temp ↑ resis ↓

S/C show -ve temperature gradient of resistance. These materials have a band gap which lies between metals & insulators.

band gap ⇅ energy or energy gap

free e^- - conduction band
no free e^- - valence band

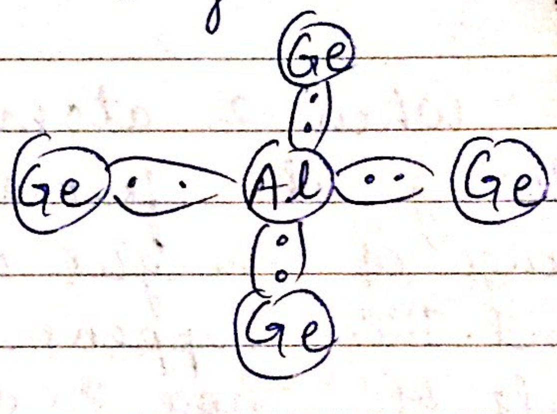
Ge - transistor diode
Si - rectifier, integrated circuit
doping

Energy level : It is a single value of energy that an electron present in that level can have.

Energy band : When 2 atoms come close to each other during the formation of material there is a range of energies which constitute an energy band. This happens due to interaction of energy levels of those 2 atoms. An e^- present in an energy band can have a range of energies assigned to that band.

Extrinsic S/C :-

In case of p type s/c three e^- of the impurity atoms are shared with three different atoms of s/c material. One other atom of the s/c is bound to the impurity atom through an unsaturated bond which contains a vacancy of an electron. This vacancy is called as a hole & it acts as a charge carrier in p-type s/c.



{ holes are the majority charge carriers

Pentavalent impurity - donor impurity (+v

trivalent impurity - acceptor impurity (-v

→ In an intrinsic s/c –:

$$\boxed{n = p} = n_i = \text{intrinsic concentration}$$

→ for extrinsic s/c –:

$$\boxed{\underbrace{n}_{e^-} + \underbrace{N_A}_{\text{no. of acceptor impurities}} = \underbrace{p}_{\text{holes}} + \underbrace{N_D}_{\text{no. of donor impurities}}}$$

→ for n type s/c –

$N_A = 0$

p is very small

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

→ for p type s/c

$N_D = 0$

n is very small

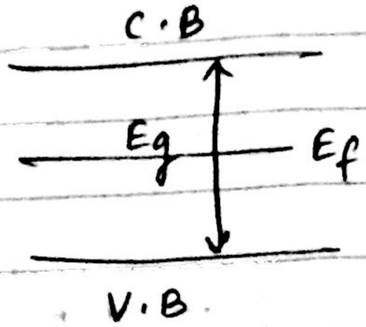
$$\boxed{p \approx N_A}$$

* Acc. to law of mass action

$$\boxed{n \cdot p = n_i^2}$$ → both for intrinsic as well as extrinsic

FERMI LEVEL :–

For an intrinsic s/c at 0 K fermi level lies in the middle of the band gap.



check

$$\boxed{f(E) = \frac{1}{e^{(E-E_f)/kT}+1}}$$

probability is $\frac{1}{2}$

when $E > E_f$ $= 0 = f(E)$
when $E < E_f$ $= 1 = f(E)$
when $E = E_f$ $= \frac{1}{2} = f(E)$

Find out the no of holes in a s/c in which $n_A = 0$, $n_D = 10^{16}\ cm^{-3}$ & $n_i = 1.8 \times 10^{16}\ m$

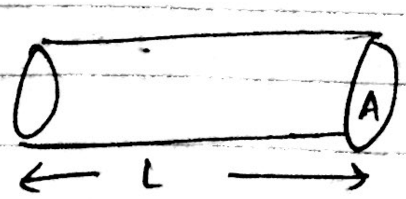
$n \cdot p = n_i^2$ $\quad N_A = 0$

$n \approx N_D$

$$p = \frac{(1.8 \times 10^{16})^2}{10^{16}}$$

$$p = 1.8 \times 1.8 \times 10^{16}$$

TRANSPORT PHENOMENON IN S/C :-



drift, diffusion current

drift $\downarrow$ ext voltage

diffusion current $\downarrow$ motion of charge carriers

$v \propto E$

$v = \mu E$

Drift current

$$I = \cancel{\frac{Ne}{T}} \quad \frac{Ne}{T}$$

$$v = \frac{L}{T} \Rightarrow T = \frac{L}{v}$$

$$I = \cancel{\frac{Nev}{L}} \quad \frac{Nev}{L}$$

current density, j, current through per unit cross section area

$$j = \frac{I}{A} = \frac{Nev}{L \cdot A}$$

$$j = \frac{Nev}{V}$$

$$j = \left(\frac{N}{V}\right) ev$$

$$\boxed{j = nev}$$

for e^-s j_n, drift $= nev$
$= ne\mu_n E$; μ_n = mobility of e^-

similarly for holes

j_p drift $= pe\mu_p E$; μ_p = mobility of ho

Total drift current $j_{drift} = (ne\mu_n + pe\mu_p)E$

$$\boxed{j = \sigma E}$$

σ = conductivity & is given by

$$\boxed{\sigma = ne\mu_n + pe\mu_p}$$

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

✓ $\boxed{\sigma = ne(\mu_n + \mu_p)}$

diffusion current

for e^-s. $j_n = e D_n \frac{dn}{dx}$

D_n = diffusion coeff for e^-s

$j_p = -e D_p \frac{dp}{dx}$ (opp direcⁿ & also conc. decreases)

$\frac{dn}{dx}$ & $\frac{dp}{dx}$ is the rate of dec of e^-s & hole resp.

(concentration gradient)

D_n & D_p are diffusion coefficients of e^-s & holes
Then the total current can be written as,

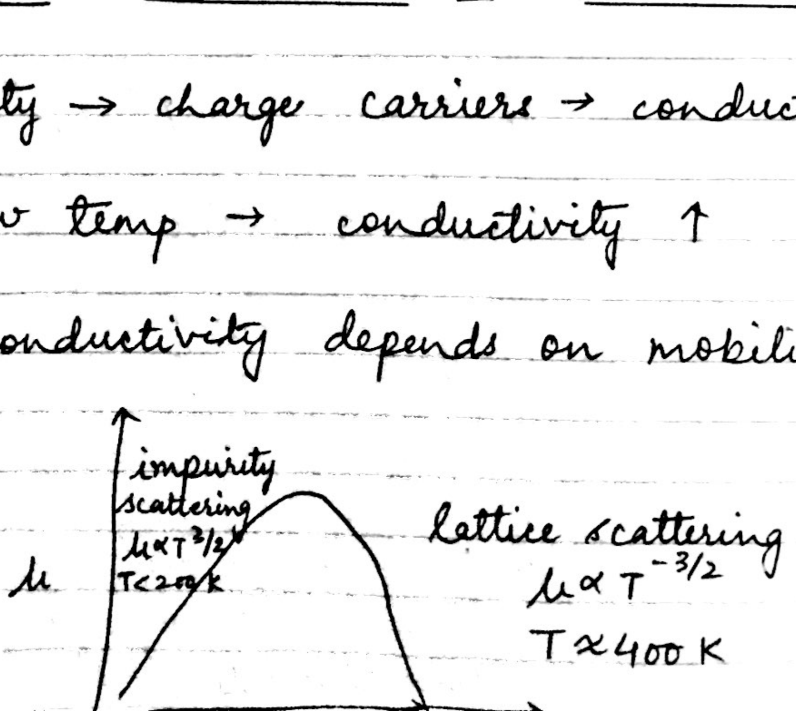
$$\boxed{j = j_{drift} + j_{diffusion}}$$

TEMPERATURE DEPENDANCE OF CONDUCTIVITY -

g → impurity → charge carriers → conductivity

at low temp → conductivity ↑

∴ conductivity depends on mobility



&

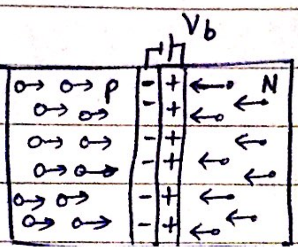
* ambient temp at which s/c works best

For $T > 400\,K$

$$\sigma \propto e^{-E_g/kT}$$ E_g = band gap

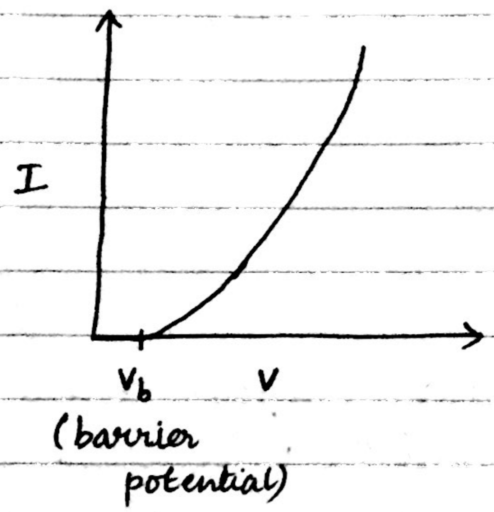
Q For an n type s/c at 300 K the e^- concentration vary linearly from 1×10^{18} to $7 \times 10^{17}\ cm^{-3}$ over a distance of 0.1 cm. Calculate the diffusion current. if diffusion coeff $D_n = 225\ cm^2/s$

P-n junction diode -:

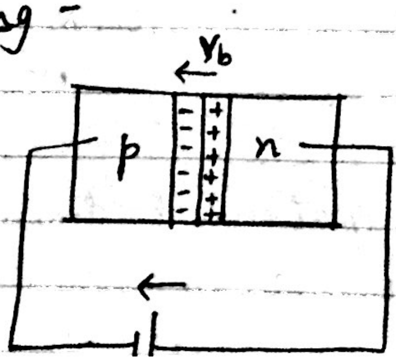


characteristic curve

vanishes.



b). Reverse biasing -



width of depletion layer increases

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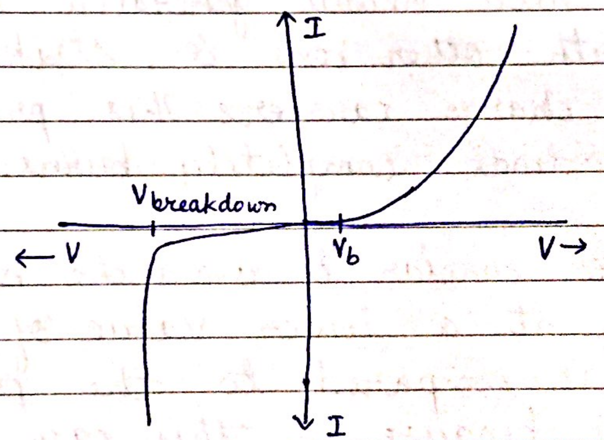
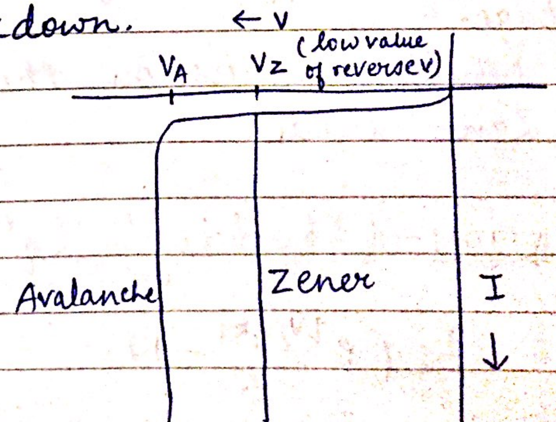
When the reverse voltage becomes sufficiently high it breaks the covalent bonds of the diode & new charge carriers are generated due to which the reverse saturation current increases abruptly. This phenomenon is known as breakdown of the diode and the value of voltage at which it occurs is known as breakdown voltage of that diode.

If the reverse voltage is further increased, the diode may stop working.



Breakdown :-

1. Avalanche breakdown
2. Zener breakdown.



AVALANCHE BREAKDOWN Under reverse bias only minority charge carriers are able to cross the junction and we get a small current which is known as reverse saturation current. For a sufficiently high value of reverse voltage, this reverse current increases abruptly due to breakdown.

In Avalanche breakdown, due to high value of reverse voltage, some of the covalent bonds are broken and new charge carriers are generated. These newly generated charge carriers collide with other ions & strike out more and more charge carriers. This process continues till the diode completely burns.

2.) **ZENER BREAKDOWN**

- It is similar to avalanche breakdown but occurs at a lower value of reverse voltage as compared to the previous case. It happens because in this case the diode is highly doped and charge carriers are generated at a sufficiently low value of reverse voltage.

A diode which works on this principle is known as Zener Diode.

DIODE EQUATION – (Shockley's Eq^n) ☆

$$I = I_s \left(e^{qV/\eta kT} - 1\right)$$

I = diode current

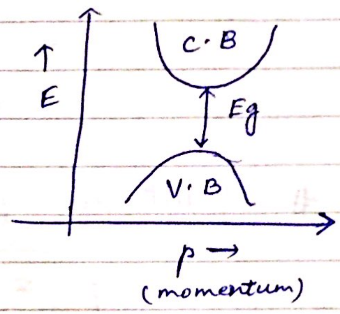
I_s = constant (saturation current)

q = Electronic charge

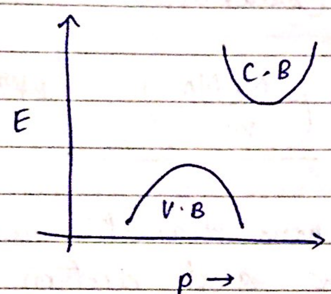
V = applied voltage

* η = ideality factor
k = Boltzmann constant
T = temperature

$n = 1$; indirect band gap semiconductors (Si, Ge)
$n = 2$; direct semiconductor (GaAs, InP etc...)



(direct band gap s/c)



(indirect band gap s/c) (shifted curve)

In the eq^n, the term $\frac{kT}{q}$ is known as thermal voltage, V_{TH}
so the eq^n becomes,

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

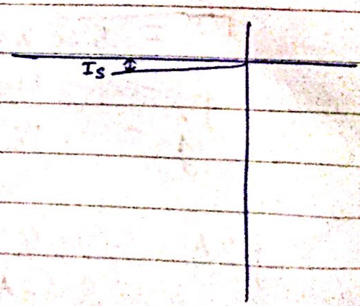
$\Rightarrow$ $V_{TH} = 25.9$ mV at 300 K

For reverse bias, V is negative,

ex: $e^{-V/nV_{TH}} - 1$

$\frac{1}{1000}$ $\left(\frac{1}{e^{V/nV_{TH}}}\right) - 1 = 0.000$

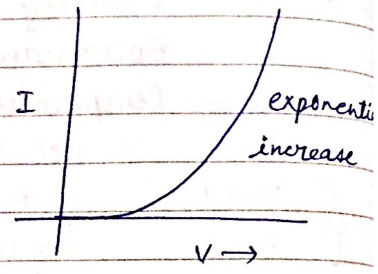
$I \sim -I_s$



For forward bias ;

$$e^{V/nV_{TH}} >> 1$$

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



Built in potential (breakdown voltage)

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

Q. A copper wire of 2mm diameter with conductivity of 5.8×10^7 seimens/m and electron mobility of 0.0032 m^2/Vs is subjected to an electric field of 20 mV/m. Find

a) the number density of free electrons ($1.132 \times 10^{29}\ m^{-3}$)
b) the current density ($1.16 \times 10^6\ A/m^2$)
c) the current flowing in wire (3.67 A)
d) the drift velocity. (64 m/s)

→ $d = 2mm = 2 \times 10^{-3}\ m$

$r = 1mm = 1 \times 10^{-3}\ m$

$\sigma = 5.8 \times 10^7\ S/m$

$\mu = 0.0032\ m^2/Vs$

$E = 20mV/m = 20 \times 10^{-3}\ V/m$

$j = nAv_d e$

$j = \frac{I}{A}$

i) $I = \frac{Nev}{L}$

$\boxed{j = \sigma E}$

$= 5.8 \times 10^7 \times 20 \times 10^{-3}$

$j = 116 \times 10^4$

$j = 1.16 \times 10^6\ A/m^2$

$5.8 \times 2.0 = 11.6.0$

$I = j \times A = 1.16 \times 10^6 \times 3.14 \times 1 \times 10^{-3} \times 1 \times 1$

$= 3.67 A$

$$i = nAv_de$$

$$\frac{i}{nAe} = v_d$$

$$\frac{3.67}{1.132\times10^{29}\times 3.14\times1\times10^{-3}\times1\times10^{-3}\times1.67\times10^{-19}} = v_d$$

$$\frac{3.67}{5.93\times10^{4}} = 0.61\times10^{-4} \approx 64\,m/s$$

29/10 Q Find the intrinsic carrier concentration of germanium if its intrinsic resistivity at 300K is 0.47 Ωm. It is given that the electronic charge is 1.6×10^{-19} C and electron & hole mobilities at 300K are 0.39 and 0.19 m^2/Vs respectively. [$\sigma \Rightarrow ne(\mu_n+\mu_p)$]

→ $0.47\,\Omega m = \rho$

$\therefore \sigma = \frac{1}{0.47}$

$\therefore$ and $\sigma = ne(\mu_n+\mu_p)$

$$\frac{1}{0.47} = n\times1.67\times10^{-19}(0.39+0.19)$$

$$\frac{1}{0.47} = n\times1.67\times10^{-19}\times0.58$$

$$\frac{1}{0.47\times1.67\times0.58} = n$$

$$n = 2.3\times10^{19}$$

$$\begin{array}{r} 0.39 \\ 0.19 \\ \hline 0.58 \end{array}$$

Q Calculate the donor concentration in n-type Ge having resistivity of 100 Ωm when $\mu_n = 0.36\,m^2/Vsec$

→ $\rho = \frac{1}{\sigma} \Rightarrow \sigma = \frac{1}{100} = 0.01$

$= ~~1.67\times10^{17}~~$

Determine the concentrations of free e^- & holes in a sample of Ge at 300K which has the concentration of donor atoms $= 2\times10^{14}$ atoms/cm³ and the concentration of acceptor ions $= 3\times10^{14}$ atoms/cm³.

$N_D = 2\times10^{14}$

$N_A = 3\times10^{14}$

$$n + N_A = p + N_D$$

$n_i = 2.3\times10^{19}$

$$n.p = n_i^2$$

$$n.p = 2.3\times 2.3 \times 10^{19} \times 10^{19}$$

$$n.p = 5.29\times10^{38} \quad \text{——} ①$$

$$n + 3\times10^{14} = p + 2\times10^{14}$$

$$\cancel{n\ p} \quad p - n = 1\times10^{14} \quad \text{——} ②$$

$$\Rightarrow p = 1\times10^{14} + n$$

$$n.(1\times10^{14}+n) = 5.29\times10^{38}$$

$$n\times10^{14} + n^2 = 5.29\times10^{38}$$

$$n^2 + 10^{14}n - 5.29\times10^{38} = 0$$

$$n = \frac{\sqrt{(10^{14})^2 - 4\times1\times5.29\times10^{38}}}{2}$$

~~$p \approx N_A$~~ ~~and~~ ~~$n \approx N_D$~~

~~$np = n_i^2$~~

$$n = -10^{14}\frac{\sqrt{(10^{14})^2 - 4\times1\times5.29\times10^{38}}}{2} = -\frac{\sqrt{10^{28} - 21.16\times10^{38}}}{2}$$

$$= -10^{14}\sqrt{10^{28} - 21.16\times10^{28}\times10^{10}} = -\frac{\sqrt{10^{28} - 21.16\times10^{28}\times10^{10}}}{2}$$

$= -10^{14}\times10^{28}$

$$= \frac{-10^{28}\sqrt{10^{14} - 21.16\times10^{10}}}{2}$$

2.29×10^{19}

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

$I = 0.5 \times 10^{-3} A$

$$I = I_s \left(e^{qV/nkT} - 1\right)$$

$\cancel{I / = I_s}$

$$0.5 = I_s \left(e^{\cancel{1.67\times10^{-19}/n\times}}\right.$$

$$\frac{qV}{nkT} = \frac{1.67 \times 10^{-19}}{n \times 1.38 \times 10^{23} \times 300} = \frac{1.67 \times 10^{-19}}{414 \times 10^{23} \times n}$$

$$= \frac{0.0040 \times 10^{-42}}{n}$$

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

$$10^{-3} \times 0.5 = I_s e^{0.45/n\times25.9} \qquad = 4.0 \times 10^{-3} \times 10^{-42}$$

$$\cancel{0.5 \times 10^{-3} = I_s e^{\frac{0.45}{n\times25.9}} \qquad = 4 \times 10^{-45}}$$

$$0.5 \times 10^{-3} = I_s \left(e^{\frac{4\times10^{-45}}{n}} - 1\right) \quad \text{—— (1)}$$

$$0.5 \times 10^{-3} = I_s \; e^{\frac{0.45}{n\times25.9}}$$

$$\frac{0.5 \times \cancel{10^{-3}}}{e^{\frac{4\times10^{-45}}{n}} - 1} = \frac{0.5 \cancel{\times 10^{-3}}}{e^{\frac{0.45}{n\times25.9}}}$$

$$e^{\frac{4\times10^{-45}}{n}} - 1 = e^{\frac{0.017}{n}}$$

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

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

$$0.5 \times 10^{-3} = I_s e^{\frac{0.45V}{n\times25.9\times10^{-3}}}$$

$$25 \times 10^{-3} = I_s \, e^{0.65/n\times25.9\times10^{-3}}$$

$$50 = e^{\frac{0.65 - 0.45}{n\times25.9\times10^{-3}}}$$

The current flowing in a certain p-n junction at room temp is 2×10^{-7} A when a large reverse bias is applied. Calculate the current when a forward voltaage of 0.1 Volt is applied across the junction. (9.16 µA)

$I_S = 2 \times 10^{-7} A$

$$I = I_S \left[e^{V/nV_{TH}} - 1\right]$$

$$I = I_S \, e^{V/nV_{TH}}$$

$$= 2 \times 10^{-7} \, e^{0.1/1 \times 25.9}$$

$$I = 2 \times 10^{-7} \, e^{0.0038}$$

$$= 2 \times 10^{-7}$$

for a Si diode at room temp, the forward current is I at a voltage V. Find the voltage at which the forward current is 3I. ~~(0.057 Volt)~~ (0.057+V)

$$I = I_S e^{V/nV_{TH}}$$

$$\cancel{3I = ?}$$

$$3I = I_S e^{V_1/1 \times 25.9}$$

$$\frac{\cancel{I}}{\cancel{3}I} = \frac{\cancel{I_S} \cancel{e^{V/nV_{TH}}}}{\cancel{I_S} \cancel{e^{V/nV_{TH}}}}$$

$$\frac{3\cancel{I}}{\cancel{I}} = e^{(V_1 - V)\,nV_{TH}}$$

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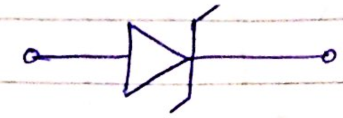
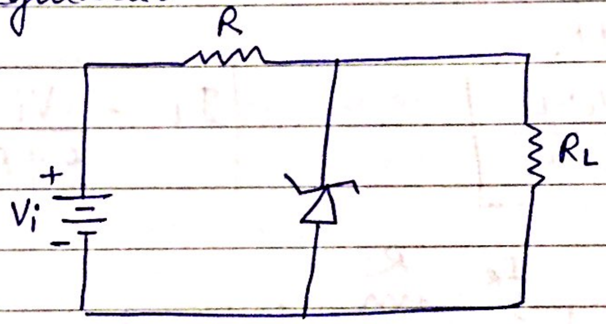
ZENER DIODE AND ITS APPLICATIONS :
(reverse bias)

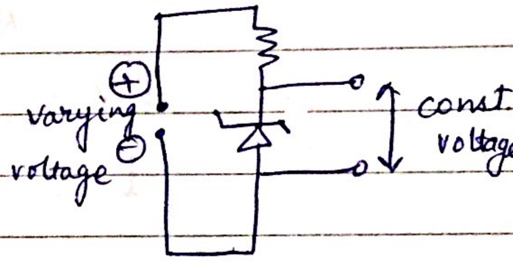


Zener diode is a device which is based on the principle of Zener breakdown. Zener diode is fabricated with highly doped p and n type s/c so that we may achieve breakdown at a smaller value of reverse bias voltage as compared to avalanche breakdown.

APPLICATIONS

1. Voltage regulator

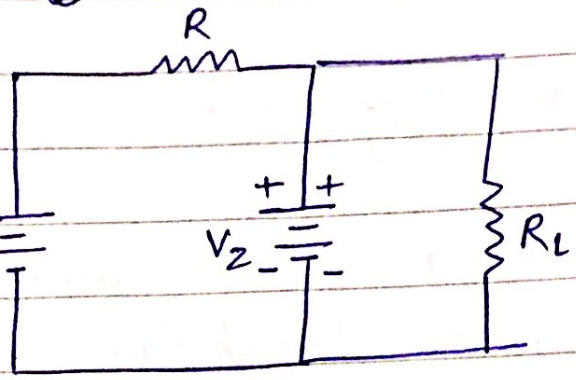




If the voltage drop across Zener diode is less than Zener breakdown voltage, then the zener diode will be in 'OFF' state

R

If $V >$ or $= V_Z$ ($V \geq V_Z$) then the zener diode will be in 'ON' state



'ON' STATE

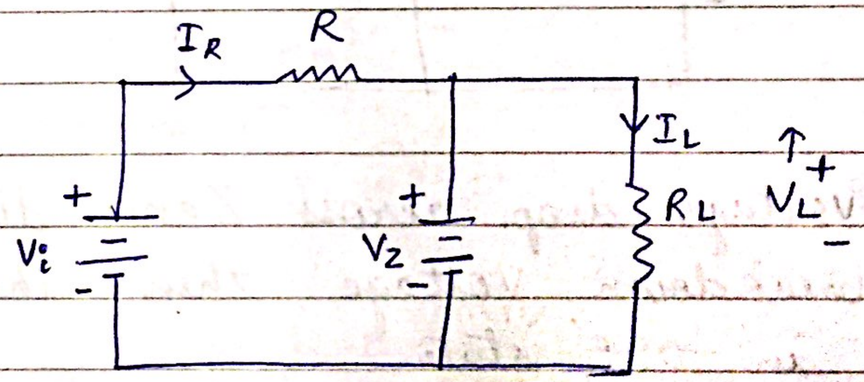
To determine V

$V < V_Z$ (OFF)

$V \geq V_Z$ (ON)

$$V = V_L$$
$$= I_L R_L$$
$$I_L = \frac{V_i}{R + R_L}$$

$$\boxed{V = \frac{V_i R_L}{R + R_L}} \qquad \boxed{I_L = \frac{V_i}{R + R_L}}$$



$V_Z = V_L$ (parallel)

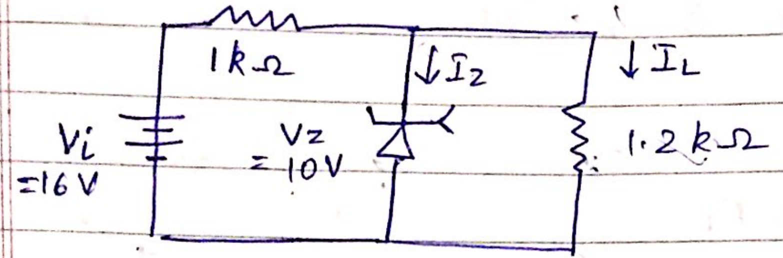
$I_R = I_Z + I_L$ (by Kirchoffs law) $\Rightarrow \boxed{I_Z = I_R - I_L}$

$I_R = \frac{V_R}{R}$; $I_L = \frac{V_L}{R_L}$

$$\therefore \boxed{I_R = \frac{V_i - V_L}{R}}$$

Power dissipated across zener diode :

$$\boxed{P_Z = V_Z I_Z}$$



determine ON or OFF

V_L, V_R, I_Z, P_Z

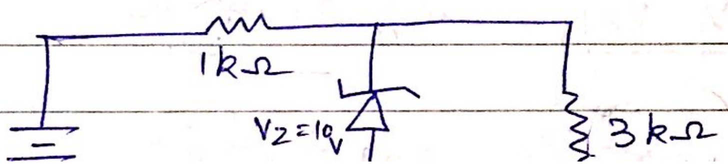
$$V = \frac{V_i R_L}{R + R_L} \qquad\qquad V_L = I_L R_L$$

$$V = \frac{16 \times 1.2 \times \cancel{10^3}}{1 \times 10^3 + 1.2 \times \cancel{10^3}} = \frac{19.2 \times \cancel{10^3}}{2.2 \times \cancel{10^3}} = \frac{96}{11}$$

diode will be in OFF state. ($V < V_Z$)

$\therefore I_Z = 0$

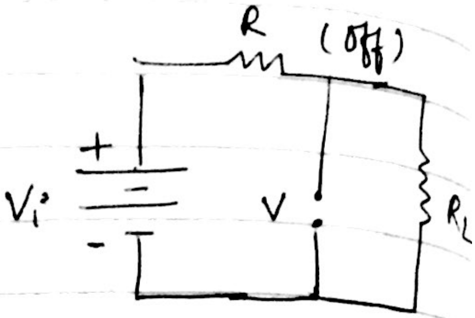
$\therefore$ Power dissipation $= 0. = P_Z$



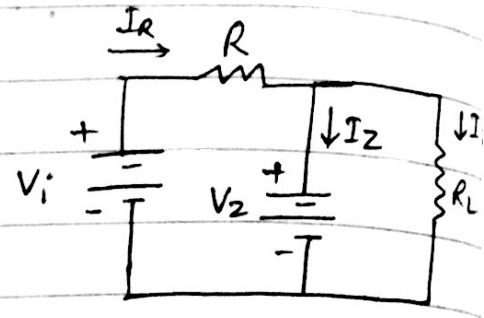
— CONDITIONS OF ZENER DIODE —

V_i and R_L are fixed

fixed V_i, R_L is varying



for the zener diode to be 'ON'



$V \geq V_Z$ (on)

$$V \geq V_Z$$

$$V = V_Z = \frac{V_i R_L}{R + R_L}$$

$$V_i R_L = V_Z R + V_Z R_L$$

$$(V_i - V_Z) R_L = V_Z R$$

$$R_L = \frac{V_Z R}{V_i - V_Z}$$

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

— minimum value for diode to be 'ON'

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

$$\therefore \boxed{I_{L\,max} = \frac{V_Z}{R_{L_{min}}}}$$

$I_{ZM} \rightarrow$ max. current the zener diode can sustain

$$I_Z = I_R - I_L$$

$$I_L = I_R - I_Z$$

$$I_{L_{min}} = I_R - I_{ZM}$$

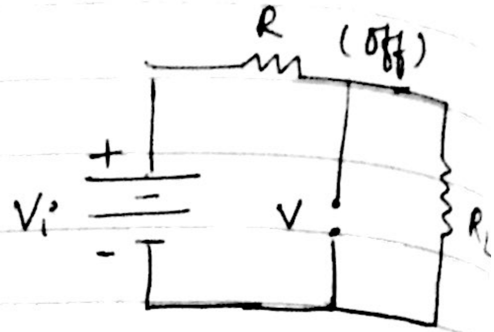
$$\boxed{I_R = \frac{V_i - V_Z}{R}}$$

$$R_{L\,max} = \frac{V_Z}{I_{L\,min}}$$

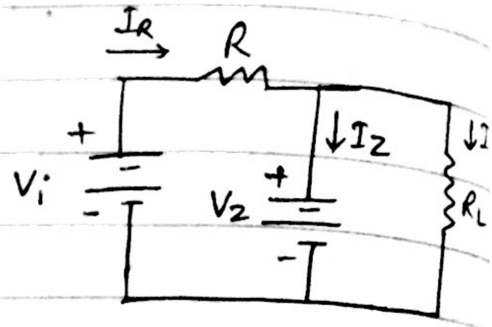
— CONDITIONS OF ZENER DIODE —

V_i and R_L are fixed

fixed V_i, R_L is varying



for the zener diode to be 'ON'



$V \geq V_Z$ (on)

$$V \geq V_Z$$

$$V = V_Z = \frac{V_i R_L}{R + R_L}$$

$$V_i R_L = V_Z R + V_Z R_L$$

$$(V_i - V_Z) R_L = V_Z R$$

$$R_L = \frac{V_Z R}{V_i - V_Z}$$

$$\boxed{R_{L\,min} = \frac{V_Z R}{V_i - V_Z}}$$ — minimum value for diode to be 'ON'

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

$$\therefore \boxed{I_{L\,max} = \frac{V_Z}{R_{L\,min}}}$$

$I_{ZM} \rightarrow$ max. current the zener diode can sustai

$$I_Z = I_R - I_L$$

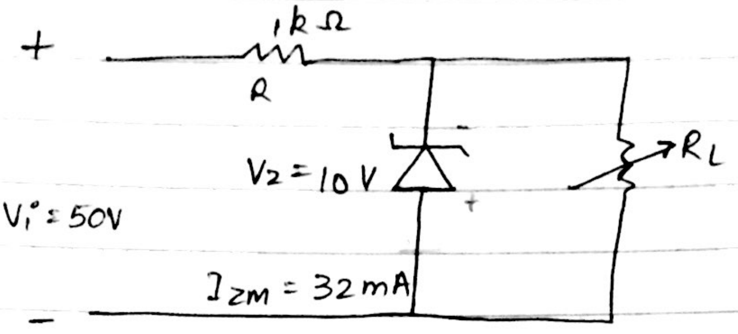
$$I_L = I_R - I_Z$$

$$I_{L\,min} = I_R - I_{ZM}$$

$$\boxed{I_R = \frac{V_i - V_Z}{R}}$$

$$R_{L\,max} = \frac{V_Z}{I_{L\,min}}$$

Question



$R_{L\,min}$ = ??
$R_{L\,max}$ = ?

$$R_L = \frac{V_z R}{V_i - V_z}$$

$$R_L = \frac{10 \times 1000}{50 - 10} = \frac{100\cancel{0}}{4\cancel{0}}$$

$$R_L = 250\,\Omega$$

$$R_{L\,min} = \frac{V_z R}{V_i - V_z} = 250\,\Omega$$

$$\cancel{I_L} = \cancel{\frac{V_L}{R_L}} = \cancel{\frac{V_z}{R_L}}.$$

$$R_{L\,max} = \frac{V_z}{I_{L\,min}} \qquad \cancel{I_L} = \cancel{\frac{10}{250}}$$

$$I_{L\,min} = I_R - I_{zM}$$

$$= \left(\frac{V_i - V_z}{R}\right) - 32 \times 10^{-3}$$

$$= \frac{50 - 10}{1000} = \frac{4\cancel{0}}{100\cancel{0}} = \cancel{0.25 - 32 \times 10^{-3}}$$

$$= \cancel{0.25 \times 10} \;\; \cancel{00} \;\; \cancel{0.04}$$

$$I_{L\,min} = 40 - 32 = 8mA$$

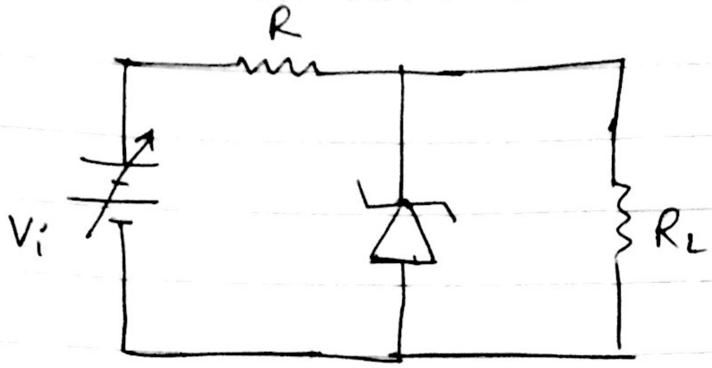
$$R_{L\,max} = \cancel{\frac{10V}{8mA}} \qquad 20.008A$$

$$= \cancel{1.2\,\Omega}$$

R_L ...

$$\begin{array}{r} 250 \\ 4\,\overline{)1000} \\ 8\downarrow \\ \hline 20 \\ 20 \\ \hline 00 \\ 0 \\ \hline \end{array} \qquad \begin{array}{r} 1.2 \\ 10\,\overline{)18} \\ 8 \\ \hline 20 \end{array}$$

V_i is variable, R_L is fixed



$$V = \frac{V_i R_L}{R + R_L}$$

$$V = V_Z = \frac{V_i R_L}{R + R_L}$$

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

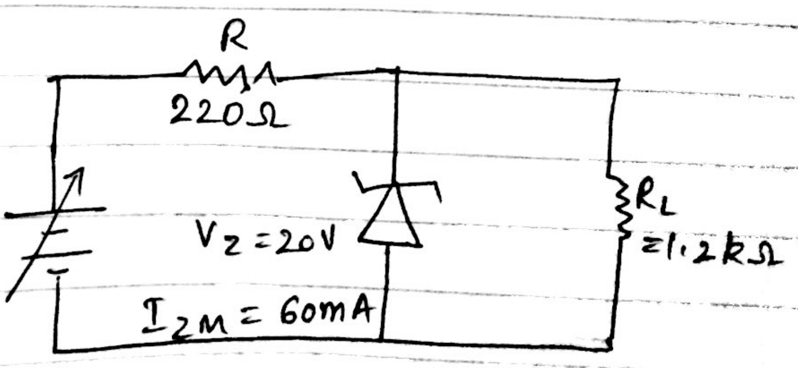
$$\boxed{V_{imin} = \frac{V_Z (R + R_L)}{R_L}}$$ — if V_i is less than this, diode is OFF

$$V_i = V_R + V_Z$$

$$V_{imax} = V_{Rmax} + V_Z$$

$$V_{Rmax} = I_{Rmax} \cdot R$$

$$\boxed{I_{Rmax} = I_{ZM} + I_L}$$



$V_{imax} = ?$

$V_{imin} = ?$

$60 \times 10^{-3} A$

$1.2 \times 10^3 \Omega$ $\quad$ $60000A$

1200

$$V_{i\,min} = \frac{V_Z (R + R_L)}{R_L}$$

$$= \frac{20 (220 + 1200)}{1200}$$

$$= \frac{\cancel{20} (142\cancel{0})}{\cancel{12}\cancel{00}_{6}} = \frac{142}{6} =$$

$$6 \overline{)142}\ \ 23.6$$

12
22
18
40
36

$$= 23.6\ V$$

$$V_{i\,max} = V_{R\,max} + V_Z$$

$$V_{R\,max} = I_{R\,max} \cdot R \qquad I_R = I_Z + I_L$$

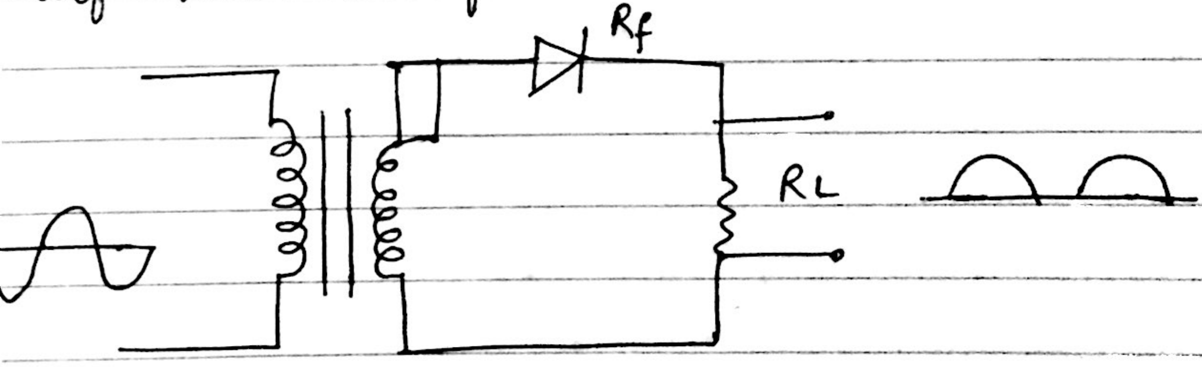
$$I_{R\,max} = I_{ZM} + I_L$$

$$I_L = \frac{V_Z}{R_L} = \frac{2\cancel{0}}{120\cancel{0}} = \frac{1}{60}.$$

$$I_{R\,max} = \frac{60000}{} + \frac{1}{60}$$

RECTIFIER :-

Half wave Rectifier



1. $\boxed{I_{dc} = \frac{I_m}{\pi}}$

$$I_{dc} = \frac{V_m}{\pi(R_f + R_L)}$$

2. $I_{rms} = \frac{I_m}{2} = \frac{V_m}{2(R_f + R_L)}$

$$\boxed{I_{rms}^2 = I_{dc}^2 + I_{ac}^2}$$

(total current)

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

Form factor,

$$F = \frac{I_{rms}}{I_{dc}} = \frac{\cancel{I_m}}{2} \times \frac{\pi}{\cancel{I_m}} = \frac{\pi}{2} = \frac{3.14}{2} = 1.57$$

$$F = \frac{V_{rms}}{V_{D.C}}$$

$$\boxed{F = 1.57}$$

Ripple factor, (how much DC component is there)

$$r = \frac{I_{ac}}{I_{dc}} = \frac{V_{ac}}{V_{dc}}$$

$$r = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

$$r = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{\sqrt{I^2}}$$

$\therefore$ Now,

$$\eta = \frac{\cancel{I_m^2}}{\pi^2} R_L \frac{4}{\cancel{I_m^2}(R_f + R_L)}$$

$$= \frac{4}{\pi^2} \frac{R_L}{(R_f + R_L)}$$

$$\boxed{\eta = \frac{4}{\pi^2} \cdot \frac{1}{\left(\frac{R_f}{R_L} + 1\right)}}$$

$R_f = 10\,\Omega$

$R_L = 100\,\Omega$

$V_{rms} = 50V$

$i_m = ?$

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

$$\therefore V_m = V_{rms} \times \sqrt{2}$$

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

$$\therefore I_m = \frac{50\sqrt{2}}{10+100} = \frac{5\cancel{0}\sqrt{2}}{11\cancel{0}} = \frac{5\sqrt{2}}{11} A = 0.64$$

$$I_{dc} = \frac{I_m}{\pi} = \frac{\frac{50\sqrt{2}}{110}}{\frac{22}{7}} = \frac{\overset{5}{\cancel{\overset{25}{\cancel{50}}}}\sqrt{2}}{\underset{22}{\cancel{110}}} \times \frac{7}{\underset{11}{\cancel{22}}}$$

$$\frac{35\sqrt{2}}{242} = 0.2A$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{5\sqrt{2}}{11} \times \frac{1}{2}$$

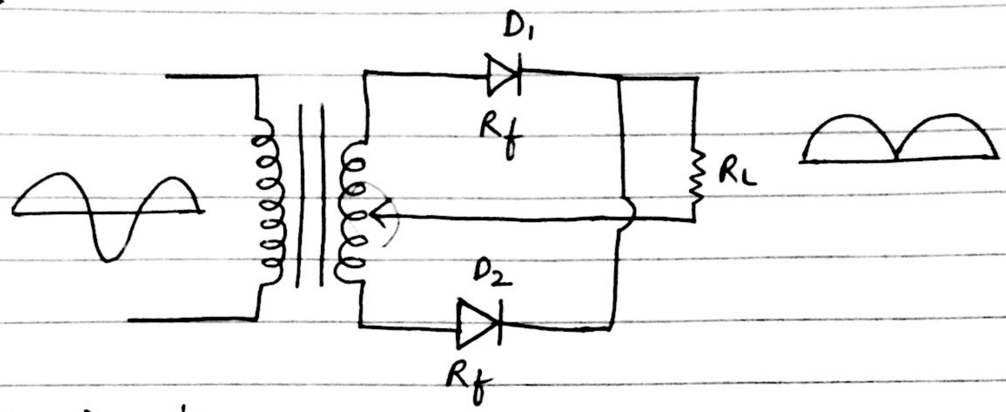
$$= \frac{5\sqrt{2}}{22} \cancel{A} = 0.32A$$

$$\eta = \frac{4}{3.14 \times 3.14} \cdot \frac{1}{\left(\frac{10}{100} + 1\right)} = 0.369.$$

FULL WAVE RECTIFIER -

1. Centre tapped
2. Bridge.

centre tapped



$$V = V_m \sin \omega t$$

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

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

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

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

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

$$F = \frac{I_{rms}}{I_{dc}}$$ (form factor)

Ripple factor

$$\gamma = \sqrt{F^2 - 1} = \sqrt{(1.11)^2 - 1}$$

$$\gamma = \frac{I_{ac}}{I_{dc}}$$

$$\boxed{\gamma = 0.48}$$

Rectification efficiency : 81%

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

$$\eta = \frac{4 \cancel{I_m^2} R_L}{\pi^2} \times \frac{2}{\cancel{I_m^2}(R_f + R_L)}$$

$$I_{dc} = \frac{I_m}{\pi} = \frac{0.45}{3.14} = 0.14\,A$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{0.144}{1.414} = 0.10\,A$$

V_{dc}

$$\eta = \frac{8}{3.14 \times 3.14} \cdot \frac{1}{\left(\frac{\cancel{10}}{\cancel{100}} + 1\right)}$$

$$= \frac{8}{9.85} \times \frac{1}{0.1+1}$$

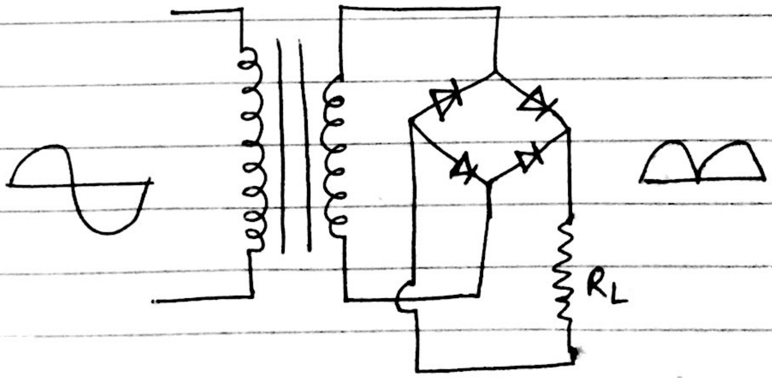
$$= \frac{0.81}{1.1} = 0.73 = 73\%$$

$$\boxed{V_{dc} = I_{dc} \cdot R_L}$$

$$V_{dc} = 0.14 \times 100 = 14V$$

FULL WAVE BRIDGE RECTIFIER (does not require centre tapping)

(81% efficiency)



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

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

$$\frac{I_{rms}}{I_{dc}} = \text{Ripple factor} = \frac{\pi}{2\sqrt{2}}$$

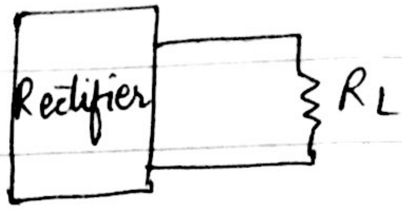
$$I_m = \frac{V_m}{2R_f + R_L}$$

$$\text{efficiency} = \eta = \frac{P_{dc}}{P_{ac}}$$

same

FILTER CIRCUITS -

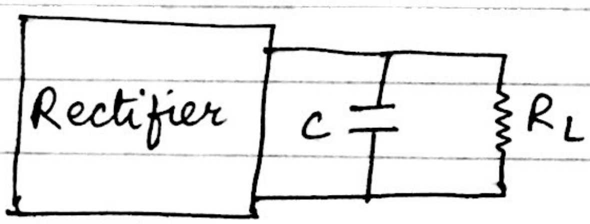
to get rid of a.c component



The output from a rectifier consists of ripples which means there is variation in the output across the load. To improve the quality of rectification some specially designed circuit is required which opposes the voltage variation across the output. These circuits are known as filter circuits.

Depending upon the components used & structure filters are of several types-

Shunt capacitor filter - ($V\downarrow$ $I\uparrow$)

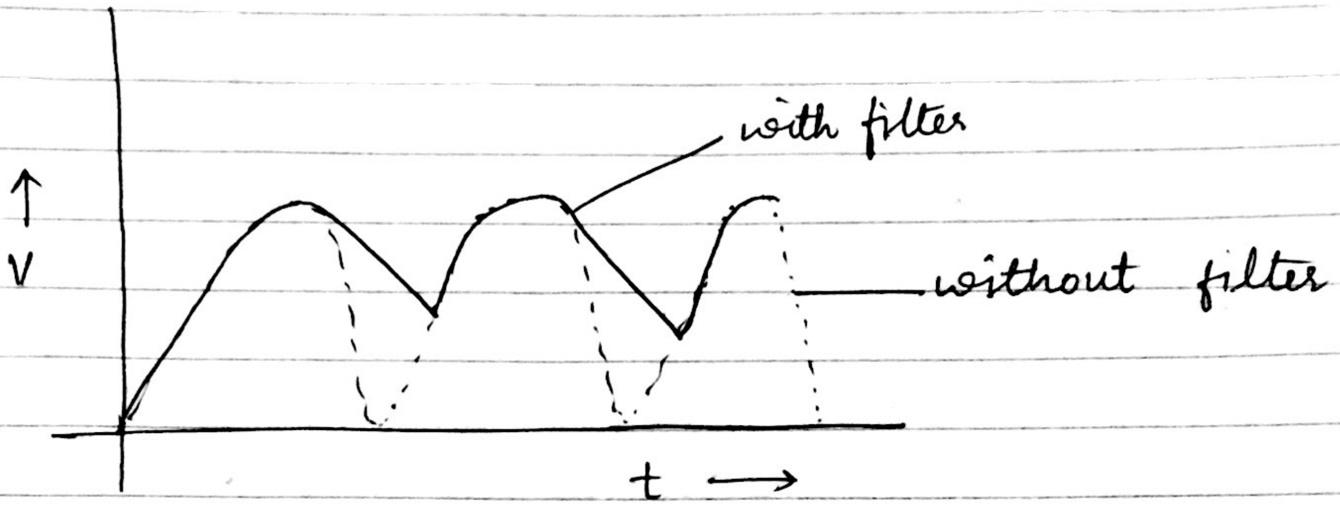


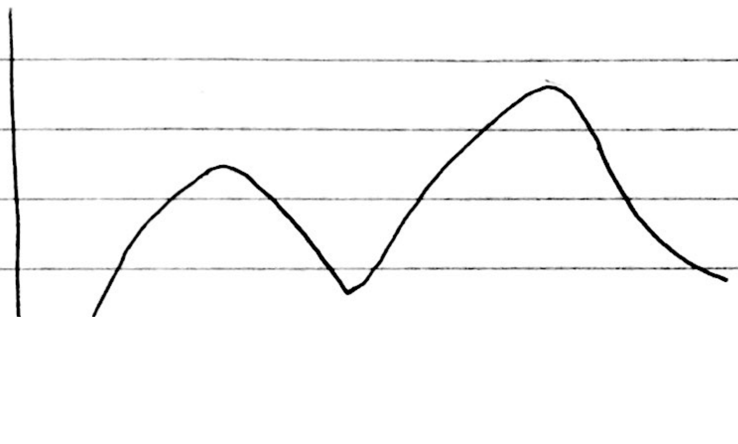
capacitive reactance

$$X_C = \frac{1}{\omega C}$$

$$= \frac{1}{2\pi f C}$$

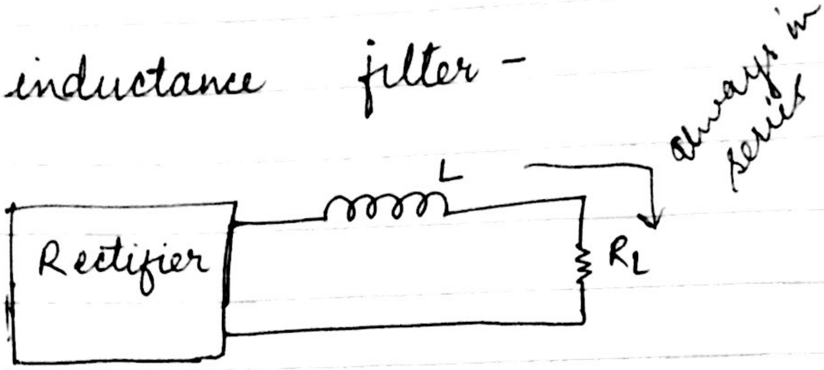
connected in parallel to the load, it bipasses the a·c component from the rectifier output. and allows only D·c component to appear across the load. In this way the quality of the rectification is improved.





For a given value of load resistance, larger capacitance, smaller will be its impedence which will result in better bypassing of a.c component i.e smaller ripple factor.

Series inductance filter -

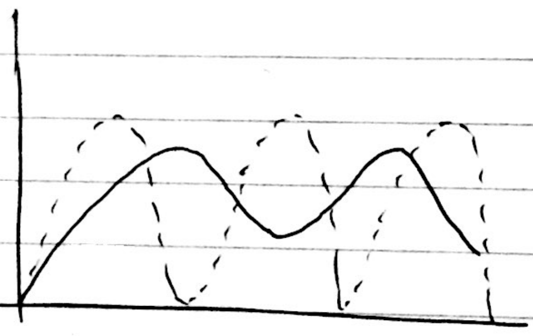


The inductor in series offers a high resistance to a.c & 0 resistance to d.c. Therefore, in the rectifier output a.c will be stopped by the series inductor filter & only d.c will appear across the load. Thus, quality of rectification is improved.

$\omega L = 2\pi \nu L$

$\frac{1}{\omega C} = \frac{1}{2\pi \nu C}$

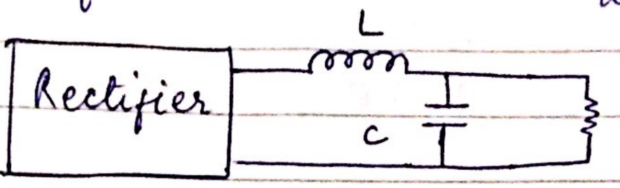
age $\nu = 0$



When the load current ↑, the induced voltage across the inductor, opposes the increase because its polarity is such that it sends an induced current in opposite direction. When the load current ↓, the polarity of the induced voltage is reversed so that the induced current flows in the same direction as the load current & load current ↑. The variations in the load current are thus minimized.

(3). L - section filter : explain

L - C filter :

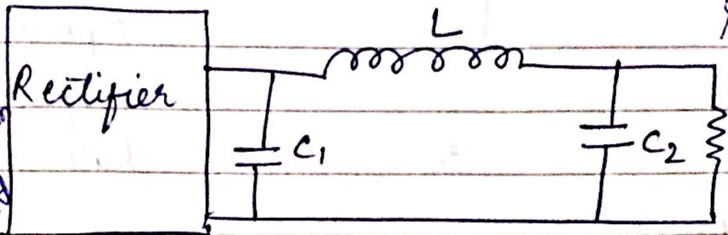


shunt cap filter will reduce the ripple voltage but diode current will ↑ this may damage the diode. And a series inductor filter reduces both the peak & effective values of output current & voltage. So if they are combined a new filter is formed which has a good efficiency, with restricted diode current and enough ripple ~~factor~~ removal.

(4). π filter : explain

adv. higher d.c voltage, small ripple factor

disad poor voltage regulation, high peak diode current & high p.I.V



resemblance of circuit with π shape with 2 shunt capacitance. Output is directly to capacitor divided into two a capacitor filter & an L-section filter. output voltage falls off rapidly with inc in load current.

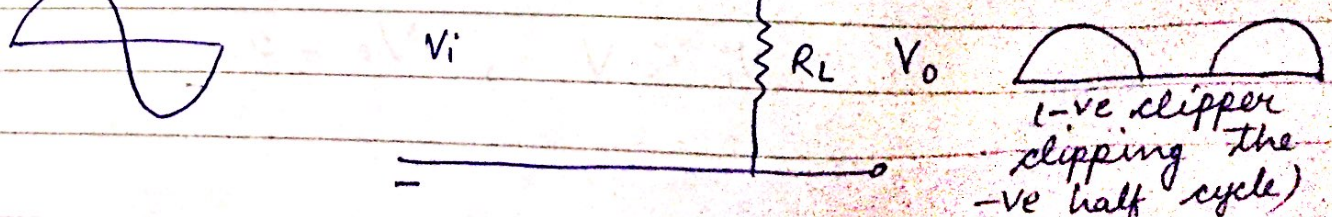
CLIPPERS

The diode networks which have ability to clip off a portion of the input signal without distorting the remaining part of the alternating wave form are known as clippers. If we want to clip a portion of the waveform we use clippers & if we want to shift or clamp the dc voltage level we use clampers.

- Series clipper
  - Biased
    - +
    - −
  - Unbiased
    - +
    - −
- Parallel clipper
  - Biased
    - +
    - −
  - Unbiased
    - +
    - −

1) Series Unbiased clippers

a) negative



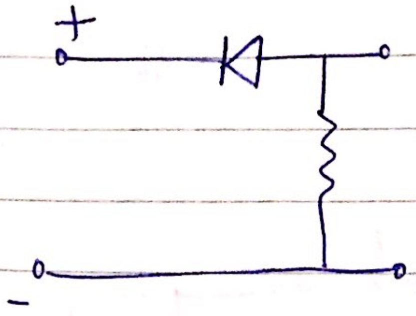
(-ve clipper clipping the -ve half cycle) for negative clipper

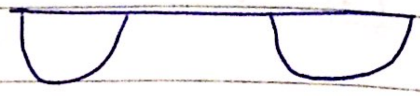
$V_i > 0$; $V_o = V_i$

$V_i = 0$; $V_o = 0$

$V_i < 0$; $V_o = 0$

positive :-





(positive clipper clipping the +ve half cycle)

for +ve clipper;

$V_i > 0$; $V_o = 0$

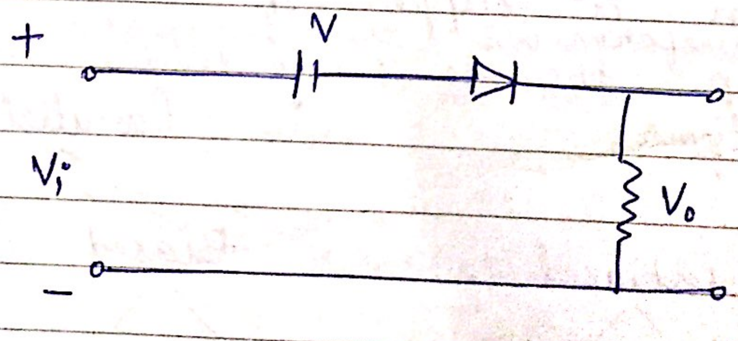
$V_i = 0$; $V_o = 0$

$V_i < 0$; $V_o = -V_i$

<u>Series biased clippers</u> :

↓

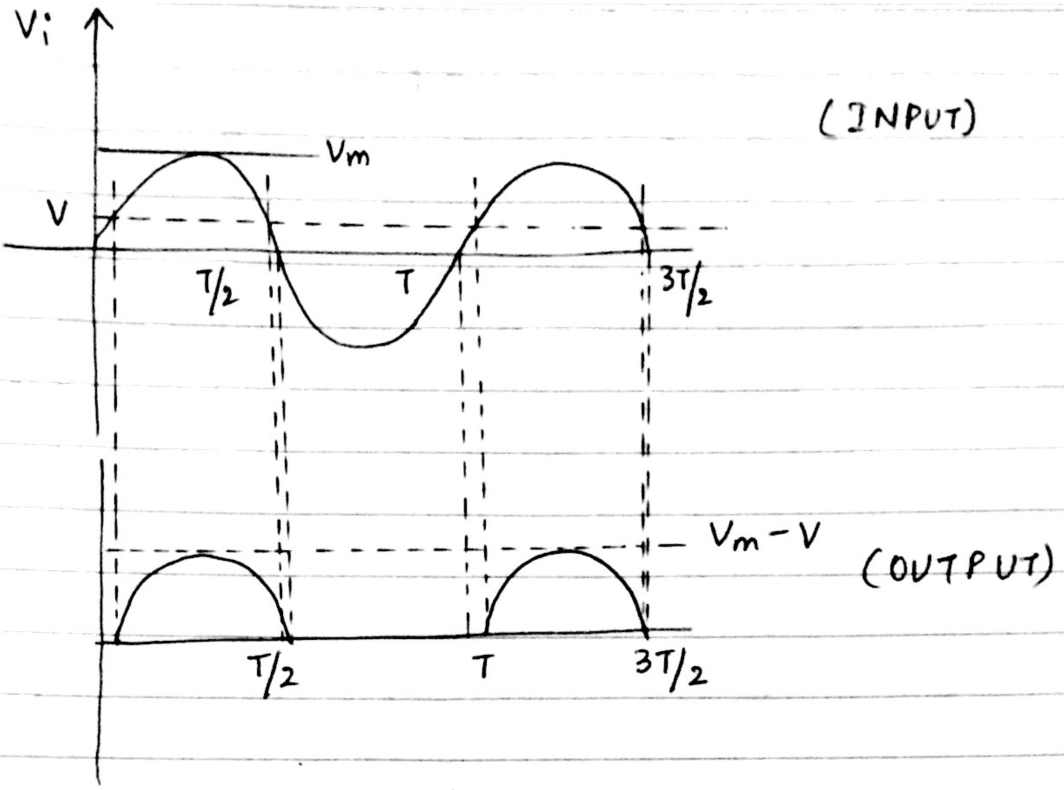
(battery connected with diode)



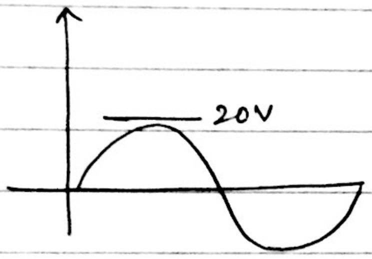
$V_i = V$, $V_o = 0$

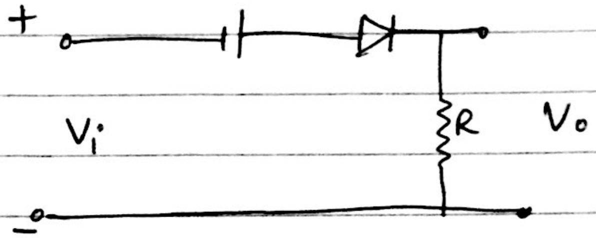
$V_i > V$, $V_o = V_i - V$

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



Q

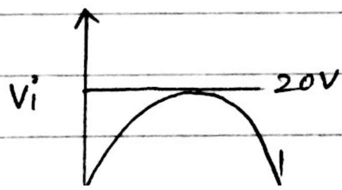


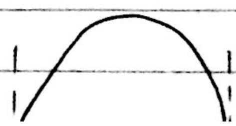


$V_i = -5V$, $V_o = 0$

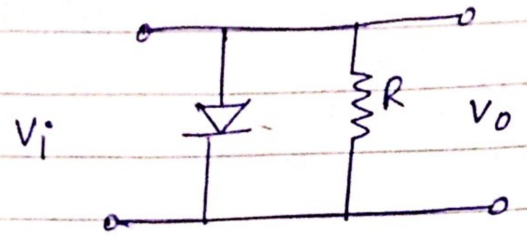
$V_i < -5V$, $V_o = 0$

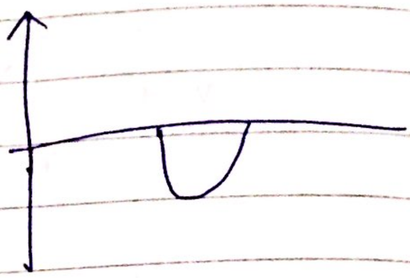
$V_i > -5V$, $V_o = V_i + 5$





3) Parallel unbiased clippers :-



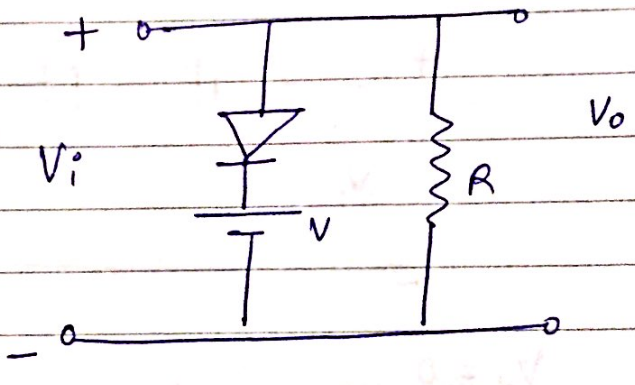


$V_i > 0$; $V_o = 0$

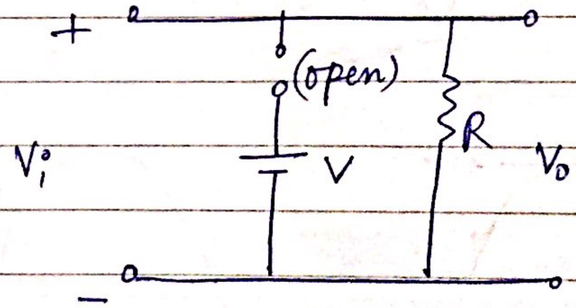
$V_i = 0$; $V_o = 0$

$V_i < 0$; $V_o = -V_i$

4). Biased parallel clipper -:



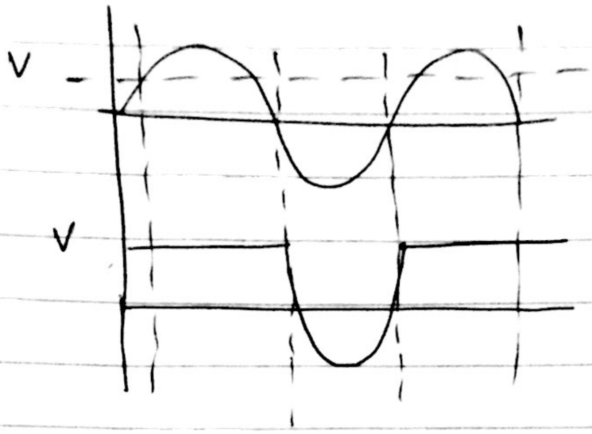
$V_i < V$ (reverse bias)



$V_o = V_i$

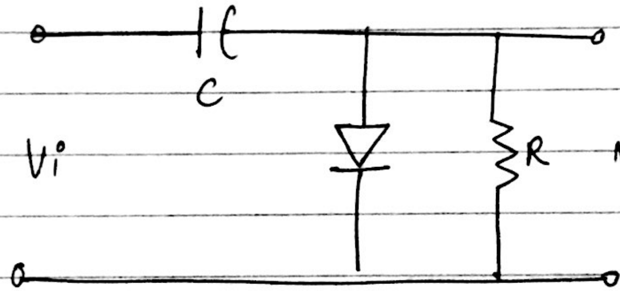
$V_i > V$

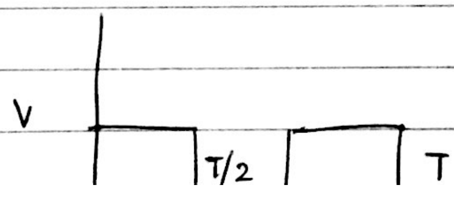
+



CLAMPERS:

The diode networks which clamp a signal to a different D.C level are known as clampers. The network must have a capacitor, an inductor & a resistor, but can also employ an D.C supply to introduce an additional shift.





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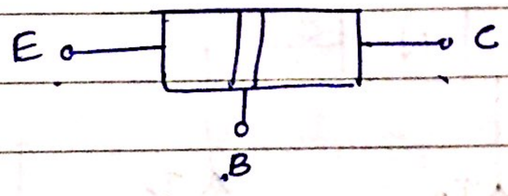
BIPOLAR JUNCTION TRANSISTOR (BJT)

[P | N] + [N | P] ⇒ [P | N | P]

[N | P] + [P | N] ⇒ [N | P | N]

Base - (thin & lightly doped, central region).

Emitter - the region on one side of the base, supplies charge carriers responsible for conduction through ~~Collector~~ the transistor & it is known as emitter



Collector :- The region on the other side of the base, collects the charge carriers supplied by emitter and it is known as collector.

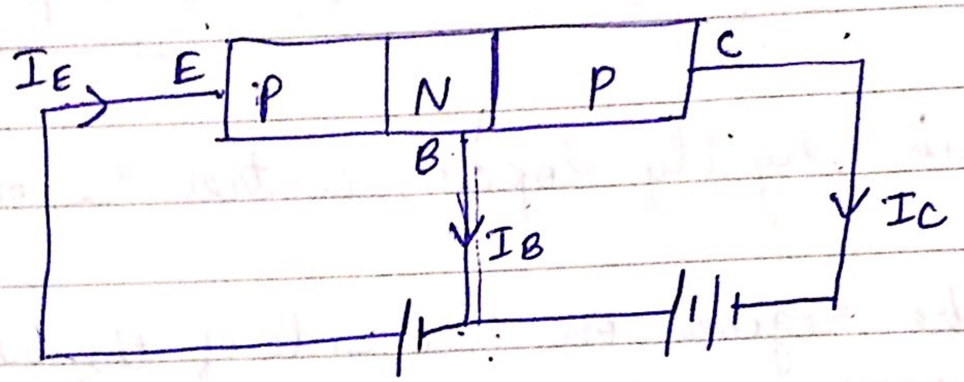
Transistor Symbol:-

PNP

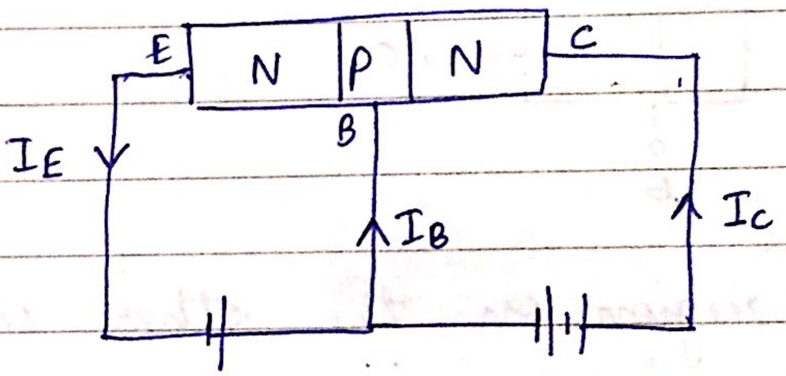
NPN

WORKING OF TRANSISTOR :

For transistor operation, it is necessary that EB junction is forward bias & CB junction is reverse biased.



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



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

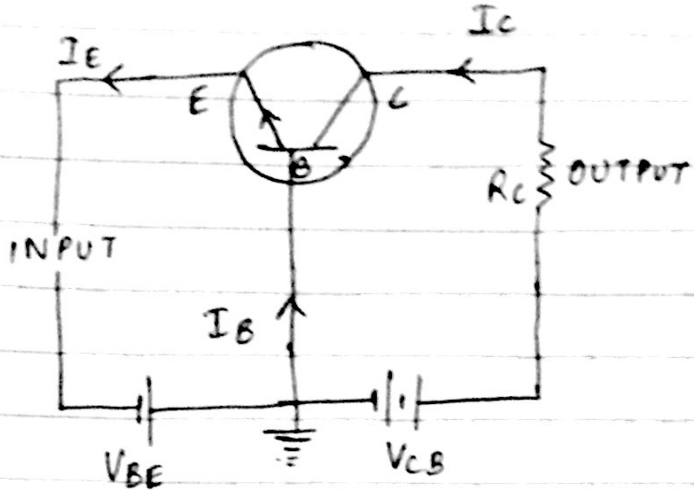
TRANSISTOR CONFIGURATIONS :-

Common base configuration (CB)

Common emitter —" —— (CE)

Common collector —" —— (CC)

common base (CB) :-



Current gain,

if common base then I_E or I_C — $\boxed{\alpha = \frac{\Delta I_C}{\Delta I_E}}$ (for AC)

$= \frac{I_C}{I_E}$ (for D.C)

दोनों में I_C ऊपर

No I_B

⇒ Collectar current consists of 2 parts

(i) αI_E

(ii) The current due to minority charge carriers under reverse bias of CB junction → leakage current

$$I_C = \alpha I_E + I_{leakage}$$

$$= \alpha (I_B + I_C) + I_{CBO}$$

$$I_C (1-\alpha) = \alpha I_B + I_{CBO}$$

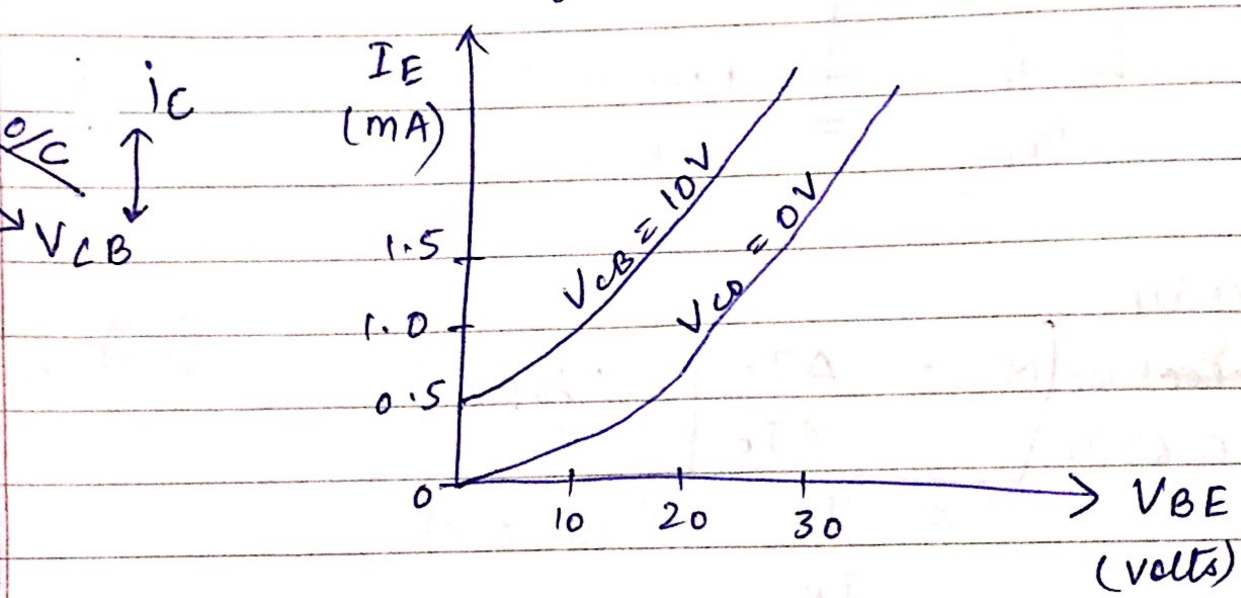
$$\boxed{I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha}}$$

(leakage curre

Transistor characteristics

Input characteristics

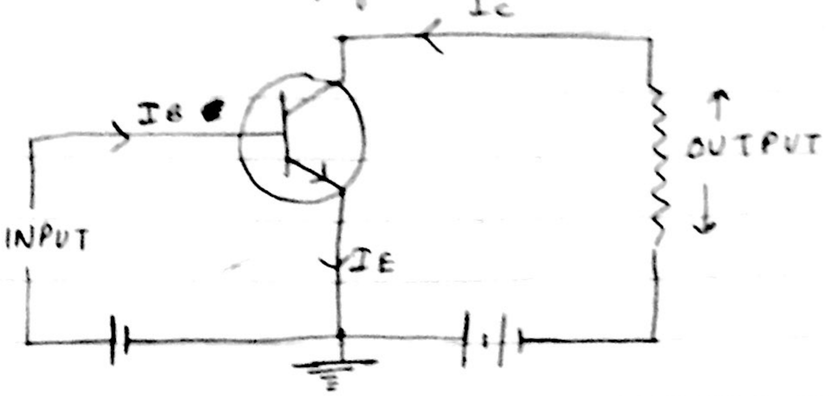
It is a plot of I_E Vs V_{BE} at constant V_{CB}.



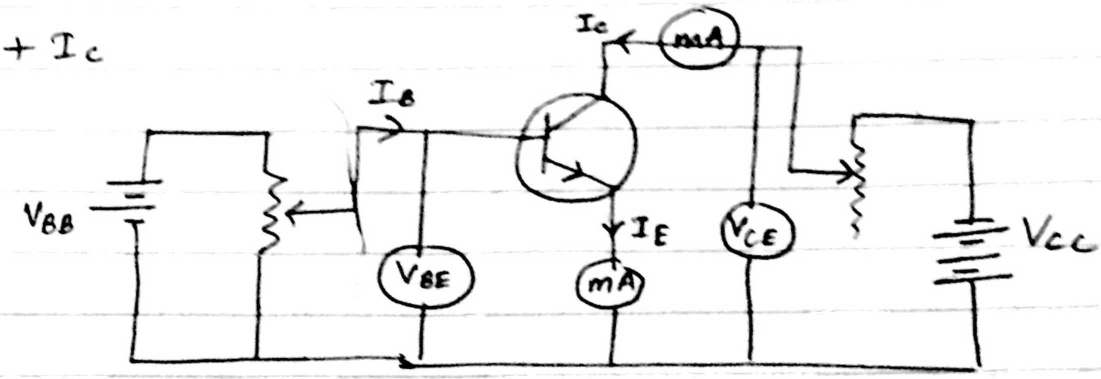
$$r_i = \left(\frac{V_{BE}}{I_E}\right) \text{ is small}$$

Output characteristics :-

(b) Common emitter configuration : (CE)



$$I_E = I_B + I_c$$



Current Gain :-

if common emitter then I_c or I_B.

$$\beta = \frac{\Delta I_c}{\Delta I_B} \quad (\text{for A.C})$$

no I_E

$$\beta = \frac{I_c}{I_B} \quad (\text{for D.C})$$

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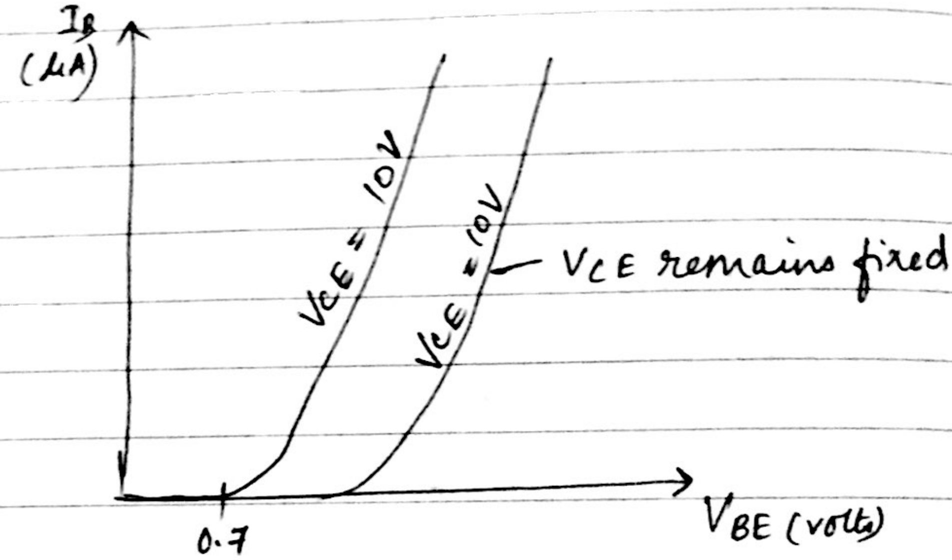
$$\beta = \frac{\Delta I_c}{\Delta I_B} = \frac{\Delta I_c}{\Delta I_E - \Delta I_c}$$

$$= \frac{\Delta I_c / \Delta I_E}{1 - \Delta I_c / \Delta I_E}$$

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

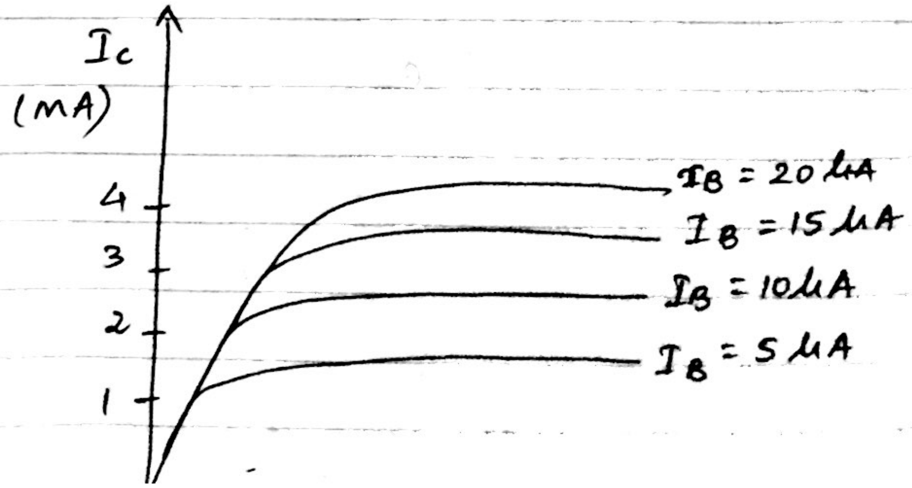
Input characteristics:



$$r_i = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right) \text{ is small.}$$

Output characteristics:

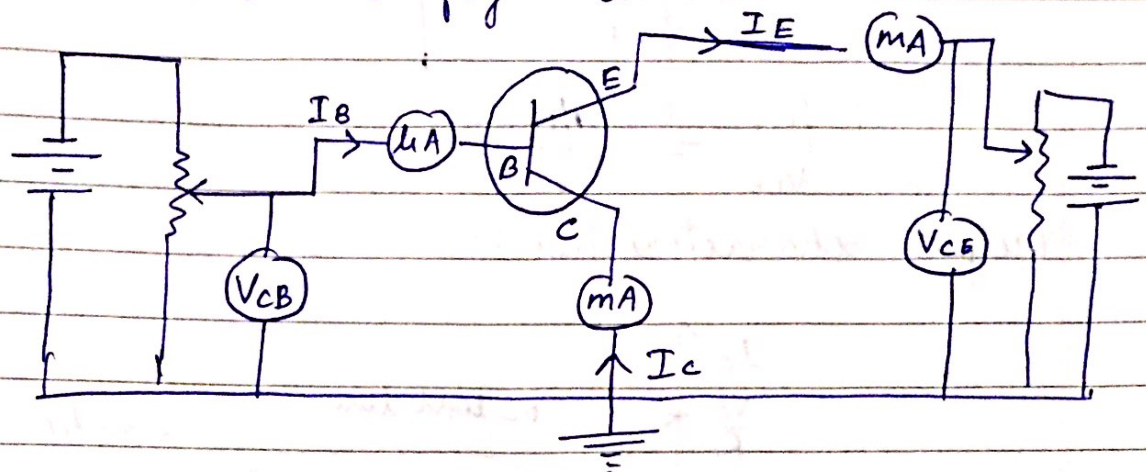
fixed)



The value of V_{CE} upto which I_c changes with V_{CE} is called knee voltage. Above knee voltage I_c is almost constant.

(c) not imp

Common collector configuration :-



only used for impedence matching.

COMPARISON :-

Properties	CB	CE best	CC
input resistance	low (~100 Ω)	low (~150 Ω)	Very high (~750 kΩ)
Output resistance	Very high (~450 kΩ)	High (~45 kΩ)	low (~50 Ω)
Voltage Gain	~150	~500	less than 1
Applications	High frequency	Audio frequency	impedence matching.
Current Gain	less than 1 (α)	high (β)	appreciable

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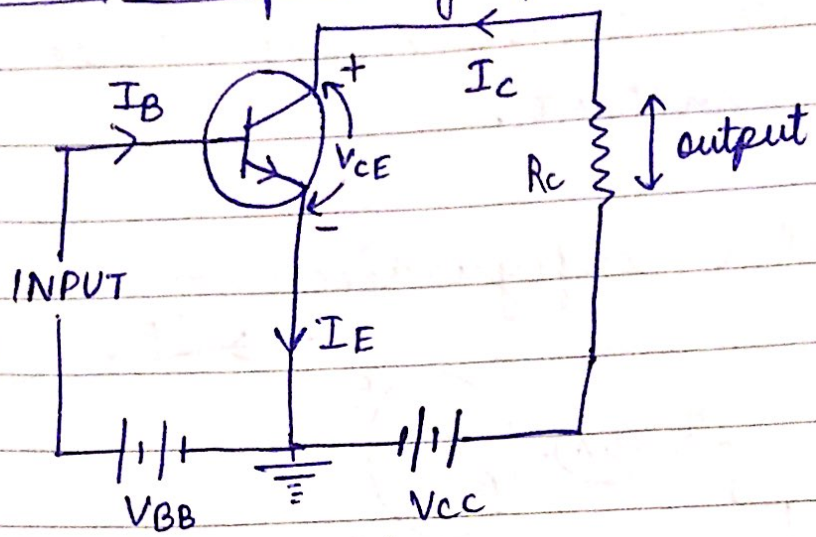
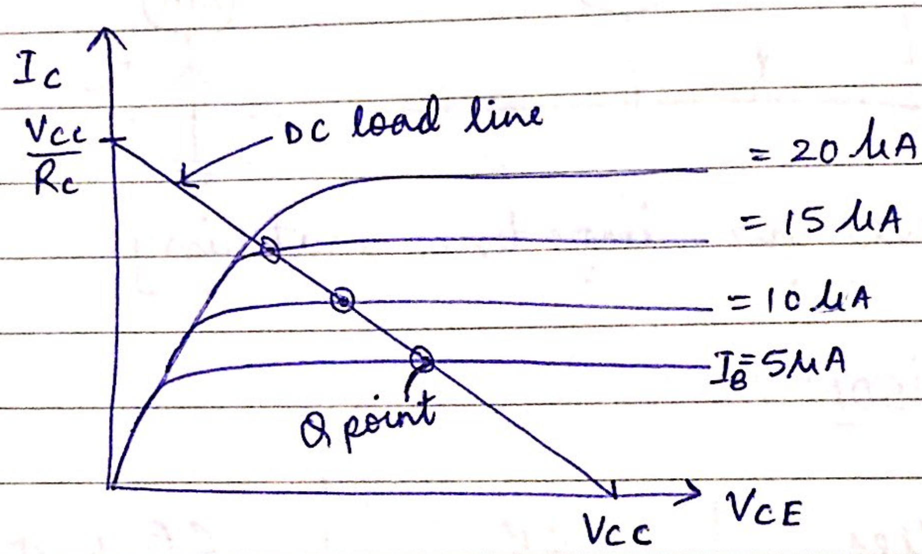
Load line & Operating point :-



output characteristics :-



Applying KVL to output circuit :-

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

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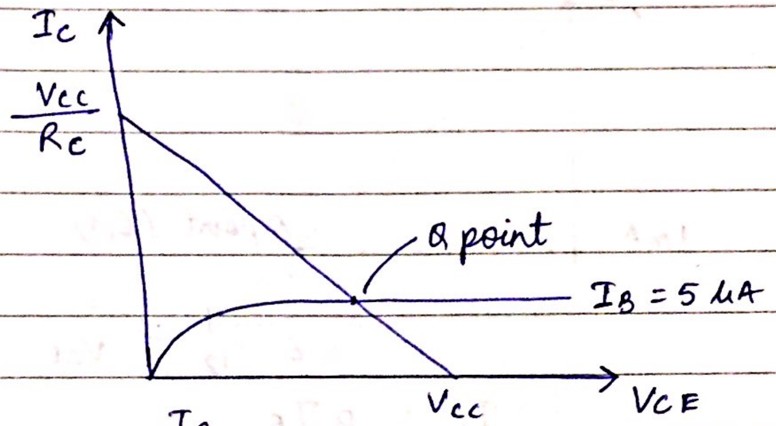
For $V_{CE} = 0$, $I_C = \frac{V_{CC}}{R_C}$
for $I_C = 0$, $V_{CE} = V_{CC}$

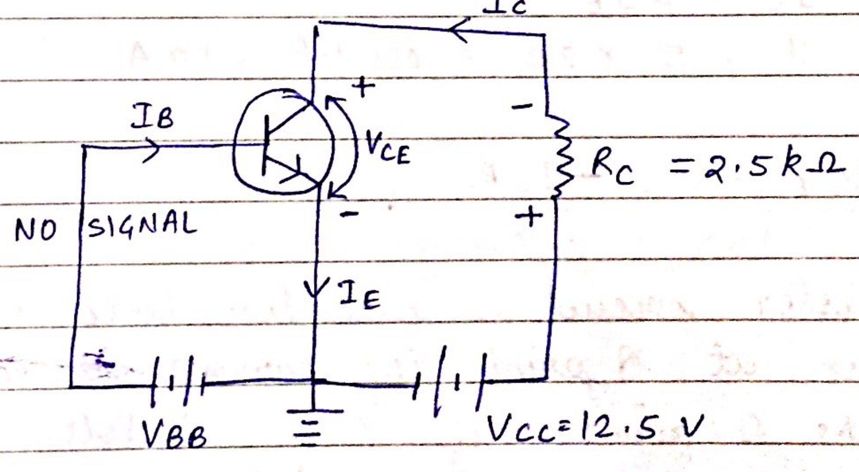
} End points of DC load line

Operating point :

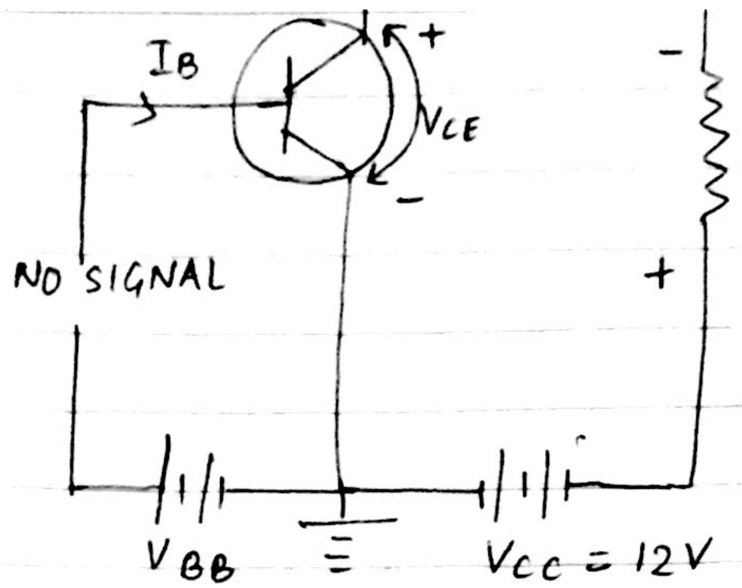
Quiescent point or Q point :-
intersection point of output characteristic curve and D.C load line when input signal is zero.



Q1



Draw the load line.

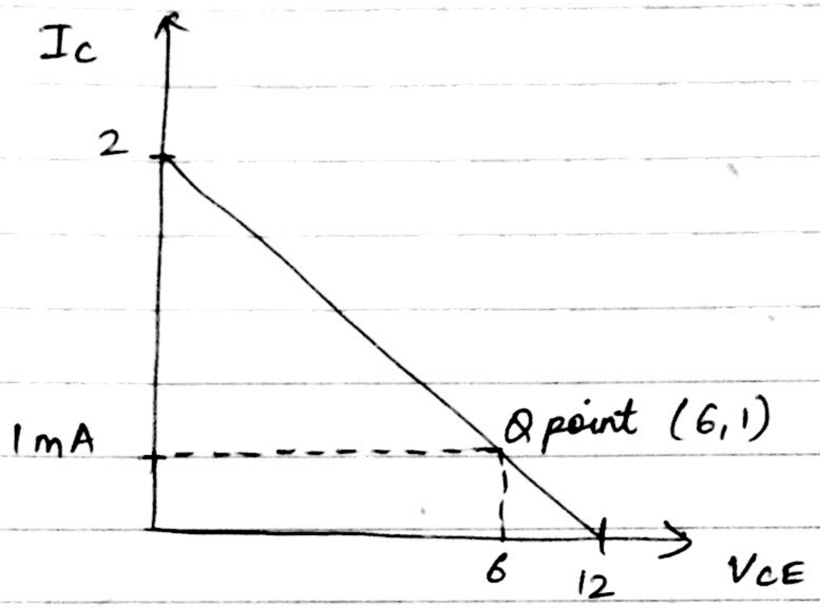


$I_B = 20\,\mu A$

$\beta = 50$

draw load line

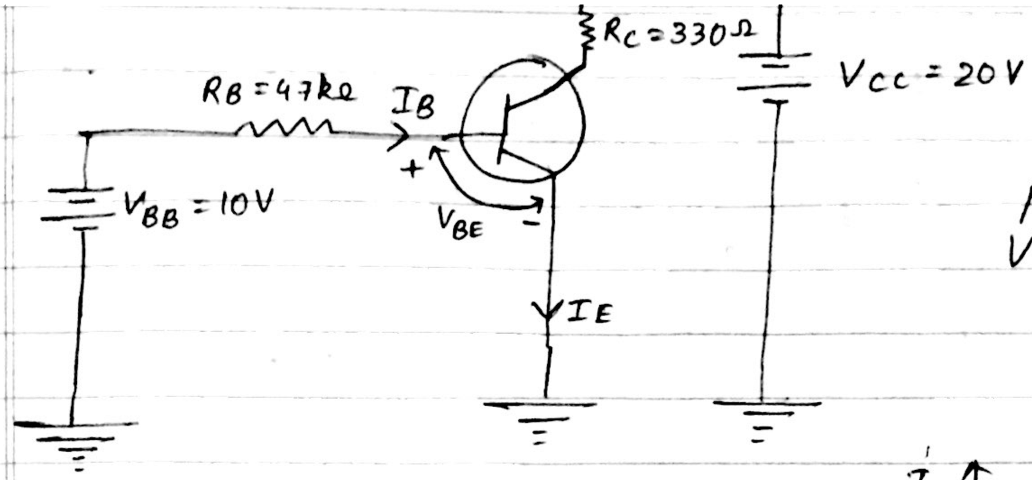
find Q point



$$I_C = \beta I_B$$

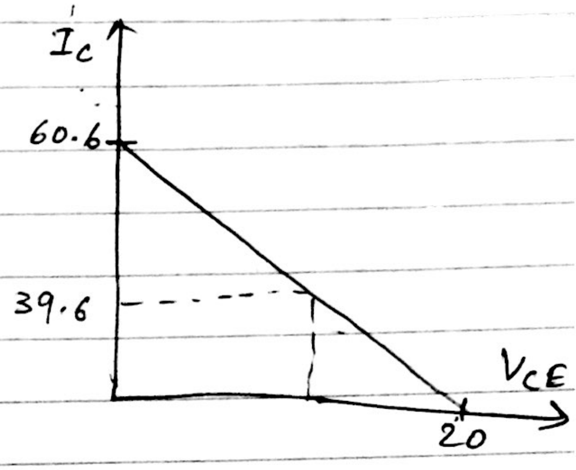
$$I_C = 50 \times 20 = 1000\,\mu A = 1\,mA$$

Q.



$\beta = 200$

$V_{BE} = 0.7V$



$$V_{BB} - I_B R_B - V_{BE} = 0$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$I_C = \beta I_B$$

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

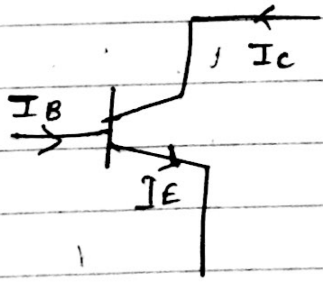
$$I_C = \beta I_B = 200 \times$$

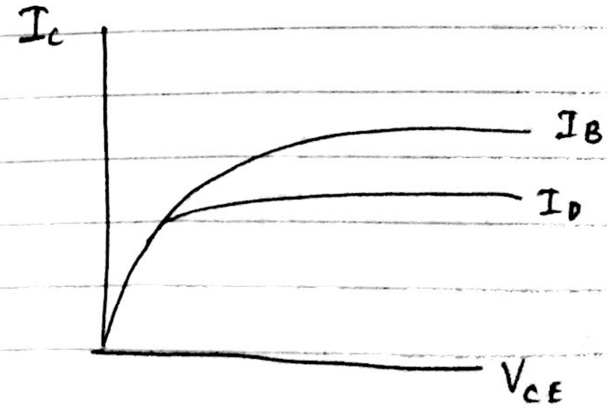
$$\begin{array}{r} 10.0 \\ 0.7 \\ \hline 9.3 \end{array}$$

$$I_B = \frac{10 - 0.7}{47 \times 10^3} = \frac{9.3}{47 \times 10^3} = 0.206 \times 10^{-3}$$

$$I_B = 200 \times 0.206$$

Q. # <u>Field effect Transistor</u> - (FET) (voltage controlled device)





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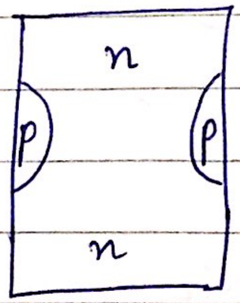
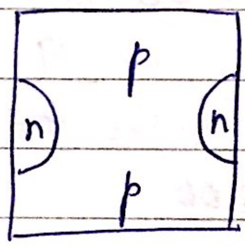
In BJT, output characteristics are controlled by input current. Field effect transistor is a transistor in which output characteristics are controlled by input voltage (field).
It is of two types :-
Junction field effect transistor (JFET)
Metal oxide semiconductor field effect transistor (MOSFET)

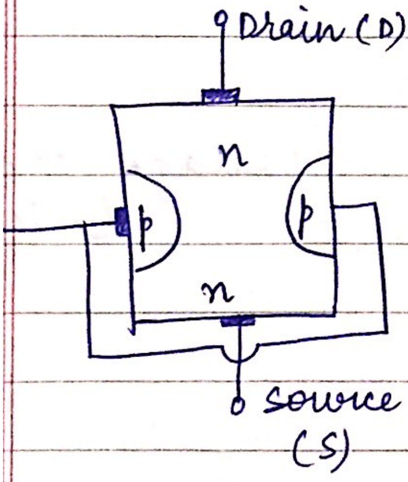
Junction field effect transistor - (JFET)



- n channel JFET

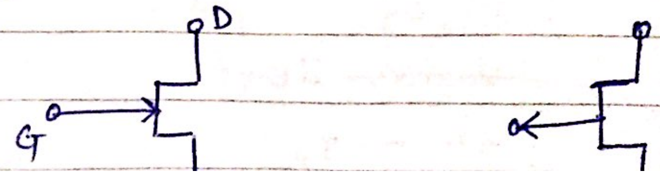


p channel JFET

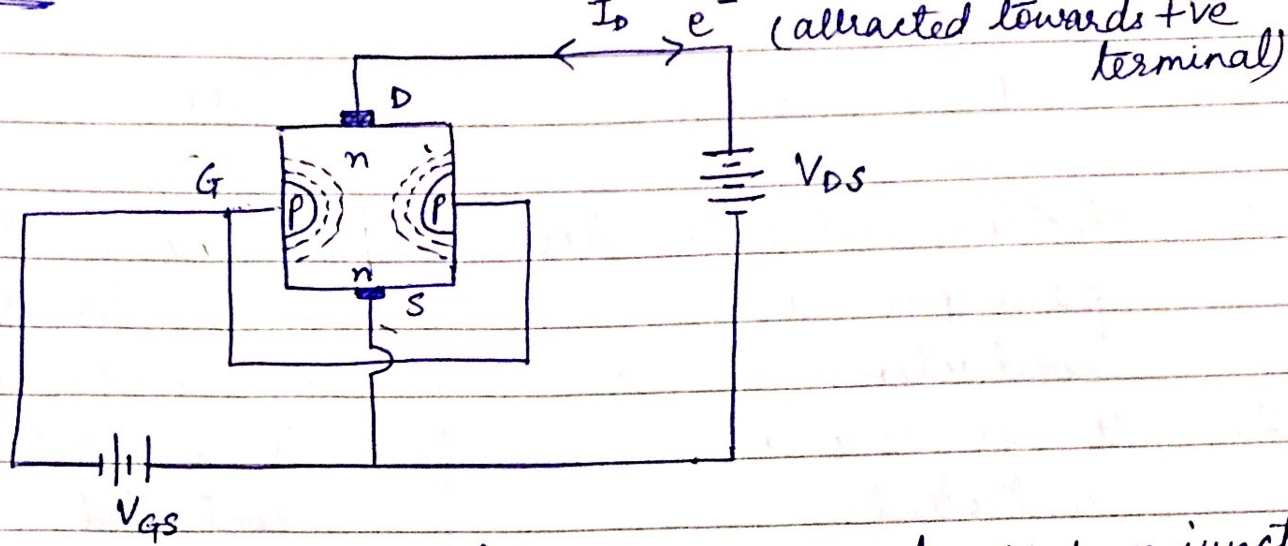


The main drawback with JFET is gate is always reverse bias i.e in the operation of JFET, width of channel always decreases. This mode of operation in which the channel width ↓ is known depletion mode. So JFET always works in depletion mode.

Symbol of JFET :-



WORKING :-



more V_{GS} depletion layer expands as p-n junction is Reverse biased

↓

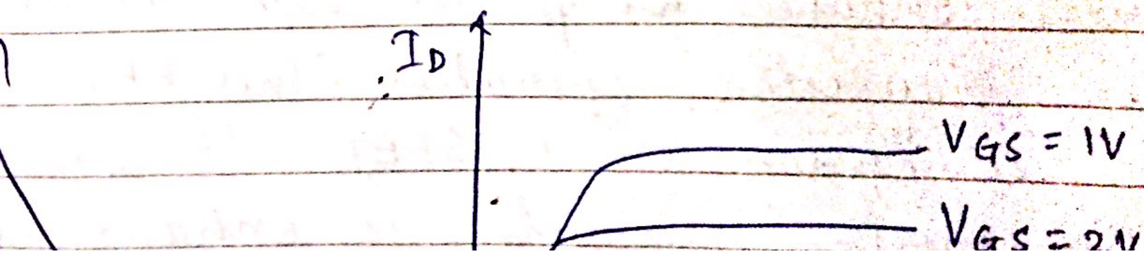
channel narrows

The gate to source circuit is reverse biased and the drain to source biasing should be such that the current flows from source to drain. In n-channel JFET, free electrons move through the channel and constitute the current I_D. ~~For Vgs~~

For $V_{GS} = 0$, some value of I_D exists which increases ~~width~~ with increase in V_{DS}.

when V_{GS} is increased reverse bias increases and depletion layer expands in the channel, narrowing down the path of the free electrons. Therefore, I_D decreases, when V_{GS} reaches to such a value that depletion layer completely blocks the channel I_D becomes zero.

This situation is known as cut-off situation.



BJT	JFET
electrons and holes both participate in conduction	1. Only one type of charge carrier is responsible for conduction.
It is current controlled	2. It is voltage controlled
low input resistance	3. High input resistance due to reverse bias.
It has a high noise level (unwanted signal)	4. noise level is less
It is characterized by current gain.	5. It is characterized by trans conductance. $\left(\frac{\text{output current}}{\text{input voltage}}\right)$

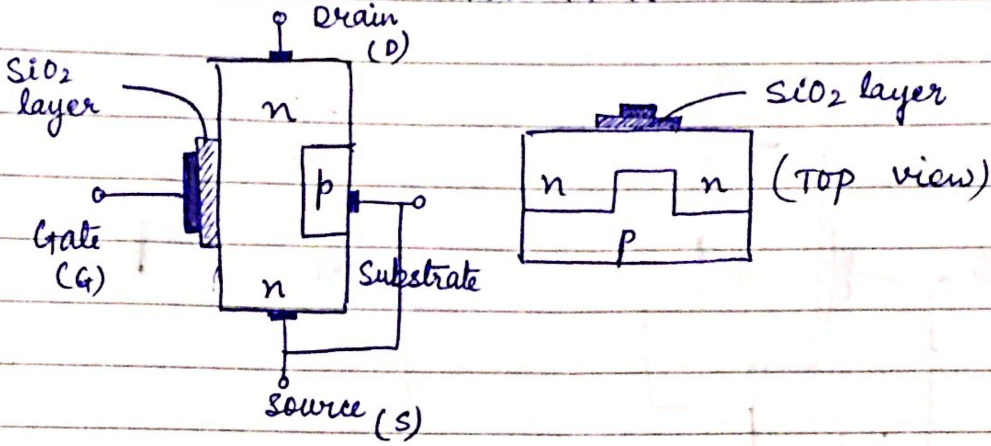
$$\text{Trans conductance} = \frac{\Delta I_D}{\Delta V_{GS}}$$

(MOSFET) :-

D-MOSFET - can work in depletion mode as well as enhancement mode.

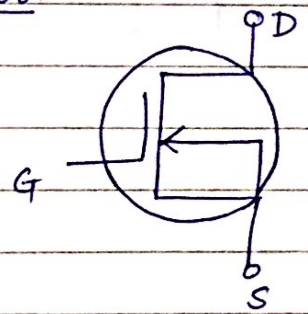
E-MOSFET - only works in enhancement mode.

D-MOSFET - CONSTRUCTION



→ Metal plate and channel make two plates of the capacitor, SiO_2 layer acts as di-electric.

→ Symbol:-



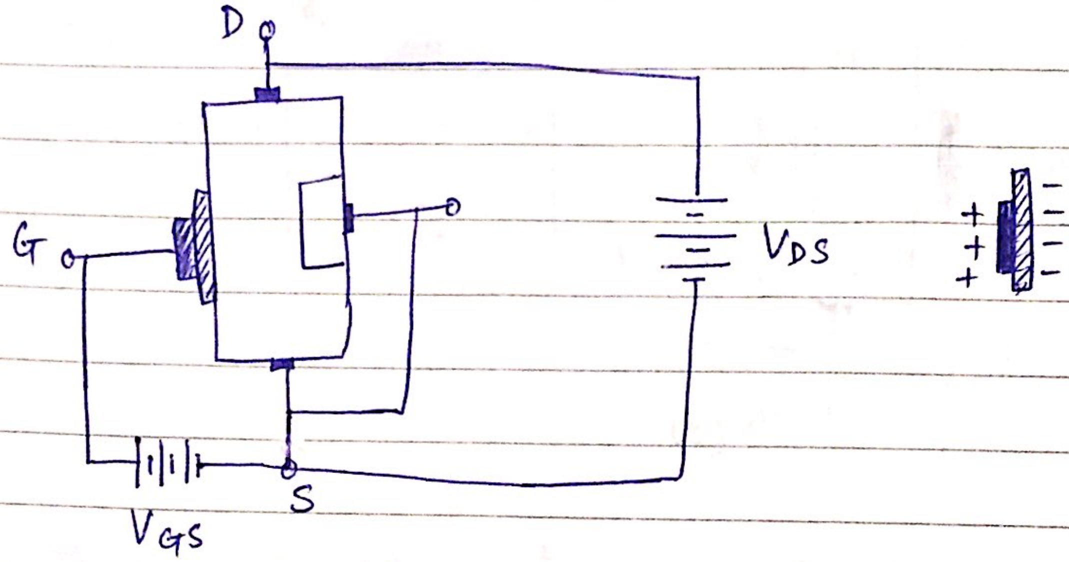
n - channel D-MOSFET

Operation / Working:-

Depletion mode -

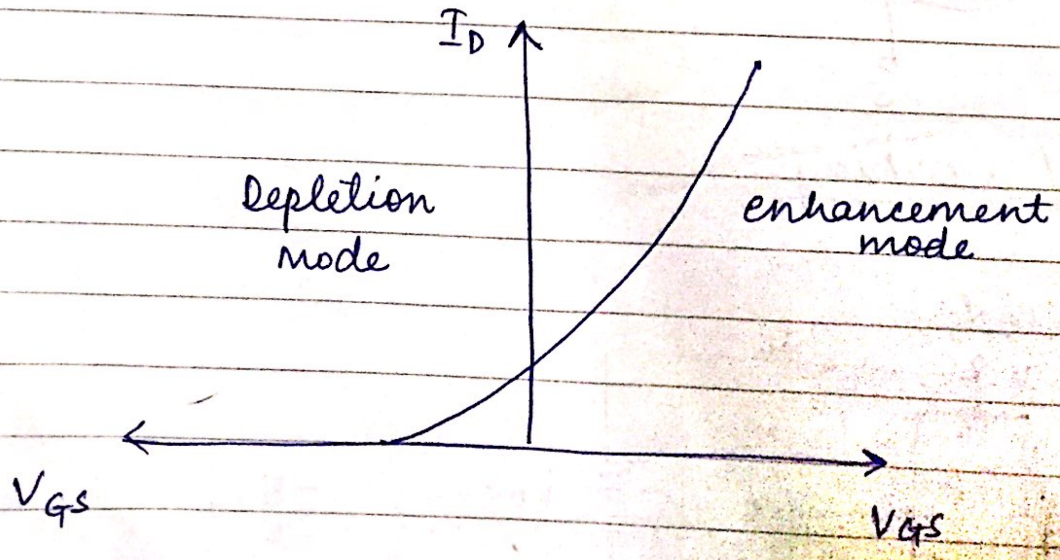
V_{GS} is $-ve$, $+ve$ charges ~~will~~ are induced in the channel near SiO_2 layer. No. of free e^- ↓
Id decreases.

Enhancement mode -

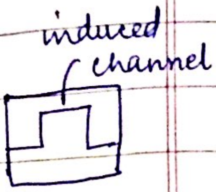


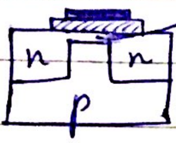
V_{GS} is $+ve$, $-ve$ charges are induced in the channel near SiO_2 layer. No of free e^- ↑
Id increases.

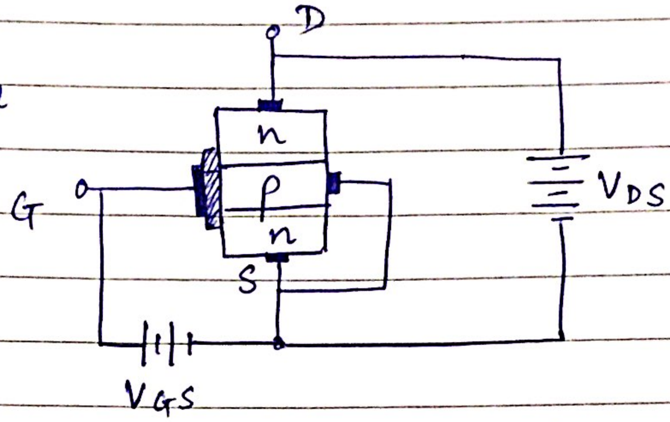
Transfer Characteristics -



Construction :







initially there is no channel but for a proper +ve value of V_{GS}, a channel is induced in the substrate and conduction starts.

$V_{GS} \uparrow$ channel width $\uparrow$ $I_D \uparrow$

Transfer Characteristics :