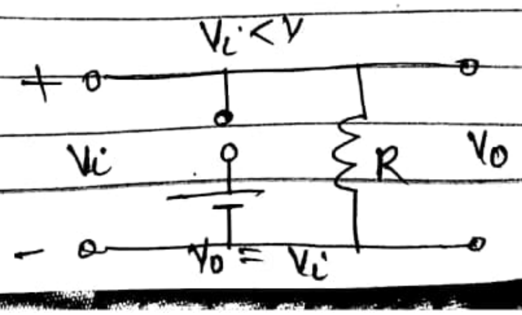




PARALLEL CLIPPERS.

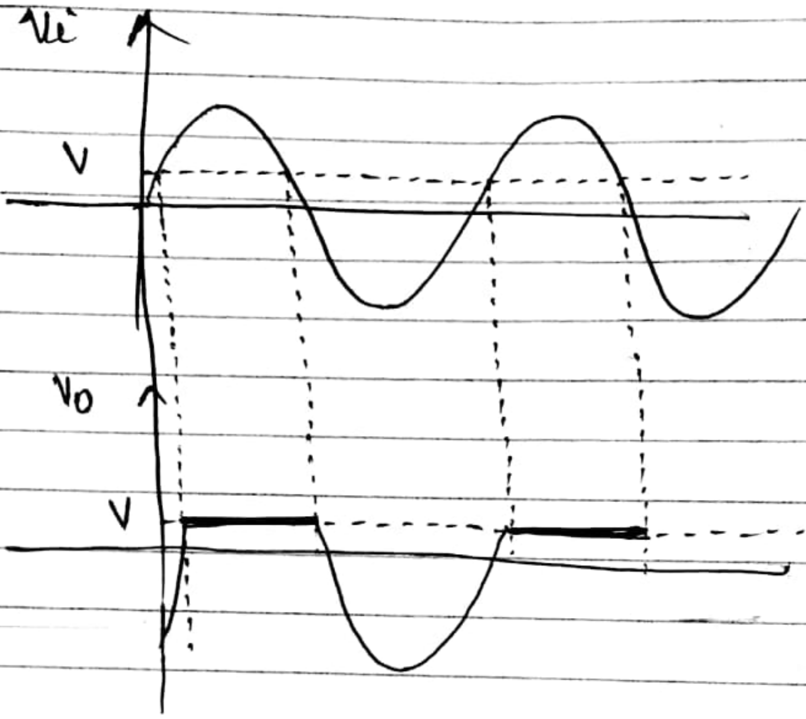




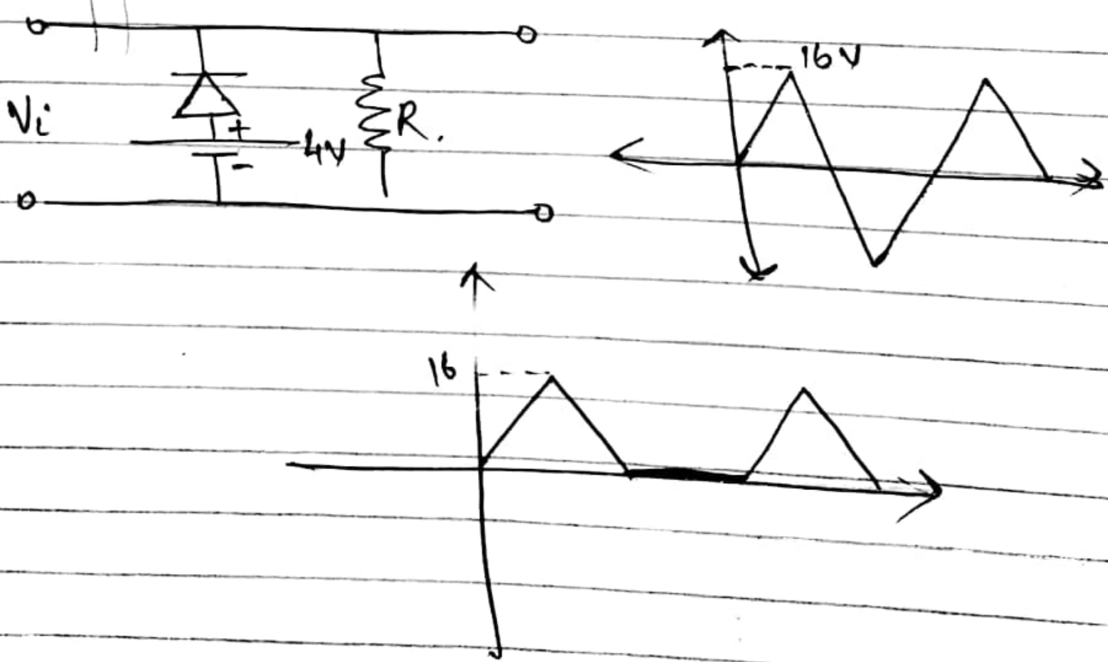


Date :
Page No. :

$V_i = V$
$V_0 = V$ } (Transition condition from reverse bias to forward bias.)

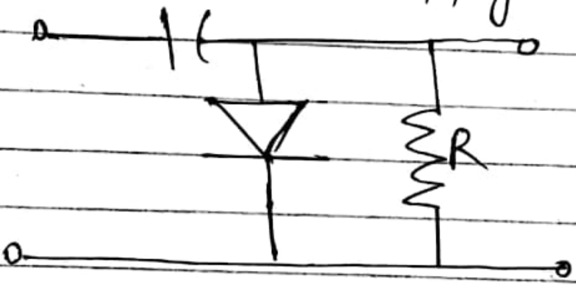


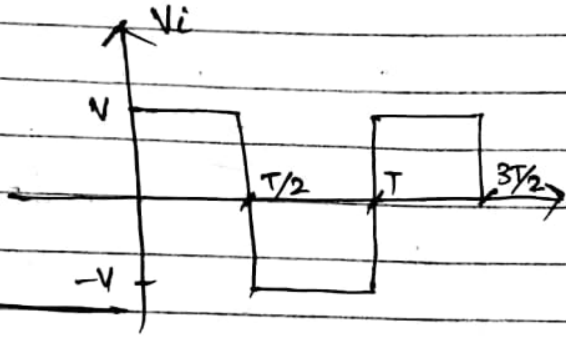
8)



CLAMPERS

Clampers are those diode networks which clamp a signal to a different d.c. level. The network must have a capacitor, a diode and a resistive element. To introduce additional shift, sometimes it uses an independant d.c. supply.



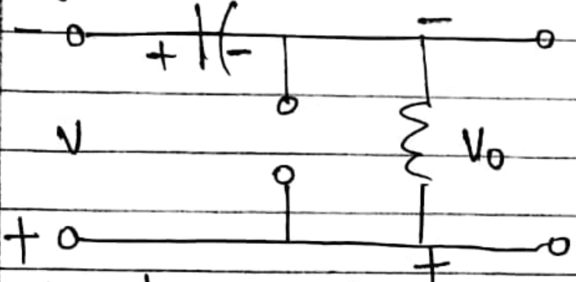


for $0 \rightarrow T/2$.

$V_0 = 0$

$\boxed{V_0 = 0}$

for $T/2 \rightarrow T$



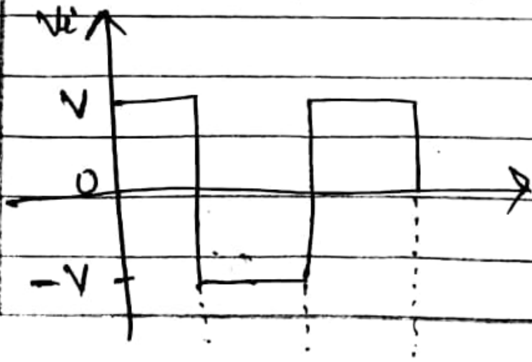
$V + V - V_0 = 0$

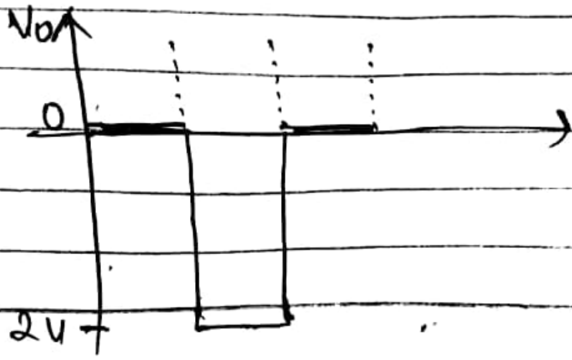
$2V = V_0$

or

$\boxed{V_0 = 2V}$

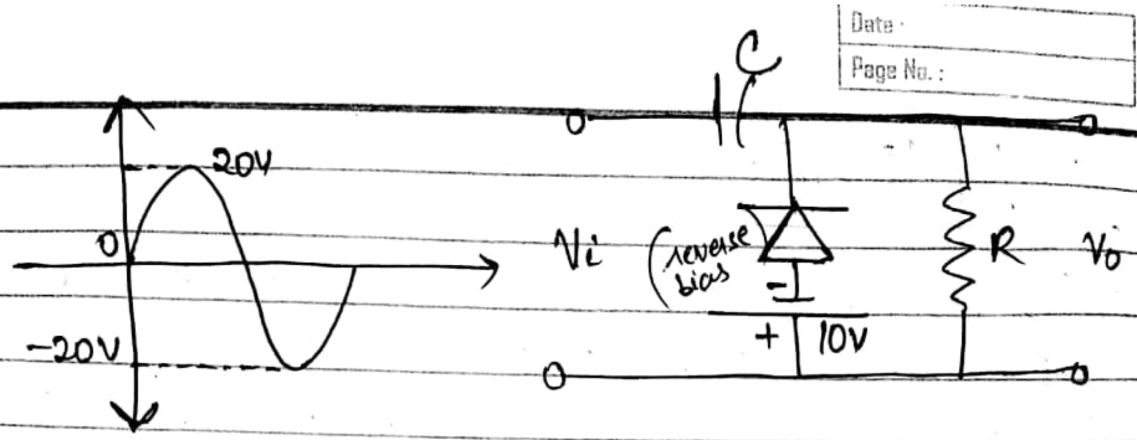
Now plotting the graph;





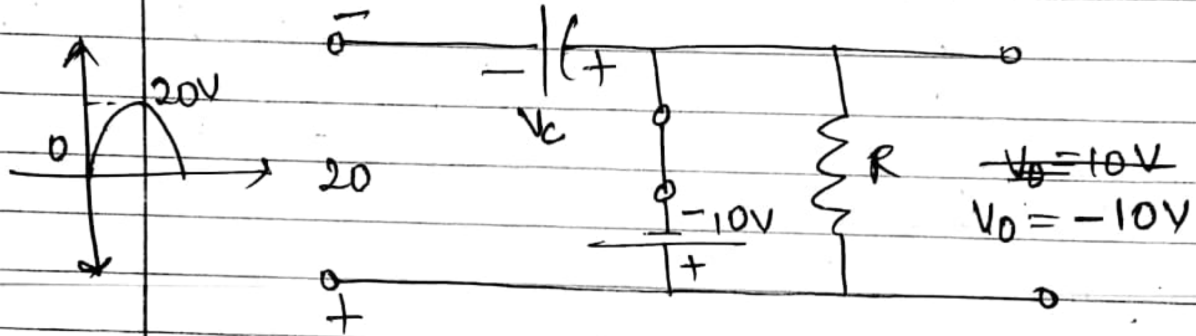
Date:
Page No.:

Q



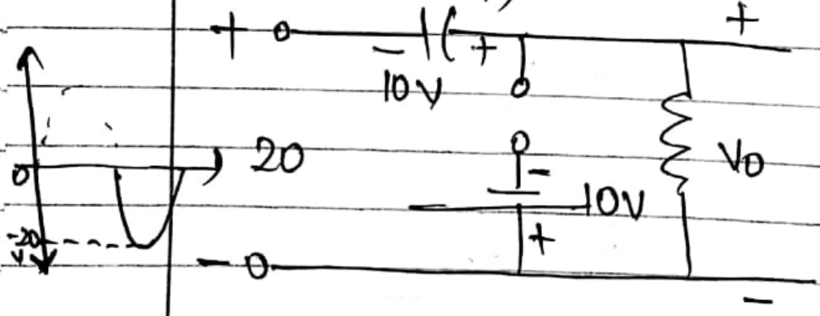
first, we have to consider that portion of input signal for which the diode is in forward bias.

For the cycle $T/2 \to T$, the diode becomes forward biased.

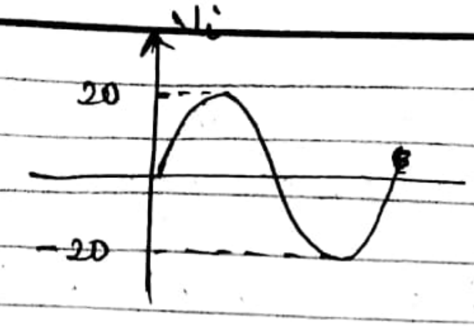


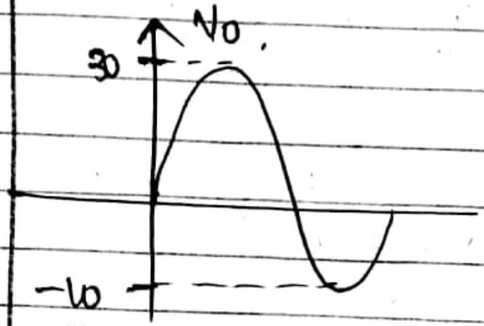
$$20 - V_C - 10 = 0$$
$$10 - V_c = 0$$
$$V_c = 10.$$

for $0 \to T/2$, diode will be reverse biased.



$$20 - V_0 + 10 = 0$$
$$30 - V_0 = 0$$
$$V_0 = 30.$$





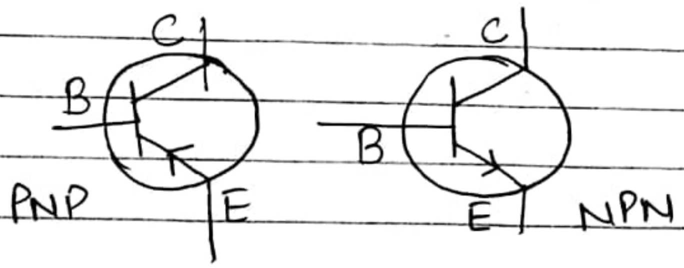
BIPOLAR JUNCTION TRANSISTORS

Invented in 1948 by Bardeen and Brattain. (BJTs)

Two junctions are joined either back to back or front to front.

| P | N | + | N | P | → | P | N | P |

| N | P | + | P | N | → | N | P | N |



→ Base (B)

→ emitter (E)

→ Collector (C)

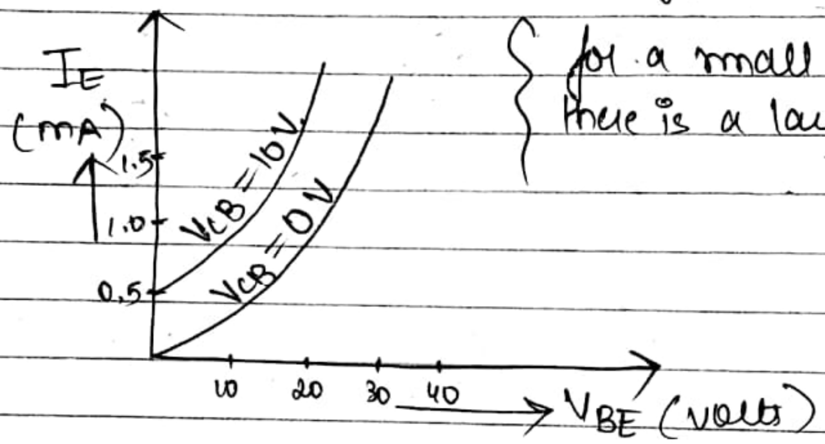
$$\therefore \boxed{I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \frac{I_{CBO}}{(1-\alpha)}}$$

Expression for collector current (I_C) in CB configuration

{Current flows due to minority charge carriers under reverse bias}

INPUT CHARACTERISTICS

It is a plot of I_E Vs V_{BE} at different values of V_{CB}.



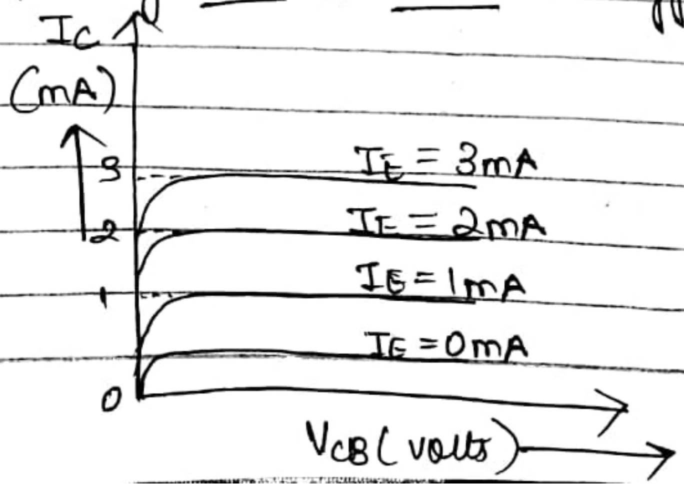
{for a small variation in V_{BE}, there is a large variation in I_E.}

$$\boxed{\text{Input resistance} = r_i = \left(\frac{\Delta V_{EB}}{\Delta I_E}\right)_{V_{CB}}}$$

(its value will be small)

OUTPUT CHARACTERISTICS.

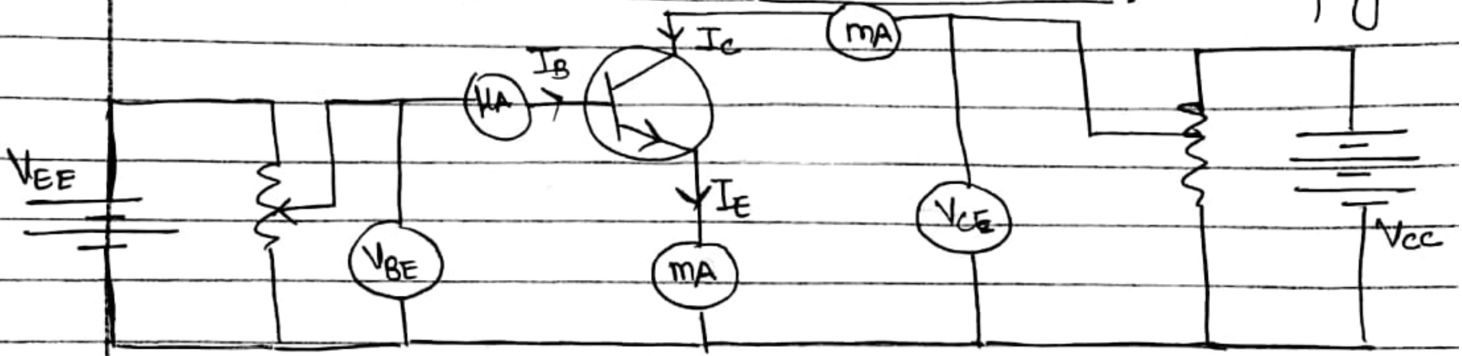
It is a plot of I_C Vs V_{CB} at different values of I_E



$$\text{Output resistance} = r_o = \left(\frac{\Delta V_{CB}}{\Delta I_C}\right)_{I_E}$$

(its value is very high)

COMMON EMITTER Config.



Relationship between α and β.

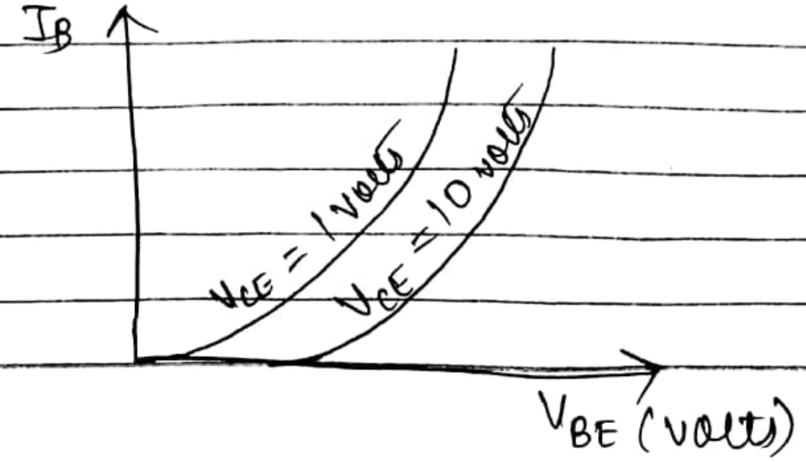
$$\alpha = \frac{\Delta I_C}{\Delta I_E} \qquad \beta = \frac{\Delta I_C}{\Delta I_B}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_B + \Delta I_C} \qquad \beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C}$$

$$= \frac{\Delta I_C / \Delta I_B}{1 + \frac{\Delta I_C}{\Delta I_B}} \qquad = \frac{\Delta I_C / \Delta I_E}{1 - \frac{\Delta I_C}{\Delta I_E}}$$

$$\boxed{\alpha = \frac{\beta}{1+\beta}} \qquad \boxed{\beta = \frac{\alpha}{1-\alpha}}$$

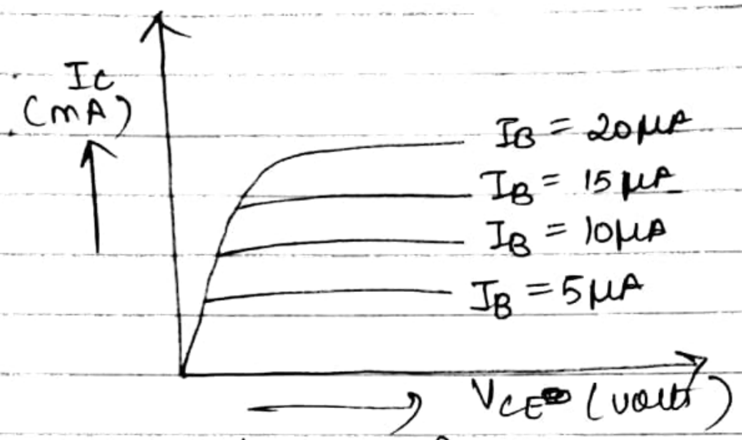
Input characteristics



$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}$$
(is small)

∴ for very low value of V_{BE}, there is a large value of I_B.

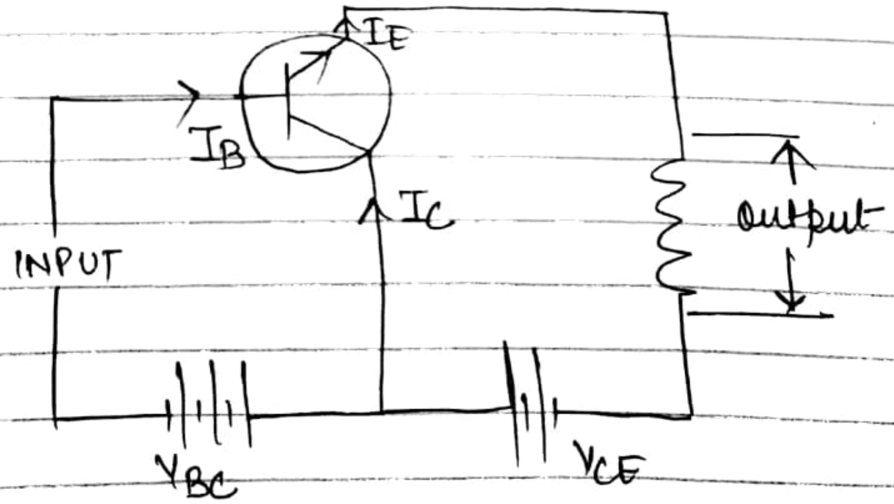
OUTPUT CHARACTERISTICS



$$r_{output} = \left(\frac{\Delta V_{CE}}{\Delta I_C}\right)_{I_B}$$
(is large)

The value of V_{CE} upto which I_C varies with V_{CE} is known as Knee voltage

COMMON COLLECTOR Config



Page No. :

Current gain ;

$$\gamma = \frac{\Delta I_E}{\Delta I_B}$$

Relationship between α, β and γ.

$$\gamma = \frac{\Delta I_C}{\Delta I_B} = \frac{\Delta I_C + \Delta I_B}{\Delta I_B}$$

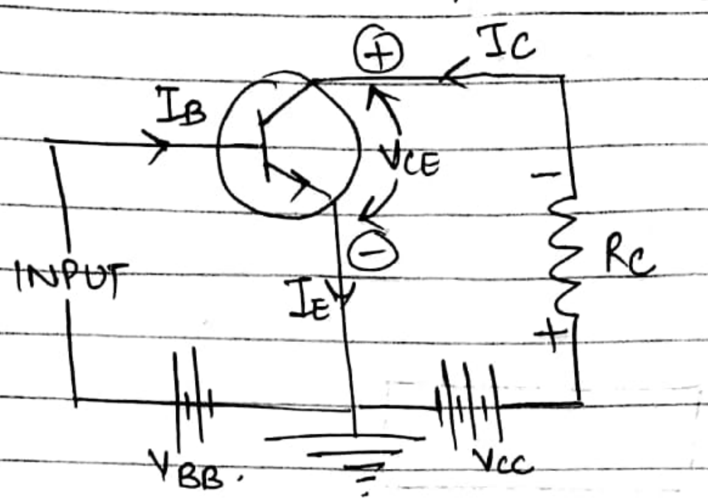
$$\boxed{\gamma = \beta + 1}$$

COMPARISON b/w CB, CE & CC configurations

PROPERTIES	CB	CE	CC
Input resistance	Low ($\sim 100\Omega$)	Low($\sim 750\Omega$)	Very high ($\sim 750 k\Omega$)
Output resistance	Very high ($\sim 450 k\Omega$)	High ($\sim 450\Omega$)	Low ($\sim 50\Omega$)
Voltage gain	~ 150	~ 500	Less than 1
Applications	High frequency	Audio frequency	Impedence matching.
Current gain	Less than 1 (α)	High (β)	Appreciable (γ)

Scanned by CamScanner

Load line and operating point



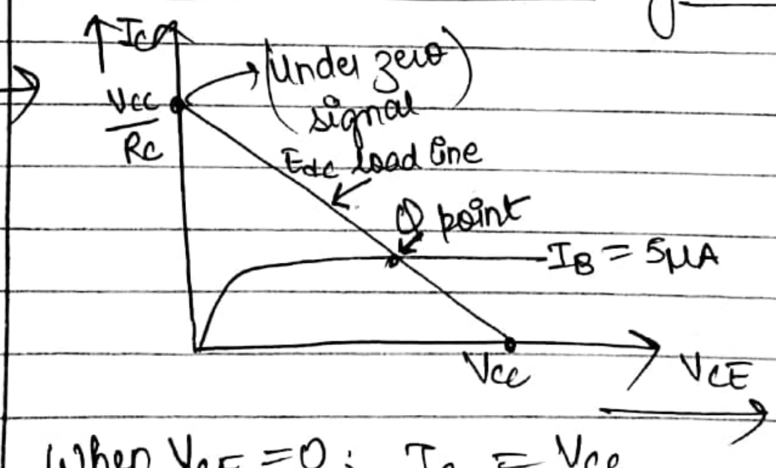
Apply kirchoff's voltage ~~low~~ law in output circuit:

$$V_{CC} - I_C R_C - V_{CE} = 0$$

$$V_{CE} = V_{CC} - I_C R_C$$

$$I_C = \frac{V_{CC}}{R_C} - \frac{1}{R_C} V_{CE}$$

OUTPUT CHARACTERISTICS of CE configuration



When $V_{CE} = 0$; $I_C = \frac{V_{CC}}{R_C}$

when $I_C = 0$; $V_{CE} = V_{CC}$

operating point / Quiescent point / Q-point

Under zero signal condition the intersection point of dc load line and output.

Field effect transistor (FET)

Bipolar Junction Transistor – current controlled device.
- Input resistance is small
- electrons and holes both participate in conduction.
- Noise level is high (several connections due to which I flows)
- Bipolar device (characterised by current gain).

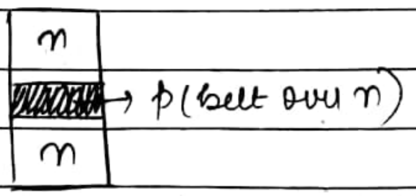
So, a new transistor was designed in which output characteristics are controlled by input voltage which was Field Effect Transistor (FET). (unipolar device)
↳ conductor due to one type of charge only.
↳ characterised by Trans conductance.
→ noise level is less.
→ input resistance is ↑ because input circuit is in reverse bias.

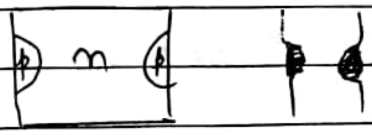
FET → JFET → Junction Field effect Transistor

FET → MOSFET → Metal oxide semiconductor field effect transistor

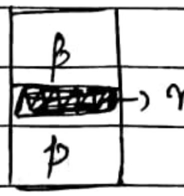
JFET

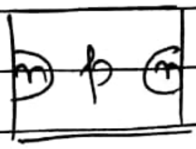
cross-sectional view





n channel → JFET ← n-channel

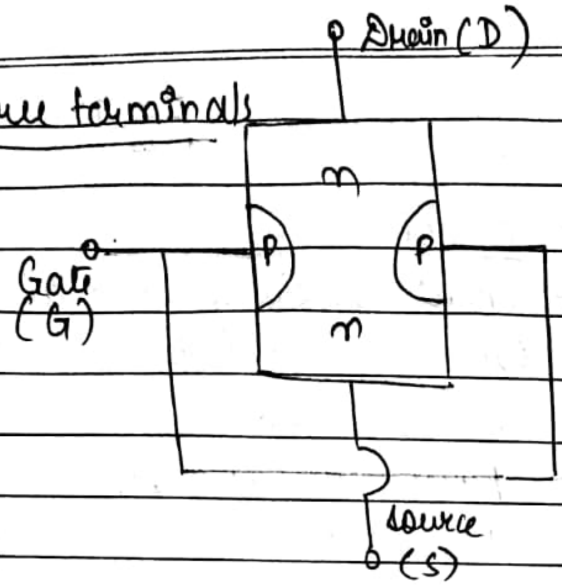


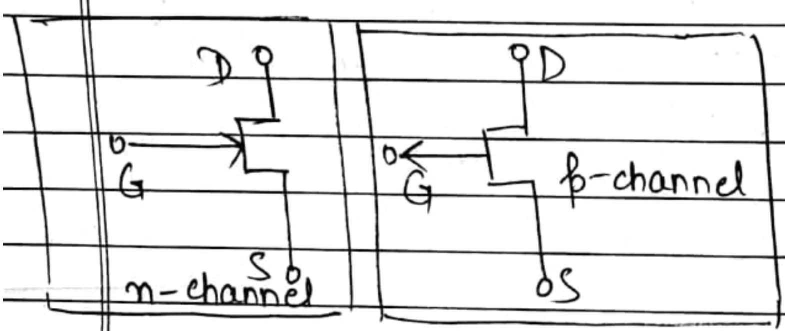


p channel → JFET ← p-channel

Date.
Page No.

Three terminals

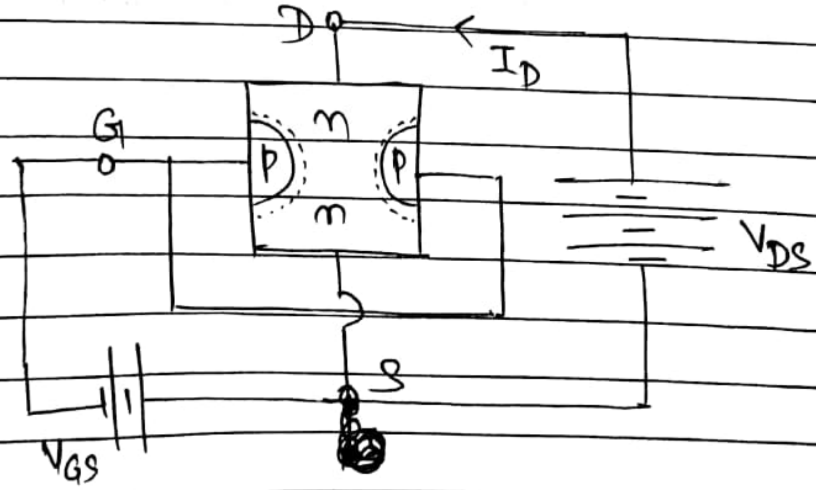




JFET: Principle and working

PRINCIPLE:

1. → Gate to source connection is kept at reverse bias.
2. → Source to drain connection is such that current flows from source to drain.



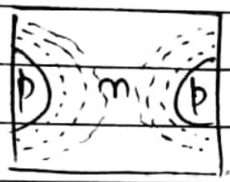
Date.
Page No.

WORKING:

(1) → As V_{DS} increases, no. of electrons increases as a result I_D increases.

$$V_{DS} \uparrow \quad I_D \uparrow$$

(2) → If V_{GS} increases, depletion layer expands and I_D decreases.

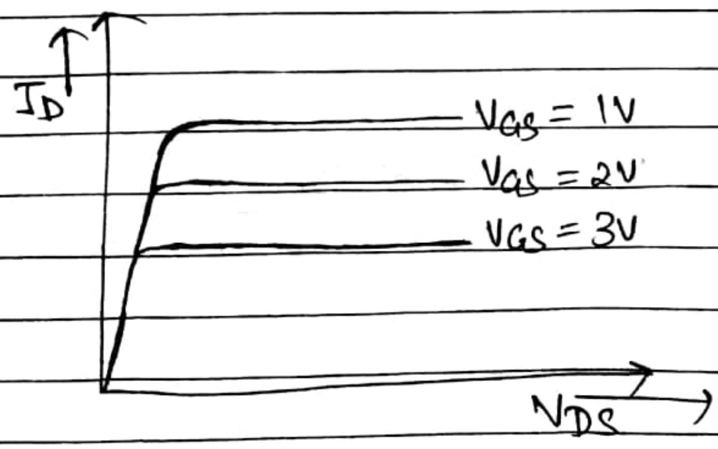


$$\therefore \quad V_{GS} \uparrow \quad I_D \downarrow$$

∴ Output current is being controlled by input voltage. Hence it is called as voltage controlled device.

(3) → If V_{GS} reaches a value such that depletion layer overlaps, $\therefore I_D = 0$. This is known as Cut-off.

OUTPUT CHARACTERISTICS



The main drawback of JFET is that gate must be reverse biased for proper operation of the device. This means that we can only decrease the width of the channel. This type of operation is known as depletion mode operation. so a JFET can only be operated in depletion mode. ~~Thu~~

There is another type of FET known as MOSFET that can be operated to enhance the width of the channel. So MOSFET works in enhancement mode as well as in depletion mode

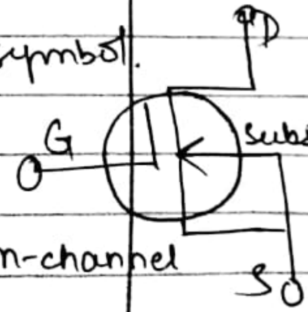
Types of MOSFET

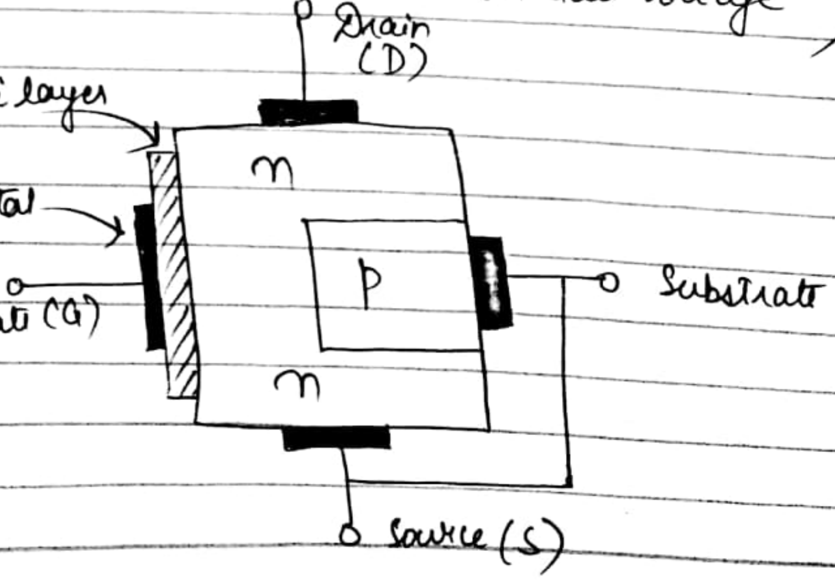
- Depletion type MOSFET (D-type)
- Enhancement type MOSFET (E-type).

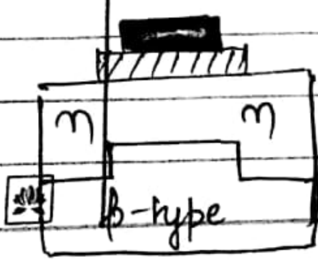
D-MOSFET

(works both in depletion mode and enhancement mode depending on Gate voltage)

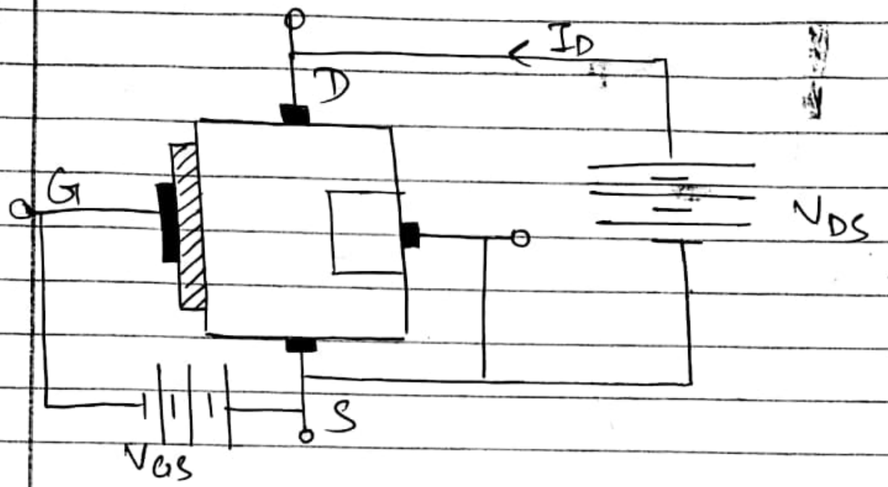
symbol.

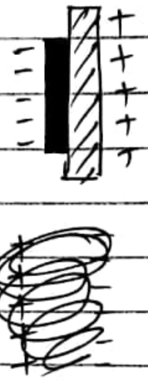






Depletion mode





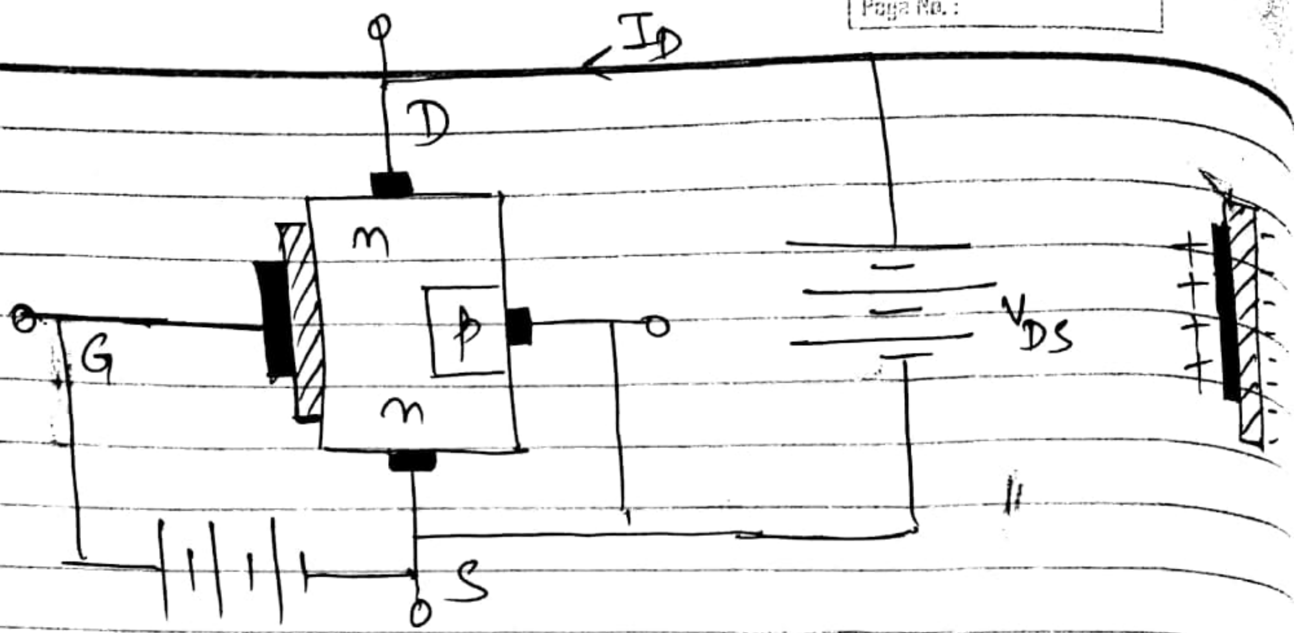
Since Gate is negative, substrate is always connected to the source, free electrons of the n-channel are repelled leaving a layer of positive charge of the channel. Therefore less number of free electrons are available for conduction. Indirectly the channel width decreases. The greater the negative voltage of the gate less will be the current from source to drain.

Working of D-MOSFET in depletion mode is similar to JFET.

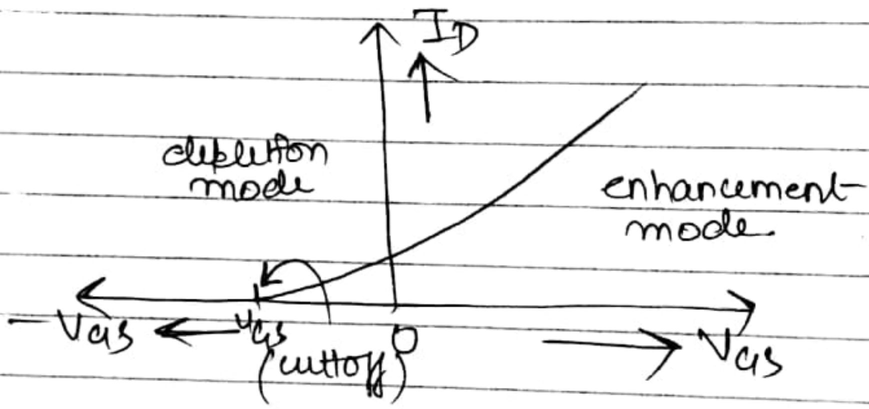
MOSFET → Insulated Gate Field Transistor (IGFET)

Enhancement mode

For enhancement mode operation, Gate is kept at positive potential so that negative charge is induced in the channel and the conductivity increases, the more the positive potential on Gate, the more will be the current from source to drain.

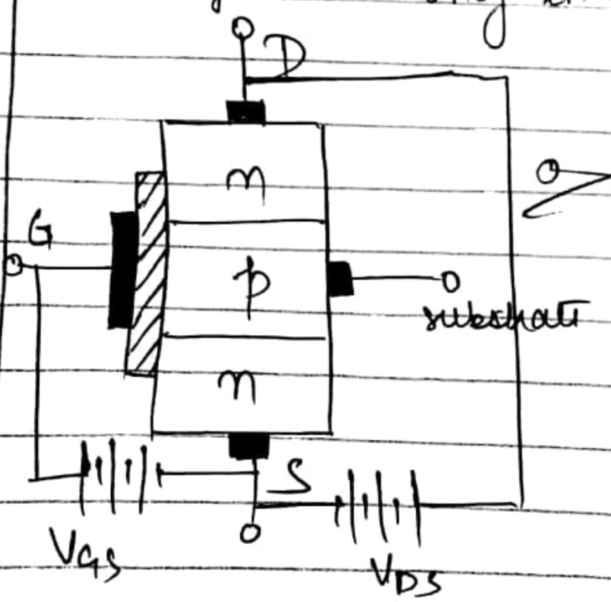


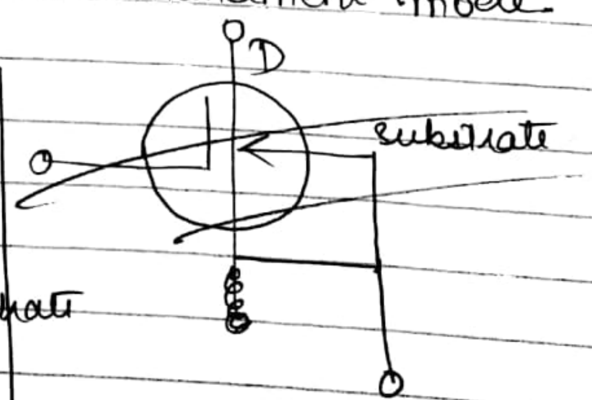
TRANSFER CHARACTERISTICS

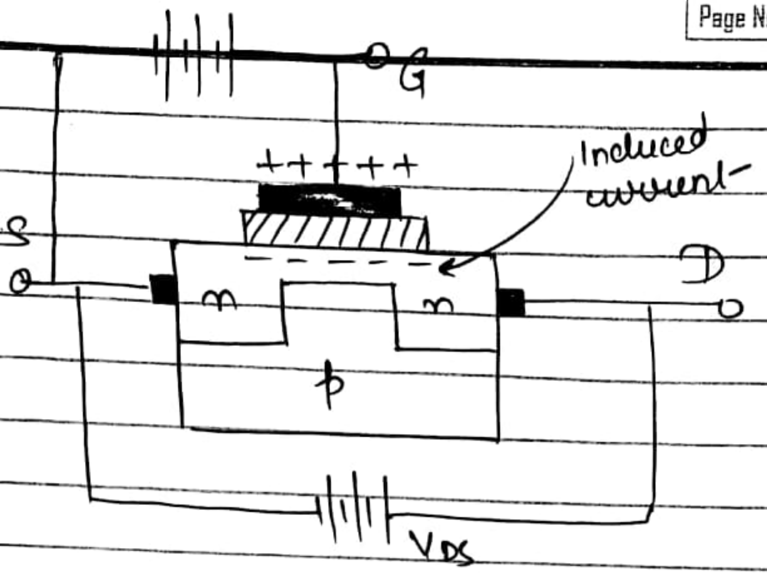


E-MOSFET

E-mosfet works only in enhancement mode.



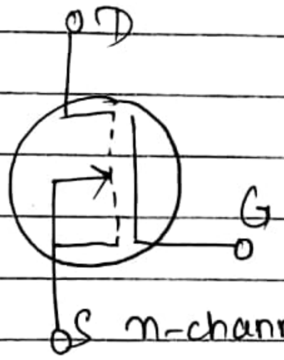




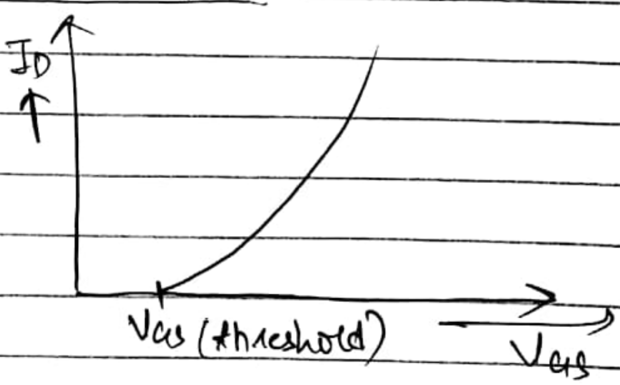
E-MOSFET has no channel, it requires a proper gate voltage to form a channel called induced channel. It works only in enhancement mode. As V_{GS} is increased, I_D increases, the minimum value of V_{GS} that turns the E-MOSFET on is known as Threshold voltage.

TRANSFER CHARACTERISTICS

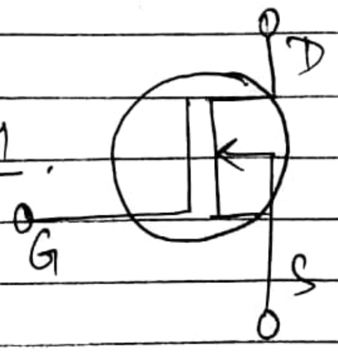
symbol.



n-channel
E- MOSFET



symbol.



n-channel
D-mosfet