CHAPTER-2

Introduction:

material - Depending upon the conductivity of materials are devided in to 3 types-

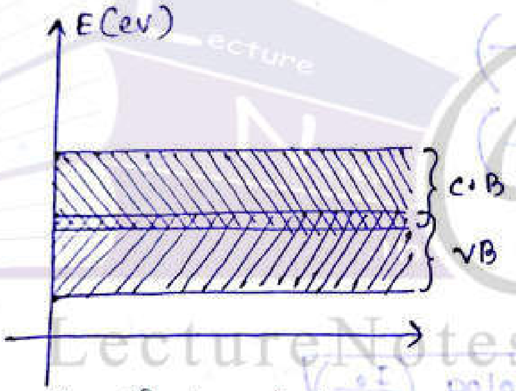
↳ conductor
↳ semiconductor
↳ insulator

conductor - conductivity of a conductor is very high.
Ex: Iron, Aluminium.

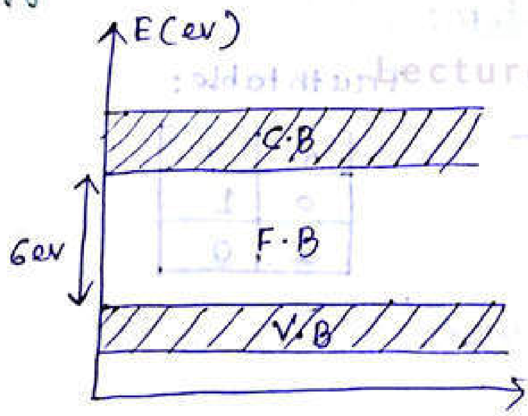
Insulator - conductivity of insulator is very poor.
Ex: wood, glass

Semiconductor - conductivity of semiconductor lies between conductor and insulator.
Ex: Si, Ge, As, GaAs, LED (Light emitting diode)

Energy band of conductor :

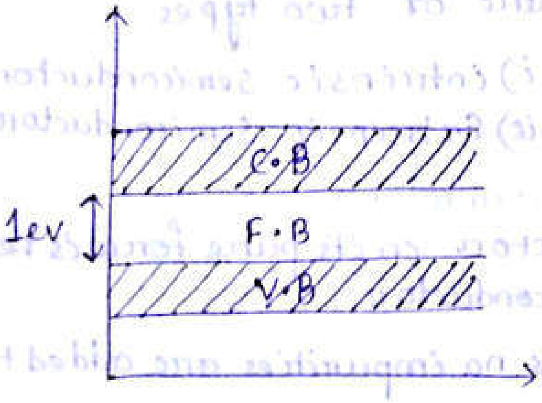


Energyband of insulator :



C.B → conduction band
V.B → valence band
F.B → forbidden energy gap

Energyband of Semiconductor :



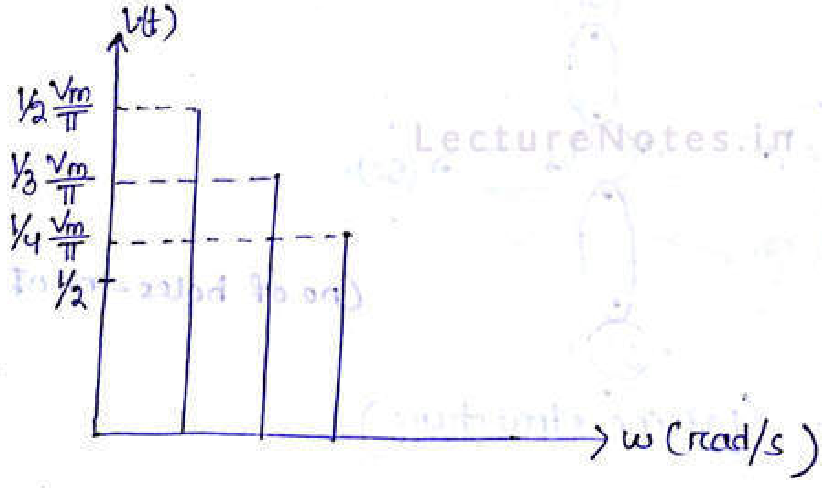
Band theory :

- → Every material has some small range of allowed band of energies where e^-s can move freely.
- → There may be more than one allowed band such as valence band, conduction band . .
- → There are some regions which are not occupied by energy levels. This regions are called forbidden band.
- → No e^-s can stay in forbidden band.
- → The measure of energy level is called ev.
- → Width of the Forbidden band determines wheather the material is conductor, insulator or semiconductor.

Assignment:

$$v(t) = \frac{1}{2} + \frac{V_m}{\pi}\left[\frac{1}{2}\sin 200\omega_0 t + \frac{1}{3}\sin 400\omega_0 t + \frac{1}{4}\sin 600\omega_0 t + \dots\right]$$

→



Semiconductor:

Semiconductor are of two types.

↳ i) intrinsic semiconductor.

↳ ii) Extrinsic Semiconductor.

i) Intrinsic Semiconductor:

→ Semiconductor in its pure form is termed as intrinsic semiconductor.

→ pure form means no impurities are added to the semiconductor.

ii) Extrinsic Semiconductor:

→ If any impurity is added to pure form of semiconductor then that is called extrinsic semiconductor.

→ Extrinsic semiconductor are of two types. i.e

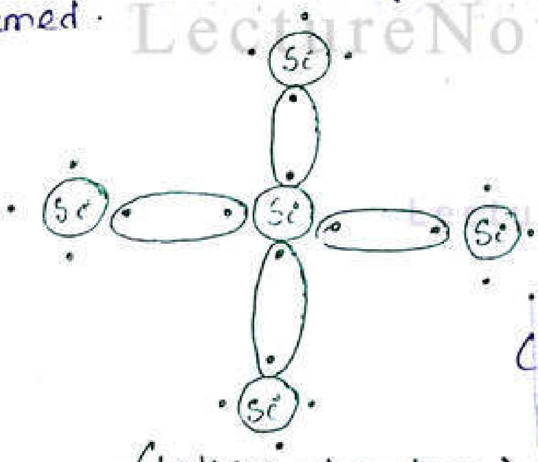
↳ a) p-type semiconductor.

↳ b) N-type semiconductor.

a) p-type semiconductor

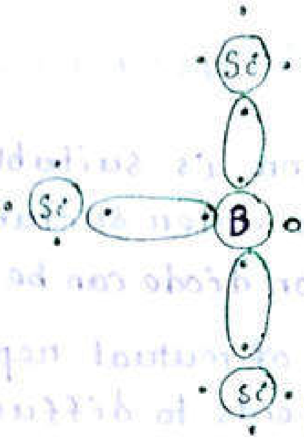
→ In a p-type semiconductor majority carriers are holes and minority carriers are e^-s

→ If a trivalent impurity is added to the pure form of semiconductor, p-type semiconductor can be formed.



(no of holes = no of e^-s)

(lattice structure)



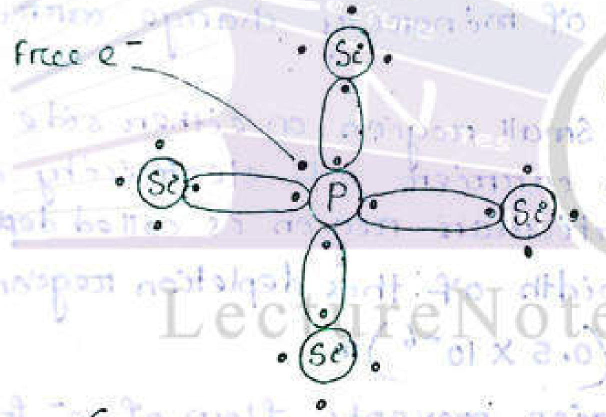
majority carrier - holes
minority carrier - e^-s
no of holes > no of e^-s

(lattice structure of p-type semiconductor)

b) N-type semiconductor:

→ majority carriers are electrons.

→ when a pentavalent impurity such as phosphorous is added to pure form of semiconductor, N-type semiconductor can be formed.



majority carriers = e^-s
minority carriers = holes
no of e^-s > no of holes.

(lattice structure of N-type semiconductor)

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p-n junction diode:

Q. what is p-n junction diode? Explain briefly the formation.

→ when a p-type semiconductor is suitably joined with N-type semiconductor under suitable temp. and pressure, p-n junction diode can be formed.

Depletion region

→ Because of mutual repulsion the free e^-s on n-side tends to diffuse towards the P-side and holes from the p-side tendes to diffuse towards n-side (Motion of holes in reality is the motion of e^-s in opposite direction)

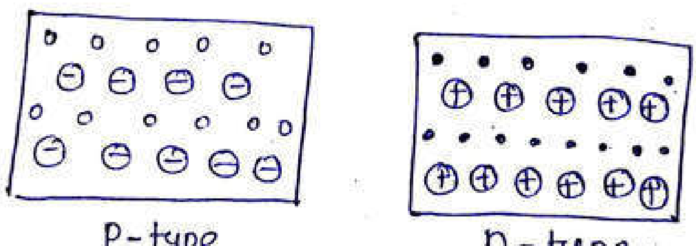
→ Ultimately a layer of −ve ions on the p-side and a layer of +ve ions on the n-side forms on the n-side forms the junction.

→ Further movement of e^-s is prevented due to repulsive force of minority charge carrier on p-side.

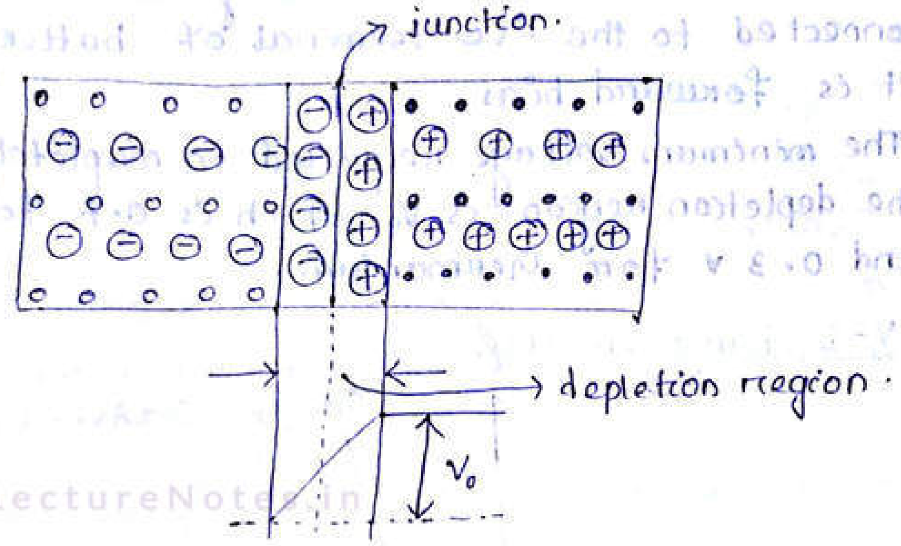
→ Hence there is a small region on either side of junction where carrier of electricity are absent. This particular region is called depletion region and the width of this depletion region is around $0.5\ \mu m = (0.5 \times 10^{-6})m$.

→ The depletion region prevents flow of e^- from n to p and flow of holes from p to n. Hence this region can be regarded to be providing of potential called barrier potential (V_0)

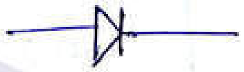
→ This gives rise to electric field which prevents the movement of majority charge carriers across the junction.



p-type   n-type.



* If p-n junction is made up of si, then the voltage=0.7v
* If p-n junction is made up of Ge, then the voltage=0.3V
* Depletion region behaves as resister.
* symbol of diode is



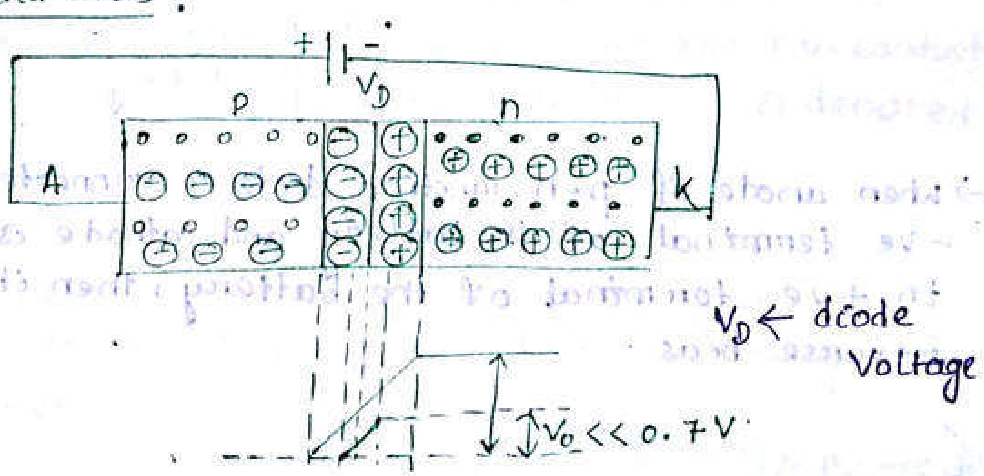
* physical representation of diode is

Q. what is diffusion?
→ Intermixing of two substances in particular temp. is called diffusion.

Diode under external bias:

↳ i) forward bias
↳ ii) Reverse bias
↳ iii) No bias.

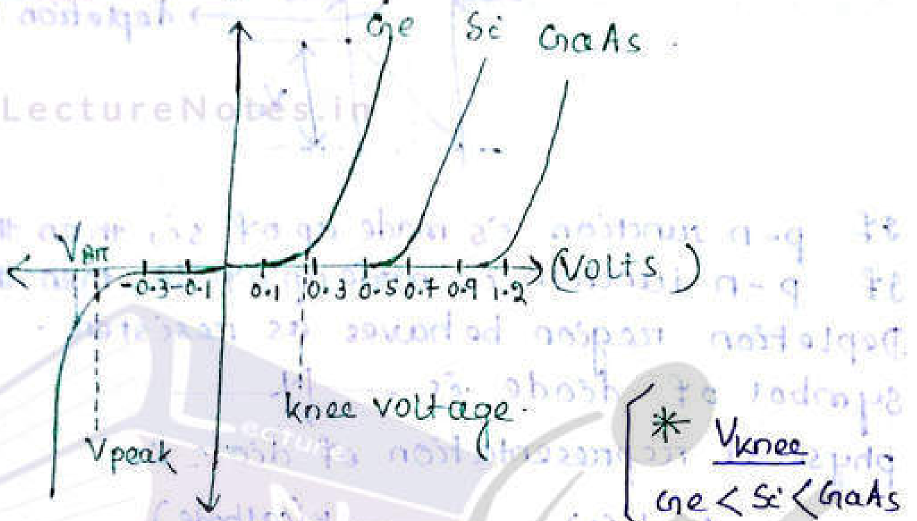
i) Forward bias:



→ when p-terminal of p-n junction is connected to the +ve terminal of the battery and n-terminal is connected to the -ve terminal of battery, then it is forward bias.

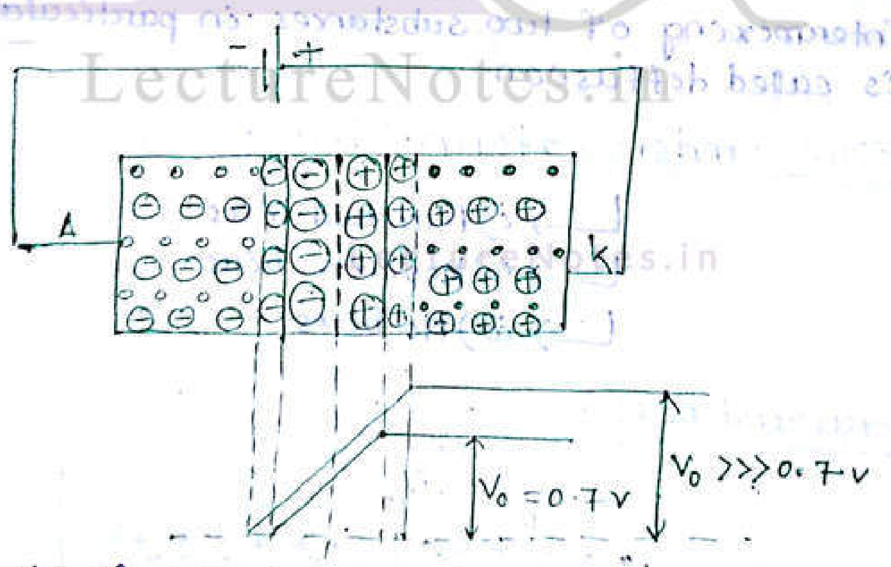
→ The minimum voltage required to completely vanish the depletion region is V_0 which is 0.7 for Silicon and 0.3 for Germanium.

V-I characteristics



* V_{knee}
Ge < Si < GaAs

ii) Reverse bias condition:



→ when anode of p-n junction diode is connected to the -ve terminal of the battery and cathode is connected to +ve terminal of the battery, then it is reverse bias.

→ In reverse bias condition the width of depletion layer region increase. Hence it provides very high resistance to the flow of current.

→ With increase in external -ve potential the breakdown in depletion region occur and the reverse saturation current increases at the particular breakdown voltage. The breakdown is called zener breakdown. The breakdown voltage representation is V_z :

Q. Describe the following parameters for p-n junction diode.

i) Breakdown Voltage
ii) knee voltage.
iii) Maximum forward current.
iv) Peak reverse Voltage.
v) Maximum power rating.

→ i) Breakdown Voltage:

It is the minimum reverse Voltage at which the p-n junction breaksdown with sudden rise in temperature and it is denoted with V_{BR}.

ii) knee vatage/cut in voltage/Threshold voltage:

It is the forward voltage at which current flow through junction starts to increase rapidly and denoted with V_K.

iii) Maximum forward Current:

It is the highest instantaneous current in the forward direction that a p-n junction can conduct without damage to the junction and it is denoted with I_f or I_D

iv) peak inverse voltage (PIV)

It is the maximum reverse voltage than can be applied to the p-n junction without damage to the junction

$\left[\begin{array}{l} PIV(si) = 1000V \\ PIV(Ge) = 400V \end{array}\right\}$ in the -ve direction]

(v) Maximum power rating :

It is the maximum power that can be dissipated at the junction without damage to the junction. The power dissipation to the junction is equal to the product of the junction current and the voltage across the junction.

Diode Current eq^n :

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

$I_D \rightarrow$ diode current.

$I_S \rightarrow$ reverse saturation current.

$V_D \rightarrow$ external voltage.

$n \rightarrow$ ideality factor (constant). It depends upon physical construction of semiconductor.

$V_T \rightarrow \frac{KT}{q}$ (Thermal voltage)

$K \rightarrow$ Boltzman Constant $= 1.38 \times 10^{-23}$ J/K

$q \rightarrow$ charge $= 1.6 \times 10^{-19}$ C.

$T \rightarrow$ Temp in kelvin

Q. At a temperature of 27°c determine the thermal voltage in millivolt (mV)

$\rightarrow$ $T = 300k$.

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

$$= 0.02587 V$$

$$= 0.02587 \times 10^3 mV$$

$$= 25.87 mV$$

$$\cong 26 mV$$

Q. The external voltage applied to the semiconductor diode is 1V. and the reverse saturation is $-30\,\mu A$. findout the diode current.

→ $V_D = 1V$

$I_S = -30 \times 10^{-6}\,A$

$V_T = 26mV = 26 \times 10^{-3}\,V$

$n = 1$

$$I_D = -30 \times 10^{-6}\left(1.6 \times 10^{-19\left(1/1\times 26\times10^{-3}\right)} - 1\right)$$

$$= -30 \times 10^{-6}\left(1.6 \times 10^{-19\left(\frac{1}{26\times10^{-3}}\right)} - 1\right)$$

$$= 27.16 \times 10^{-3}\,A$$

$$= 27.16\,mA$$

Diode Resistance :

→ The p-n junction diode is a non-linear device. Hence its resistance is different at different level of applied voltage.

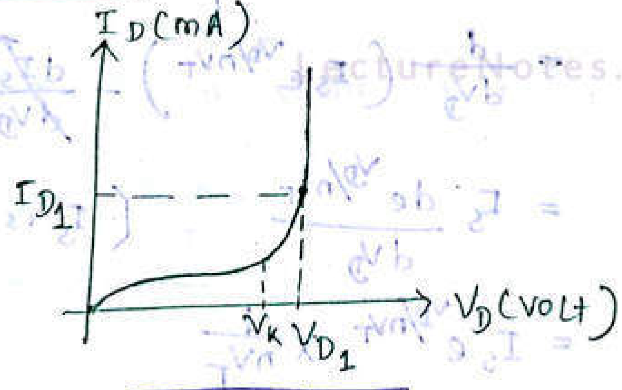
→ It is divided into 3 types.

i) Dc/static resistance (R_D)

ii) Ac/dynamic resistance (r_{ac}, r_d)

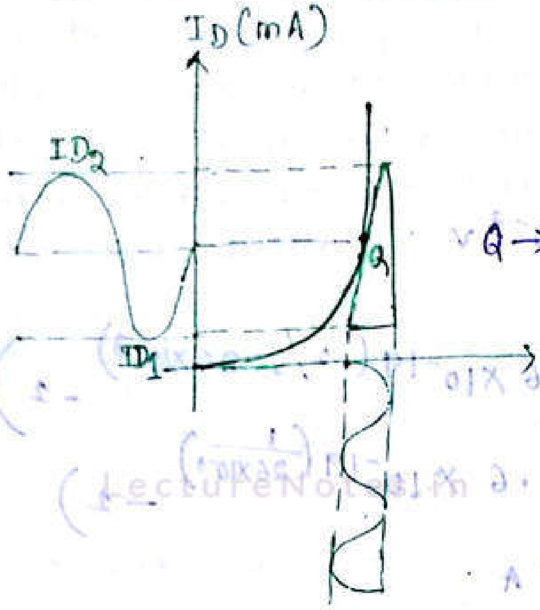
iii) Average resistance (r_{av})

i) Dc resistance :



$$\boxed{R_D = \frac{V_{D1}}{I_{D1}}}$$

(ii) Ac resistance:



$$\boxed{r_{ac} = \frac{\Delta V_D}{\Delta I_D}}$$

→ Response of a diode to a sinusoidal input signal is defined by the tangent line at the 'Q' point.

→ $$\boxed{r_{ac} = \frac{\Delta V_D}{\Delta I_D}}$$

current eqn. of diode $I_D = I_S\left(e^{V_D/nV_T} - 1\right)$

$$\Rightarrow \frac{dI_D}{dV_D} = \frac{d}{dV_D}\left\{I_S e^{V_D/nV_T} - I_S\right\}$$

$$= \frac{d}{dV_D}\left(I_S e^{V_D/nV_T}\right) - \cancelto{0}{\frac{dI_S}{dV_D}}$$

$$= I_S \frac{de^{V_D/nV_T}}{dV_D} \quad (I_S \text{ is constant})$$

$$= I_S e^{V_D/nV_T} \times \frac{1}{nV_T}$$

$$\frac{dI_D}{dV_D} = \frac{I_S}{nV_T} \times e^{V_D/nV_T}$$

$$r_{ac} = \frac{dV_D}{dI_D}$$

$$\frac{dI_D}{dV_D} = I_S\left(\frac{1}{nV_T} e^{V_D/nV_T}\right)$$

$$= I_S\left(\frac{e^{V_D/nV_T}}{nV_T}\right)$$

$$\frac{dI_D}{dV_D} = \frac{I_S\left(e^{V_D/nV_T} - 1 + 1\right)}{nV_T}$$

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

$$\frac{dI_D}{dV_D} = \frac{I_D + I_S}{nV_T}$$

$$\Rightarrow \frac{dV_D}{dI_D} = \frac{nV_T}{I_D + I_S}.$$

we know, $\boxed{n = 1}$

Hence $\frac{dV_D}{dI_D} = \frac{V_T}{I_D + I_S}.$

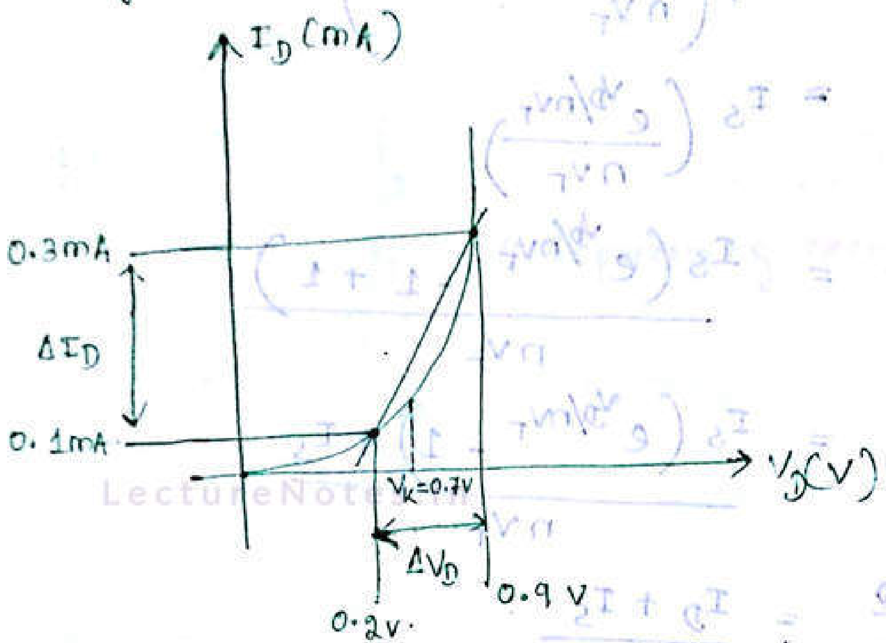
At room temperature $(25^\circ c)$ $V_T \simeq 26mV.$

so, $\frac{dV}{dI_D} = \frac{26mV}{I_D + I_S}.$

Since $I_D >> I_S$, the value of I_S can be neglected

$$\boxed{\frac{dV_D}{dI_D} = \frac{26mV}{I_D}}$$

ii) Average Resistance



The average resistance can be defined as the resistance calculated by a straightline drawn between two intersection point established by maximum and minimum value of i/p.

$$r_{av} = \frac{\Delta V_D}{\Delta I_D}\Bigg|_{\text{point to point}}$$

$$r_{av} = \frac{(0.9 - 0.2)V}{(0.3 - 0.1)mA \times 10^{-3}}$$

$$= \frac{0.7}{0.2 \times 10^{-3}}$$

$$= 3500\,\Omega$$

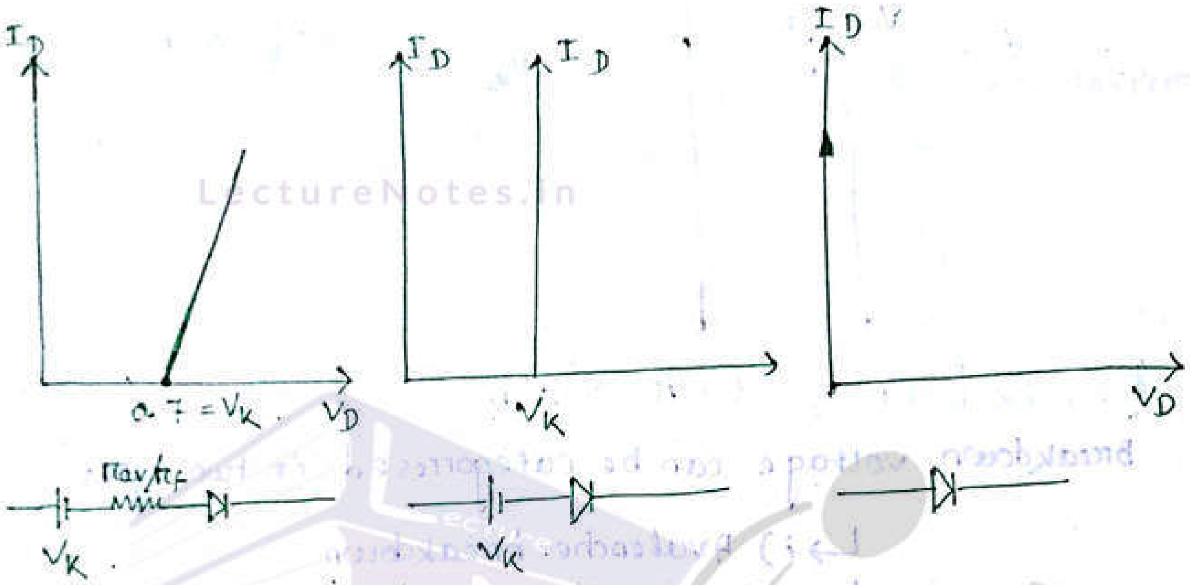
Diode equivalent Circuit :

→ An equivalent circuit is a combination of electronic components or elements properly chosen to represent the actual characteristics of a system or device in a particular operating region.

→ Diode equivalent circuits are divided on to 3 types.

(i) piece wise linear equivalent ckt.
(ii) Simplified equivalent ckt.
(iii) Ideal equivalent ckt.

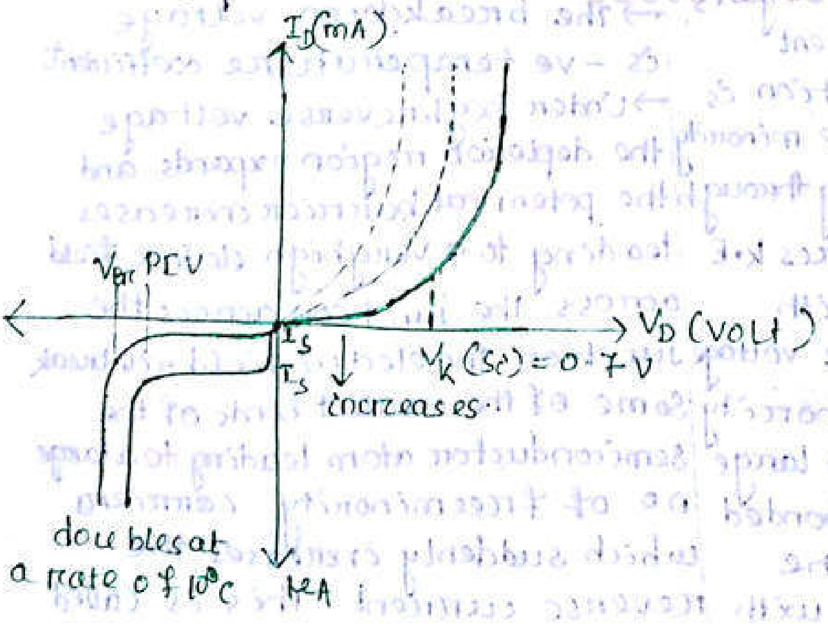
Piecewise Linear equivalent Model.	Simplified equivalent model	Ideal equivalent model.

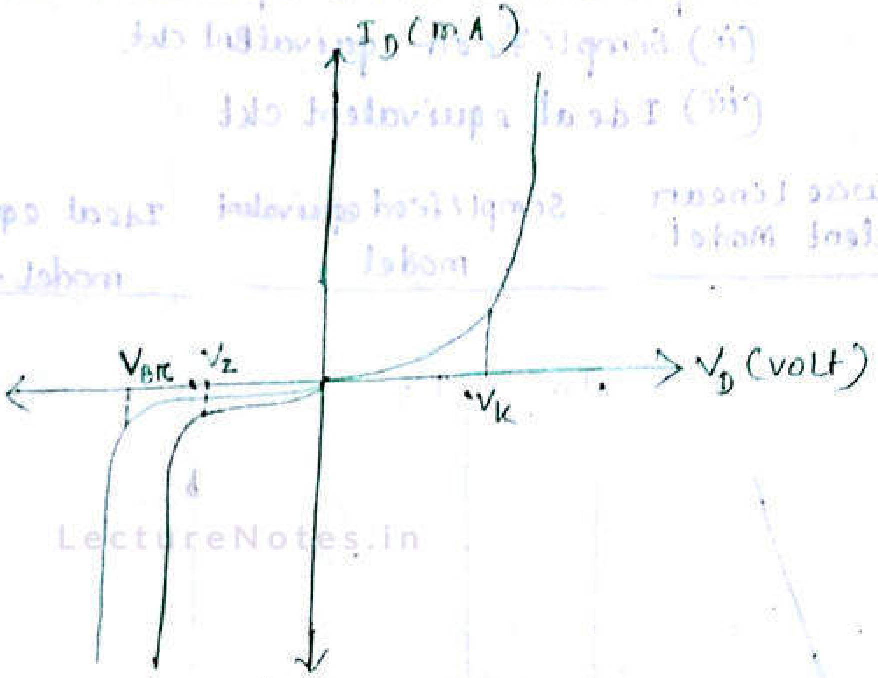


Effect of temperature on diode current

→ In the forward bias region the characteristics of a Si diode shifts to the left at a rate of 2.5 mV per degree rise in temp.

→ In the reverse bias region the reverse saturation current of Si diode doubles for every 10°c rise in temp.





Breakdown voltage:

Breakdown voltage can be categorised in two types.

↳ i) Avalanche breakdown.

↳ ii) Zener breakdown.

Avalanche breakdown

→ It is lightly dopped

→ Avalanche breakdown has high reverse voltage

→ Breakdown occurs due to carrier multiplication

→ The breakdown voltage is +ve temp. coefficient.

→ When a p-n junction is reverse biased, the minority carriers flowing through the junction acquires K.E which increases with increase in reverse voltage. If the K.E of the minority carrier become so large it dissociate the bonded e^-s and increases the minority carriers with the help of carrier multiplication

Zener breakdown

→ It is heavily dopped

→ It has low reverse breakdown voltage

→ Breakdown occurs, due to high electric field.

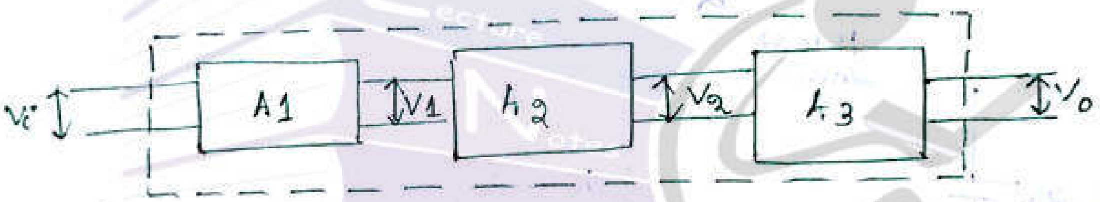
→ The breakdown voltage is -ve temperature coefficient

→ Under high reverse voltage the depletion region expands and the potential barrier increases leading to a very high electric field across the junction across the junction. The electric field will break some of the covalent bonds of the semiconductor atom leading to a large no of free minority carriers which suddenly increases the reverse current. This is called zener effect.

Si	Ge
→ $V_k = 0.7\,V$	→ $V_k = 0.3\,V$
→ high temperature sensitive	→ less temperature sensitive
→ PIV (silicon) → 1000 V	→ PIV (Ge) → 400 V
→ Reverse saturation current → 10^{-9} A	→ reverse saturation current → 10^{-6} A
→ Ex: Si type semiconductor in a rectifier, clipper, clamper.	→ Ex: opto electronics devices, high speed devices.

Amplifier in cascade:

If more than one amplifier are connected in series, then that particular ckt arrangement is called amplifiers are in cascade.



$$A_v(\text{total}) = \frac{V_o}{V_i}$$

$$AV_1 = \frac{V_1}{V_i}$$

$$AV_2 = \frac{V_2}{V_1}$$

$$AV_3 = \frac{V_o}{V_2}$$

$$AV_1 \times AV_2 \times AV_3$$

$$= \frac{\cancel{V_1}}{V_i} \times \frac{\cancel{V_2}}{\cancel{V_1}} \times \frac{V_o}{\cancel{V_2}} = \frac{V_o}{V_i} = A_v(\text{total})$$

$$\boxed{A_v(\text{total}) = AV_1 \times AV_2 \times AV_3 \times \cdots AV_n}$$

$$\Rightarrow 20 \log A_v(\text{total}) = 20 \log (AV_1 \times AV_2 \times \cdots AV_n)$$

$$\Rightarrow 20 \log A_v(\text{total}) = 20 \log AV_1 + 20 \log AV_2 + \cdots + 20 \log AV_n$$

$$\Rightarrow \boxed{A_v\,\text{total}(dB) = AV_1(dB) + AV_2(dB) + \cdots + AV_n(dB)}$$

* $P = VI$

$P_o = V_o I_o$

$P_i = V_i I_i$

$$A_P(dB) = 10\log\left(\frac{P_o}{P_i}\right)$$

$$= 10\log\left(\frac{V_o I_o}{V_i I_i}\right)$$

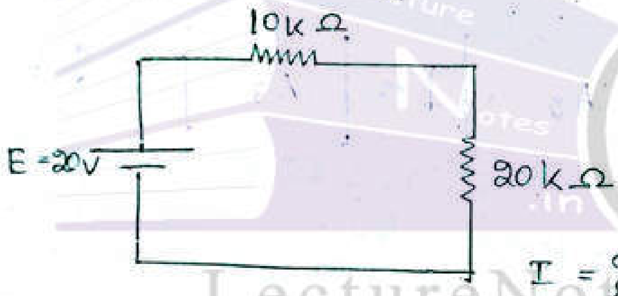
$$= 10\log\left\{\left(\frac{V_o}{V_i}\right)\times\left(\frac{I_o}{I_i}\right)\right\}$$

$$= 10\log\left(\frac{V_o}{V_i}\right) + 10\log\left(\frac{I_o}{I_i}\right)$$

$$A_P(dB) = \frac{20\log\left(\frac{V_o}{V_i}\right) + 20\log\left(\frac{I_o}{I_i}\right)}{2}$$

$$A_P(dB) = \frac{A_V(dB) + A_I(dB)}{2}$$

Q.



$I = ?$

$\rightarrow$ $R = R_1 + R_2$

$= 10\times10^3 + 20\times10^3$

$= 30$

$$I = \frac{E}{R} = \frac{20}{30\times10^3} = 0.6\times10^{-3}A.$$

or

According to KVL

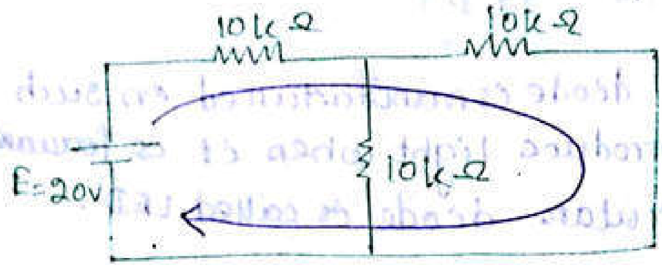
$E - IR_1 - IR_2 = 0$ ($\because$ In series connection current flow remain same)

$\Rightarrow E = I(R_1 + R_2)$

$\Rightarrow I = \dfrac{E}{R_1 + R_2}$

$\Rightarrow I = \dfrac{20}{30\times10^3} = 0.6\times10^{-3}A.$

Q.



→ According to KVL,

$$E - IR_1 - IR_2 = 0$$

$$\Rightarrow E = I(R_1 + R_2)$$

$$\Rightarrow E = I(10 + 10)$$

$$\Rightarrow E = 20I$$

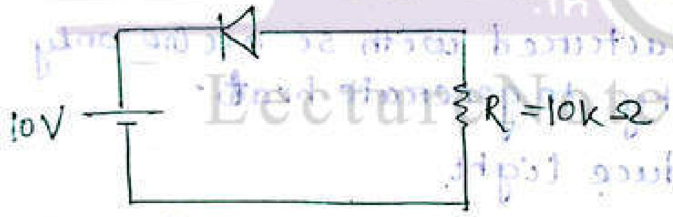
$$\Rightarrow \frac{E}{I} = 20$$

$$\Rightarrow \frac{R\cancel{I}}{\cancel{I}} = 20$$

$$\Rightarrow R = 20\Omega$$

$$I = \frac{E}{R} = \frac{20}{20 \times 10^3} = 10^{-3} A$$

Q.



$V_D = ?$

→ It is in reverse bias condition

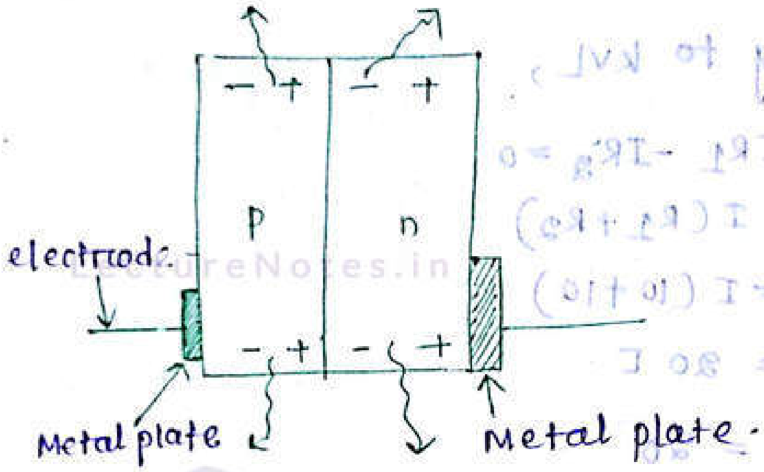
$I_R = 0, \quad I_D = 0$

$V_R = I_D \times R = 0$

$V_D = 10V$ = initial value.

Light Emitting diode (LED)

→ when p-n junction diode is manufactured in such a way that it can produce light when it is forward-biased, that particular diode is called LED.



→ when a diod is forward biased the e̅s from n-side combines with holes of the p-side. With this combination there is a generation of heat. ~~Aultimately~~ Ultimately it generates light when it is over heated. Due to the property of emitted light, these type of diodes are called LED.

→ A diode manufactured with Si or Ge only has the capability to generate heat.

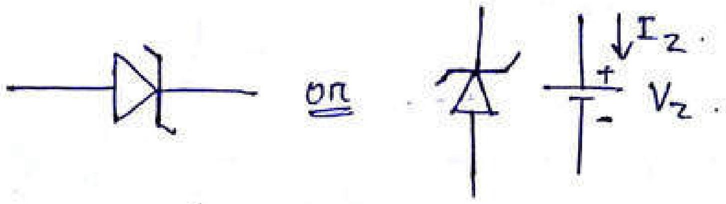
→ It can not produce light.

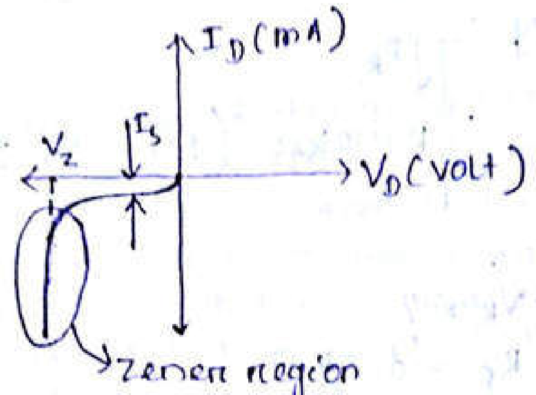
→ Some compound semiconductors such as GaAs, GaN, GaP, GaAsP has the capability to generate light in forward biasing mode.

→ GaAs emits Red colour. GaP emits Green colour. GaNS emits white colour. GaAsP emits orange.

Zener diode :

Symbol:





→ when a diode is reverse biased at a particular voltage, the reverse saturation current breakdown and increases suddenly in the reverse direction.

→ If dopping level of a semiconductor can be increased, the breakdown voltage can be acquired very soon. This particular breakdown voltage is called zener voltage and the device which operated in this zener voltage is called zener diode.

→ while increasing dopping level of the semiconductor we assure that diode is not going to burn out or destroy.

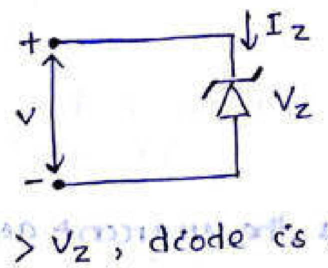
→ Application of zenerdiode is voltage regulator.

→ zener diode has two states.

i) ON state

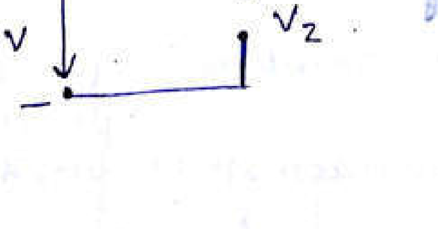
ii) OFF state.

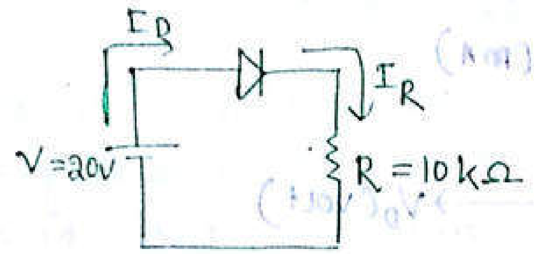
i) ON state :



IF $V > V_z$, diode is ON.

ii) OFF state : (IF $V < V_z$)



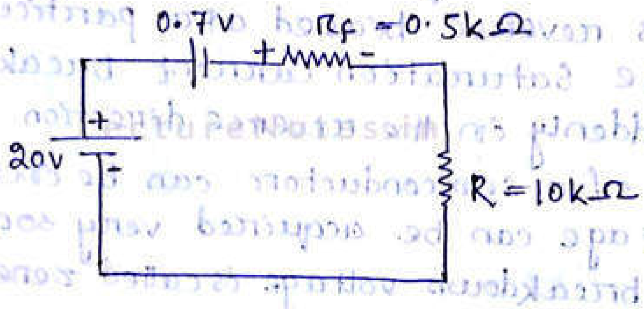


(piece wise linear model)

$I_D = ?$

$I_R = ?$ $V_R = ?$

$R_f = 0.5k\Omega$



$I_D = I_R$ ($\because$ when resistors are in series, the current in each resistor remain same)

According to Kirchoff's law

$$20 - 0.7 - (I_D \times 0.5) - (I_D \times 10) = 0$$

$$\Rightarrow 19.3 - (10.5\, I_D) = 0$$

$$\Rightarrow 10.5\, I_D = 19.3$$

$$\Rightarrow I_D = \frac{19.3}{10.5} = 1.838\, mA$$

$I_R = 1.838$

$V_R = I_D \times R$

$= 1.838 \times 10k\Omega$

$= 18.38\,V$

* When resistors are in series, the current across the resistor remains same.
* When resistors are connected in parallel, the voltage across the resistor remain same.

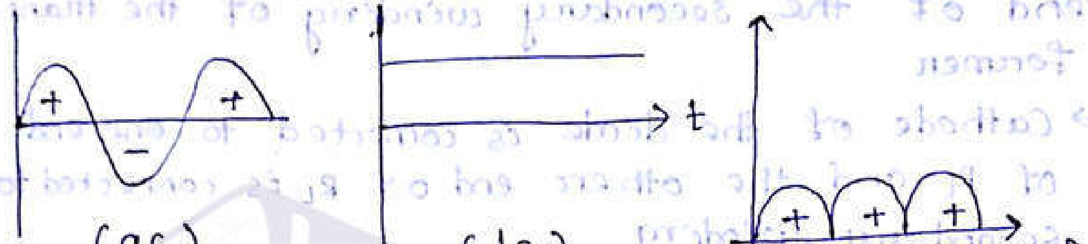
Rectifier:

↳ Half wave Rectifier (HWR)
↳ Full wave Rectifier (FWR)

Full wave rectifier (FWR):

↳ Centre tap full wave rectifier
↳ Full wave bridge type rectifier.

→ Rectifiers are electronic ckt which converts i/p ac signal pulsating dc.

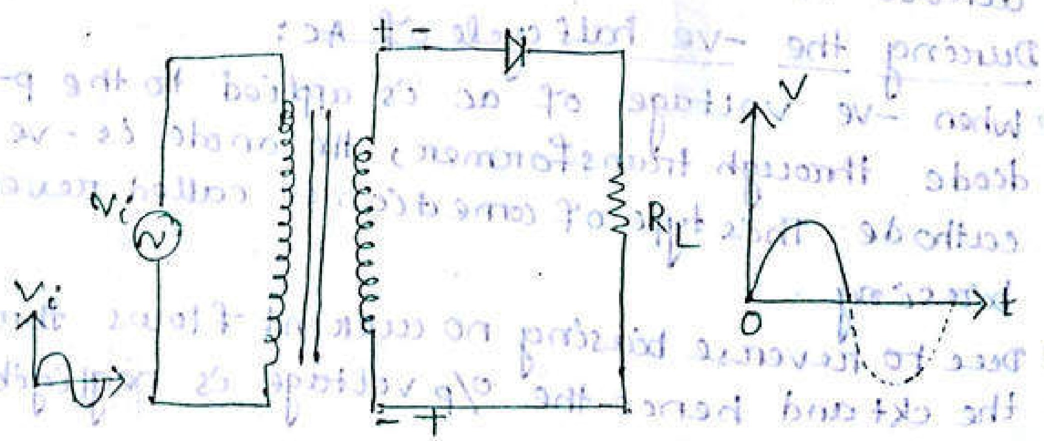


(ac) (dc) (pulsating dc)

→ Fan, heater, bulbs, airconditions etc runs with the help of ac signal. But there are some devices which can not be run with the help of ac signal such as mobile phones, toy cars, walk-man, mini emergency light, torch light etc. These equipments can be run with the help of dc supply.

→ As ac signal is generally available to run this equipments (electronic equipments), ac is converted to dc.

Half wave rectifier (HWR):



Statement :

The type of rectifier in which the o/p current flow corresponding to one half cycle of the i/p alternating current is called HWR.

Construction :

→ It consist of a single p-n junction diode

→ The ac supply is to be rectified through a transformer in series with diode and load register (R_L)

→ The anode of the diode is connected to one end of the secondary winding of the transformer

→ Cathode of the diode is connected to one end of R_L and the other end of R_L is connected to secondary winding.

→ The output voltage will be obtained across R_L.

Working :

During +ve half cycle of AC :

→ When +ve half of i/p ac is applied through transformer, the anode of p-n junction diode becomes +ve w.r.t. cathode. This type of connection is called forward biasing.

→ Due to forward biasing current flow through the circuit.

→ When the resulting current flows through the Load resistor (R_L), the o/p voltage is obtained across it.

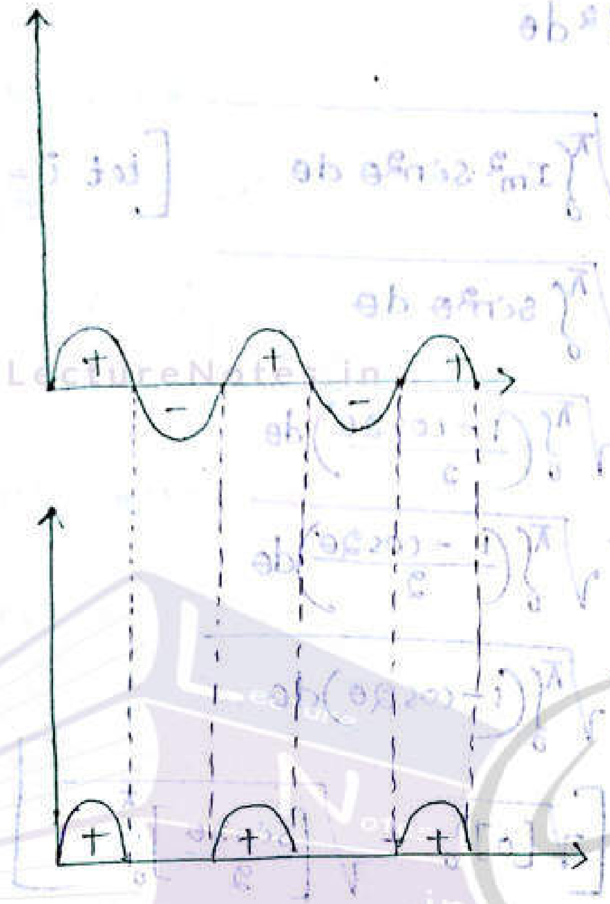
During the -ve half cycle of AC :

→ When -ve voltage of ac is applied to the p-n junction diode through transformer, the anode is -ve w.r.t. cathode. This type of connection is called reverse biasing.

→ Due to reverse biasing no current flows through the ckt and hence the o/p voltage is negligible.

conclusion:

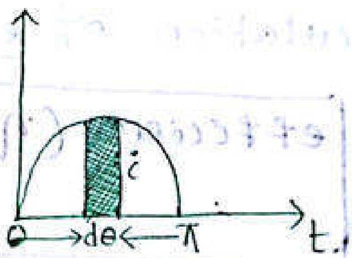
In HWR, current flows through R_L during the +ve half cycle of ac only. Hence it is unidirectional.



Disadvantage of HWR:

In HWR the flow of o/p power is due to the half cycle of the i/p signal only. Other halfcycle is wasted.

calculation of I_{dc} in HWR:



$$I_{dc} = \frac{1}{2\pi}\int_0^{\pi} i\,d\theta.$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m \sin\theta\, d\theta$$

$$\left[\text{Let } i = I_m \sin\theta\right]$$

$$= \frac{I_m}{2\pi}\int_0^{\pi} \sin\theta\, d\theta$$

$$= \frac{I_m}{2\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$= \frac{I_m}{2\pi}\left[-\cos\pi - (-\cos 0)\right] = \frac{I_m}{2\pi}\times 2 = \frac{I_m}{\pi}$$

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

Calculation of I_{rms} in HWR:

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} i^2 \, d\theta}$$

$$\Rightarrow \quad = \frac{1}{\sqrt{2\pi}}\sqrt{\int_0^{\pi} I_m^2 \sin^2\theta \, d\theta} \qquad [\text{let } i = I_m \sin\theta]$$

$$= \frac{I_m}{\sqrt{2\pi}}\sqrt{\int_0^{\pi} \sin^2\theta \, d\theta}$$

$$= \frac{I_m}{\sqrt{2}\sqrt{\pi}}\sqrt{\int_0^{\pi}\left(\frac{1-\cos 2\theta}{2}\right) d\theta}$$

$$= \frac{I_m}{\sqrt{2}\sqrt{\pi}}\sqrt{\int_0^{\pi}\left(\frac{1-\cos 2\theta}{2}\right) d\theta}$$

$$= \frac{I_m}{\sqrt{2}\sqrt{2}\sqrt{\pi}}\sqrt{\int_0^{\pi}(1-\cos 2\theta) \, d\theta}$$

$$= \frac{I_m}{2\sqrt{\pi}}\left[\sqrt{[\theta]_0^{\pi}} - \sqrt{\left[\frac{\sin 2\theta}{2}\right]_0^{\pi}}\right]$$

$$= \frac{I_m}{2\sqrt{\pi}}\left[\sqrt{(\pi - 0)} - \sqrt{\frac{\sin 2\pi}{2} - 0}\right]$$

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

Calculation of efficiency in HWR:

$$\boxed{\text{efficiency } (\eta) = \frac{\text{dc o/p power}}{\text{ac i/p power}}}$$

$$= \frac{I_{dc}^2 \times R_L}{I_{rms}^2 (R_L + r_f)}$$

$$= \frac{I_{dc}^2 \times R_L}{I_{rms}^2 \times R_L} \qquad [\because R_L >>> r_f]$$

$$= \frac{I_{dc}^2}{I_{rms}^2} = \frac{\left(\frac{I_m}{\pi}\right)^2}{\left(\frac{I_m}{2}\right)^2}$$

$$= \frac{I_m^2 \times 4}{I_m^2 \times \pi^2}$$

$$= \frac{4}{\pi^2} = 40.5\%$$

$$\boxed{\eta_{HWR} = 40.5\%}$$

Ripple factor in HWR:

$$\text{ripple factor} = \frac{I_{ac}}{I_{dc}}$$

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

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

Deviding bothsides by I_{dc}.

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

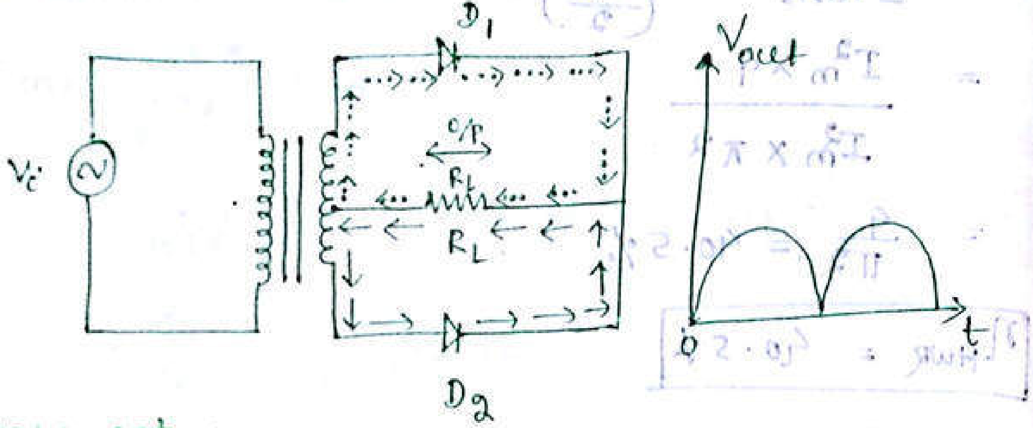
$$\frac{I_{ac}}{I_{dc}} = \sqrt{\frac{(I_m/2)^2}{(I_m/\pi)^2} - 1}$$

$$\frac{I_{ac}}{I_{dc}} = \sqrt{\frac{\pi^2}{4} - 1}$$

$$\frac{I_{ac}}{I_{dc}} = 1.21$$

$$\boxed{\text{Ripple factor of HWR} = 1.21}$$

Centre tap FWR :



Statement :

→ A rectifier in which current flows through the load resister (R_L) for both the halves of i/p ac signal is called FWR.

construction :

→ It consist of two p-n junction diodes.

→ The anodes of two diodes are connected to the opposite ends of centretapped secondary winding

→ The two cathodes of two diodes are connected to one side of load resister (R_L).

→ The other end of R_L is connected to the centre-tapped secondary winding.

→ Only one half of transformer secondary voltages appear between the anode and cathode of each diode.

→ The o/p voltage will be obtained across R_L.

Working :

During +ve halfcycle of ac signal:

→ when +ve halfcycle of ac signal is applied, the upper half of secondary becomes +ve w.r.t lower half.

→ Now the diode D_1 is forward biased and hence current flows through the load resistor R_L. Hence o/p voltage will be obtained across R_L.

→ At the sametime the anode of the diode D_2 is -ve w.r.t cathode which is called reverse biasing.

→ Due to reverse biasing, no current results hence no o/p voltage will be obtained across R_L.

During -ve halfcycle of ac signal:

→ During the -ve halfcycle of secondary voltage, the upper half of the secondary winding becomes -ve w.r.t lower half. Now the diode D1 becomes reverse biased i.e anode is -ve w.r.t cathode.

Therefore current does not take place in diode D1. Hence o/p voltage across R_L is zero.

→ But at the sametime, the diode D_2 is forward biased. i.e anode is +ve w.r.t cathode. Due to forward biasing, current flows through the load register R_L and and hence the voltage will be obtained across it.

Conclusion:

Current flows for both halfcycles of ac signal through the ckt and hence we get DC o/p.

Calculation of I_{dc} in centretapped FWR:

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} i\,d\theta$$

$$\Rightarrow I_{dc} = \frac{1}{\pi}\int_0^{\pi} I_m \sin\theta\,d\theta \quad [i = I_m \sin\theta\,d\theta]$$

$$\Rightarrow I_{dc} = \frac{I_m}{\pi}\int_0^{\pi} \sin\theta\,d\theta$$

$$\Rightarrow I_{dc} = \frac{I_m}{\pi}\left[-\cos\theta\right]_0^{\pi}$$

$$\Rightarrow I_{dc} = \frac{I_m}{\pi}\left[-\cos\pi - (-\cos 0)\right]$$

$$\Rightarrow I_{dc} = \frac{I_m}{\pi}(2)$$

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

calculation of I_{rms} in centretapped FWR

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} i^2 d\theta}$$

$$I_{rms} = \frac{1}{\sqrt{\pi}}\sqrt{\int_0^{\pi} I_m^2 \sin^2 d\theta} \quad [\text{let } i = I_m \sin\theta]$$

$$I_{rms} = \frac{I_m}{\sqrt{\pi}}\sqrt{\int_0^{\pi} \sin^2\theta d\theta}$$

$$I_{rms} = \frac{I_m}{\sqrt{\pi}}\sqrt{\int_0^{\pi}\left(\frac{1-\cos 2\theta}{2}\right)}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}\sqrt{\pi}}\sqrt{\int_0^{\pi} d\theta - \int_0^{\pi}\cos 2\theta\, d\theta}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}\sqrt{\pi}}\sqrt{\int_0^{\pi} d\theta} - \sqrt{\int_0^{\pi}\cos 2\theta d\theta}$$

$$I_{rms} = \frac{I_m}{\sqrt{2}\sqrt{\pi}}\left[\sqrt{[\theta]_0^{\pi}} - \sqrt{\left[\frac{\sin 2\theta}{2}\right]_0^{\pi}}\right]$$

$$I_{rms} = \frac{I_m}{\sqrt{2}\sqrt{\pi}}\left[\sqrt{\pi - 0} - \sqrt{\frac{\sin 2\pi}{2} - 0}\right]$$

$$I_{rms} = \frac{I_m}{\sqrt{2}\cancel{\sqrt{\pi}}} \times \cancel{\sqrt{\pi}}$$

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

calculation of efficiency in FWR:

$$\text{efficiency}(\eta) = \frac{\text{DC power output}}{\text{I/p ac power}}$$

$$= \frac{I^2_{dc} R_L}{I^2_{rms}(R_L + r_f)}$$

$$\frac{\frac{4 I_m^2}{\pi^2}}{}$$

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

$$= \frac{4I_m^2}{\pi^2} \times \frac{2}{I_m^2}$$

$$= \frac{8}{\pi^2}$$

$$= \frac{8}{\frac{22}{7} \times \frac{22}{7}}$$

$= 0.81$

$= 81\%$

Calculation of ripple factor in centre tapped FWR:

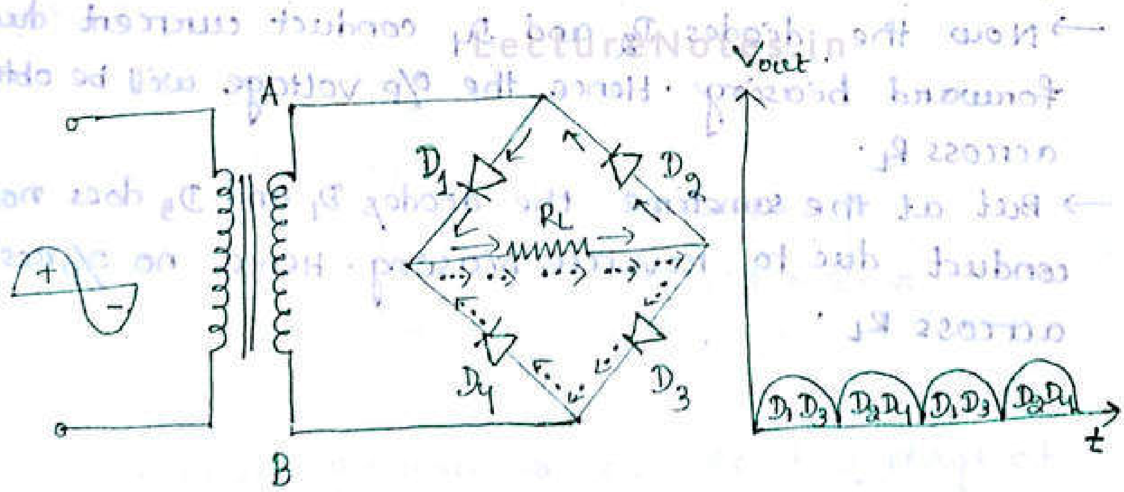
$$\frac{I_{ac}}{I_{dc}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

$$= \sqrt{\frac{\left(\frac{I_m}{\sqrt{2}}\right)^2}{\left(\frac{2I_m}{\pi}\right)^2} - 1}$$

$$= \sqrt{\frac{\pi^2}{8} - 1} = 0.48$$

$\boxed{\text{ripple factor of centretapped FWR} = 0.48}$

Bridge type FWR:



Construction :

→ It consist of 4 diodes that D_1, D_2, D_3 and D_4 which are connected to form a bridge.

→ The ac supply to be rectified is supplied to the diagonally opposite ends of the bridge through the transformer.

→ Between other two ends of the bridge, the load resistor R_L is connected.

Working :

During +ve halfcycle of ac :

→ During the +ve halfcycle of secondary voltage, the end 'A' of the secondary winding becomes +ve w.r.t other end 'B'

→ Now the diodes D_1 and D_3 are forward biassed and hence the conventional current flow through the circuit across the R_L.

As a result the o/p voltage will be obtained across R_L.

→ But at the sametime the diodes D_2 and D_4 does not conduct due to reverse biasing. Hence no o/p results across R_L.

During -ve halfcycle of ac :

→ During -ve halfcycle of secondary voltage, the end A becomes -ve w.r.t the other end 'B'

→ Now the diodes D_2 and D_4 conduct current due to forward biasing. Hence the o/p voltage will be obtained across R_L.

→ But at the sametime the diodes D_1 and D_3 does not conduct due to reverse biasing. Hence no o/p result across R_L.

Advantages and disadvantages of rectifiers :

Advantage of HWR :

- No of components used are less
- If we are available with small amplitude i/p signal we don't require transformer.

Disadvantages of HWR:

- The efficiency is very low for HWR (40.5%)

Advantages of FWCR :

- The o/p can be seen for the full input cycle.
- Efficiency is high (81 %)

Disadvantages of FWCR:

- centretap location is very difficult.
- peak inverse voltage $= 2V_m$.
- Number of components required are greater than HWR

Advantages of FWBR :

- Efficiency is very high (81 %)
- If small amplitude input signal is available, transformed is not required.
- $PIV = V_m$
- Circuit design is simple.

Disadvantages of FWBR:

- Number of components required are greater than HWR and FWCR.

	HWR	FWR CT	FWR BT
I_{dc}	I_m/π	$2I_m/\pi$	$2I_m/\pi$
I_{rms}	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
PIV	V_m	$2V_m$	V_m

	HWR	FWR CT	FWR BT
η	40.5%	81%	81%
RF	1.21	0.48	0.48

Ripple factor :

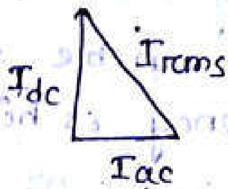
→ In rectifier the main objective is dc voltage at the o/p. But in rectifier ckt we do not get exact dc o/p. The dc o/p is pulsating in nature.

→ Some ac components along with dc component can be seen at the o/p.

→ Ripple factor is the ratio between rms value of the ac component and dc component.

$$R.F = \frac{\text{rms value of ac component } (I_{ac})}{\text{dc component } (I_{dc})}$$

$$I^2_{rms} = I^2_{dc} + I^2_{ac}$$



$$\Rightarrow \frac{I^2_{rms}}{I^2_{dc}} = 1 + \frac{I^2_{ac}}{I^2_{dc}}$$

$$\Rightarrow \frac{I^2_{rms}}{I^2_{dc}} - 1 = \frac{I_{ac}^2}{I_{dc}^2}$$

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

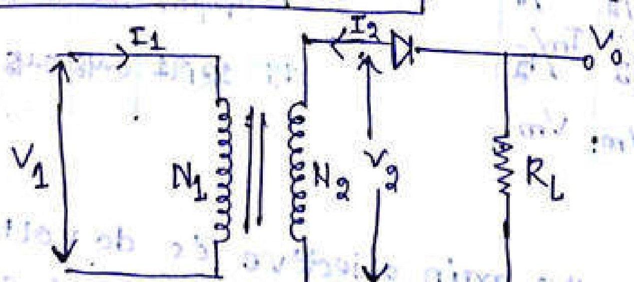
$$\Rightarrow \boxed{\frac{I_{ac}}{I_{dc}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}}$$

Q. An ac supply of 230V is applied to HWR through a transformer of turn ratio 10:1. Find out the
(1) output dc voltage
(2) Dc current

$(R_L = 800\Omega)$

→

$$\boxed{\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}}$$



$V_2 = V_m$ (HWR)

$V_{rms} = 230V$

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

$\Rightarrow 230 = \frac{V_m}{\sqrt{2}}$

$\Rightarrow V_m = 325.26\,(V_1)$

$\frac{V_1}{V_2} = \frac{N_1}{N_2}$

$\Rightarrow \frac{325.26}{V_2} = \frac{10}{1} \Rightarrow V_2 = \frac{325.26}{10} = 32.5V$

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

$V_{dc} = \frac{V_m}{\pi} = \frac{32.5}{\pi} = 10.34V$

$V_o = I_{dc} \times R_L$

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

$= \frac{V_m}{\pi} = \frac{32.5}{\pi} = 10.34V$

$\frac{V_m}{\cancel{\pi}} = \frac{I_m}{\cancel{\pi}} \times R_L$

$\Rightarrow 32.5 = I_m \times R_L$

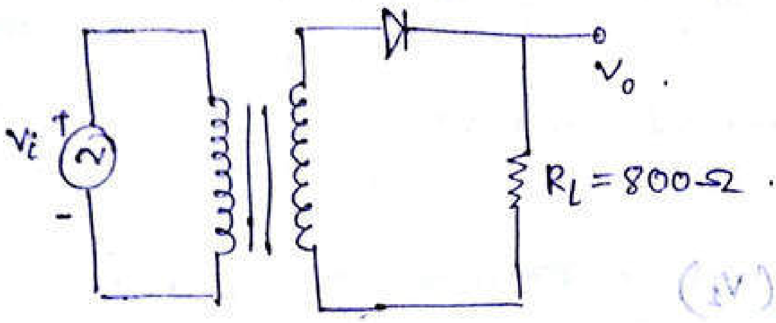
$\Rightarrow 32.5 = I_m \times 800$

$\Rightarrow I_m = \frac{32.5}{800} = 0.012A$

Q. A crystal diode having internal resistance is equal to 20Ω used in HWR. The applied voltage is equal to $50 \sin \omega t$. The load resistance 800Ω. find out I_{dc}, I_{rms}, $P_o(dc)$, $P_i(ac)$, $\underbrace{\eta\,(r_f = 20\,\Omega),\ \eta\,(r_f = 0\,\Omega)}_{\text{compare two results}}$

$V_o = V_{dc} = ?$

→



$V = V_m \sin(\omega t + \phi)$

$V = 50 \sin \omega t$

$V_m = 50$

$V_o = V_{dc} = \frac{V_m}{\pi} = \frac{50}{\pi} = 15.91\,V$

$I_{dc} = \frac{V_o}{R_L + r_f} = \frac{15.91}{820} = 0.019\,A$

$I_m = \frac{V_m}{R_L + r_f} = \frac{50}{800} = 0.0609\,A$

$I_{rms} = \frac{I_m}{2} = \frac{0.0609}{2} = 0.0304\,A$

$P_{dc} = I_{dc}^2 \times R_L = (0.019)^2 \times 800 = 0.2888$

$P_{ac} = I_{rms}^2 \times (R_L + r_f)$

$= (0.0304)^2 \times 820 = 0.7578112$

$\eta = \frac{I_{dc}^2 \times R_L}{I_{rms}^2 (R_L + r_f)}$

$= \frac{(0.019)^2 \times 800}{(0.0304)^2 (800 + 20)} = \frac{0.2888}{0.7578112} = 0.3810$

$=$ $= 38.10\,\%$

$\cong 38.10\%$

$\eta = \frac{I_{dc}^2 \times R_L}{I_{rms}^2 (R_L + \cancel{r_f}^{\,0})} = \frac{I_{dc}^2 \times \cancel{R_L}}{I_{rms}^2 \times \cancel{R_L}} = \left(\frac{I_{dc}}{I_{rms}}\right)^2$

$= \left(\frac{0.019}{0.0304}\right)^2$

$= 0.390$

$= 39\%$

Q. $I_s = 10^{-10}$ A

$\eta = 2$

$V_D = 0.65$ V

$I_D = ?$

$\rightarrow$ $V_T = \frac{kT}{q} = \frac{kT}{e} = \left(\frac{k}{q}\right) \times T = 0.02585 \cong 0.026$ V $\cong 26$ mV.

$(\because k = 1.38 \times 10^{-23}$ J/K$)$

$$I_D = I_s\left(e^{V_D/\eta V_T} - 1\right)$$

$$\Rightarrow \ln I_D = \ln\left\{I_s\left(e^{V_D/\eta V_T} - 1\right)\right\}$$

$$= \ln\left\{I_s e^{V_D/\eta V_T} - I_s\right\}$$

$$= \frac{\ln\left(I_s e^{V_D/\eta V_T}\right)}{\ln I_s} = \frac{\ln I_s + \ln e^{V_D/\eta V_T}}{\ln I_s}$$

$$= \frac{\ln I_s}{\ln I_s} + \frac{V_D/\eta V_T (\ln e)}{\ln I_s}$$

$$= 1 + \frac{\frac{V_D}{\eta V_T}}{\ln I_s}$$

$$= 1 + \frac{\frac{0.65}{2 \times 0.026}}{\ln 10^{-10}}$$

$$= 1 + \frac{0.65}{0.052} \times \frac{1}{-10}$$

$$= 1 - \frac{0.65}{0.52}$$

$$= 1 - 1.25$$

$$= -0.25$$

$$I_D = e^{-0.25} = 0.77\text{ A}$$

Q. For FWR the o/p $R_L = 2000\Omega$. The forward resistance $r_f = 1000\Omega$. It has infinite backward resistance. The rms value of transformer secondary voltage from mid point to each terminal = 250V. find I_{dc}, I_{rms}, P_{out}, efficiency, input ac power.

→

$R_L = 2000\Omega$

$r_f = 1000\Omega$

$V_{rms} = 250V$

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

$\Rightarrow V_m = V_{rms}\sqrt{2} = 250\sqrt{2}\,V$

$I_m = \frac{V_m}{R_L + r_f} = \frac{250\sqrt{2}}{3000} = 0.1178\,A$

$I_{rms} = \frac{I_m}{\sqrt{2}} = \frac{0.1178}{\sqrt{2}} = 0.083\,A$

$I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 0.1178}{\pi} = 0.0749\,A$

$P_{ac} = I_{rms}^2 \times (R_L + r_f)$

$= 20.667$

$P_{dc} = I_{dc}^2 \times R_L$

$= (0.0749)^2 \times 2000$

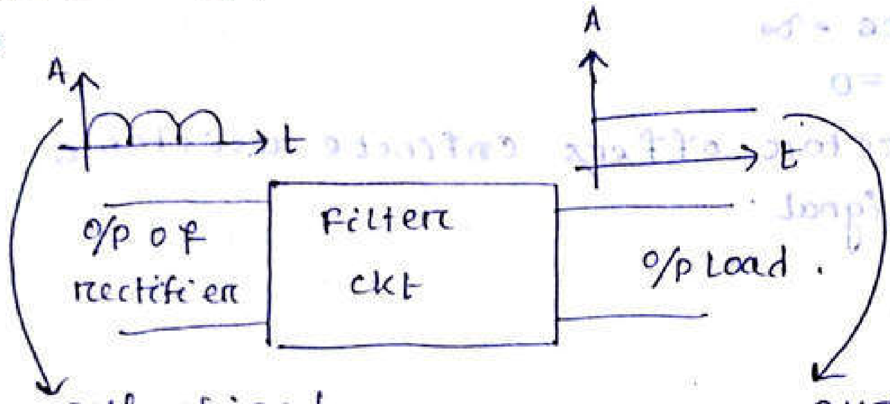
$= 11.220$

$\eta = \frac{P_{dc}}{P_{ac}} = \frac{11.220}{20.667} = 0.5428$

$= 54.28\%$

Q. What is need of using filter ckt along with rectifier ckt?

→



→ The o/p of the rectifier is pulsating and contains a steady dc component with undesirable ripples.

→ If such a pulsating dc is given to electronic ckt, it produces ham (disturbance)

→ Therefore the ac component or ripples have to kept away from the load (electronic ckts). This is achieved by using filter ckt.

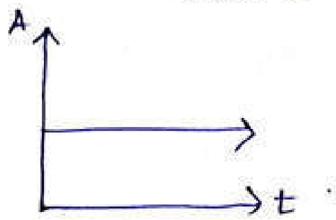
Q. What are the components used in filter ckt?

→ ↳ capacitor.
↳ inductor.

Capacitive Reactance:

The resistance offered by the capacitor to the flow of current is called capacitive reactance and is represented with X_c.

$$X_c = \frac{1}{2\pi f c} = \frac{1}{\omega c}.$$



frequency of dc = 0.

$$\text{So } X_c = \frac{1}{2\pi \times 0 \times c} = \frac{1}{0} = \infty\,\Omega.$$

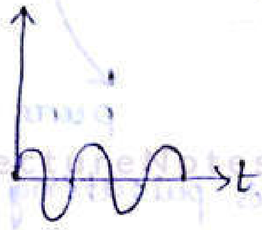
If resistance is ∞, current = 0

<u>Open ckt :</u>

resistance = ∞

current = 0

→ A capacitor offers infinite resistance to dc signal.



$f \neq f'$

$$X_c = \frac{1}{2\pi f' C} = k\Omega$$

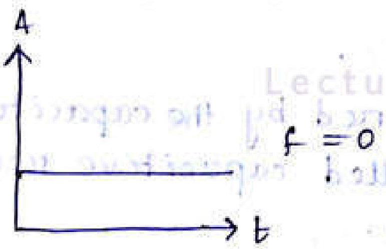
→ kΩ → (resistor)

→ A capacitor offers very low resistance to the flow of ac signal.

Inductive Reactance (X_L):

The resistance offered by the conductor to the flow of current is known as inductive reactance.

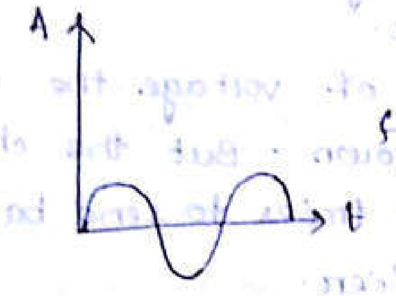
$$X_L = 2\pi f L$$



$$X_L = 2\pi \times 0 \times L = 0\Omega$$

$\rightarrow I \quad R = 0\Omega \rightarrow I$

→ The inductor allows the flow of dc signal through it.



$X_L = 2\pi f' L = \text{high}$

$X_L = R = \text{High}$

→ The inductor offers a very high resistance to the flow of ac signal.

→ A capacitor is connected parallel to the ckt in such a manner that it bypasses the ac component and blocks the dc component.

→ An inductor is connected in series with the ckt in such a manner that it blocks the ac component and gives the easy path to dc component.

Types of filter ckt :

↳ i) capacitive / shunt.

↳ ii) Inductive / series

↳ iii) LC type / choke type

↳ iv) π type / i/p capacitor

capacitive shunt filter :

→ In this case a capacitor of very large value is just connected across the o/p terminal or in parallel to the o/p load i.e why it is called shunt capacitor filter.

→ The capacitor offers a low reactive path to the ac signal and acts as an open ckt for dc signals all of the dc signal reaches at the low terminal with ac signal bypasses to ground.

working principle

→ When the rectifier voltage increases, the capacitor is charged to $V_m = V_{max}$.

→ At the maximum point of voltage the rectifier voltage tries to fall down. But the charged capacitor immediately tries to send back the current to the rectifier.

→ In this process the rectifier diodes are reverse biased and stops giving supply to the load. Thus the capacitor discharges through the load.

→ The capacitor continuous to discharge until the source voltage is more than the capacitor voltage and the capacitor is again charge peak value V_m

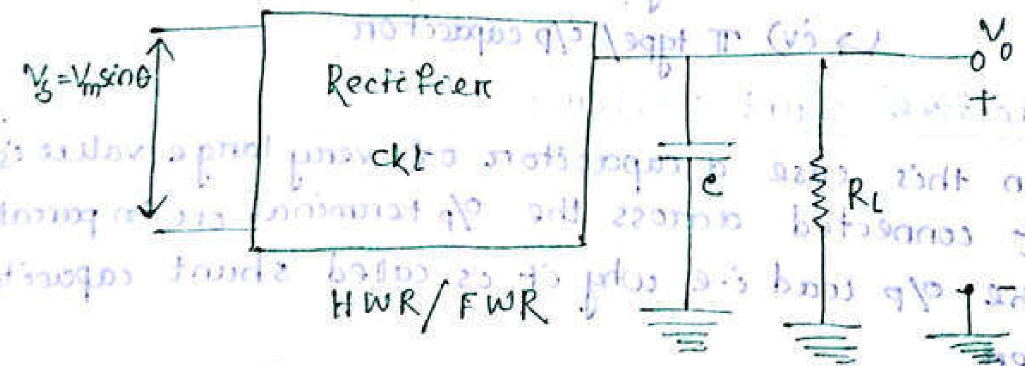
→ During this time the rectifier supplies the charging current I_C and the load current I_L.

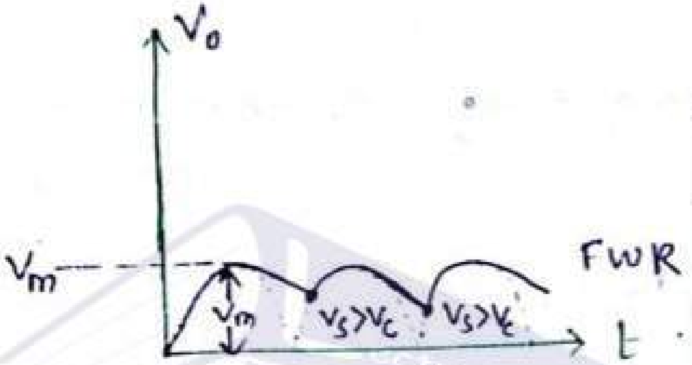
→ The smoothness of o/p voltage depends upon the time constant

→ The Longer the the timeperiod, the steadier of the o/p voltage

→ This can be achieve by using a large value of capacitor.

Filter ckt





Advantages:

→ The magnitude of o/p dc is improved because of the charging and discharging concept.

→ It can be applied to both HWR and FWR.

Disadvantages:

→ since capacitor itself draws heavy amount of current from the rectifier, the load current available at the load is very small.

Clipper and clamper :

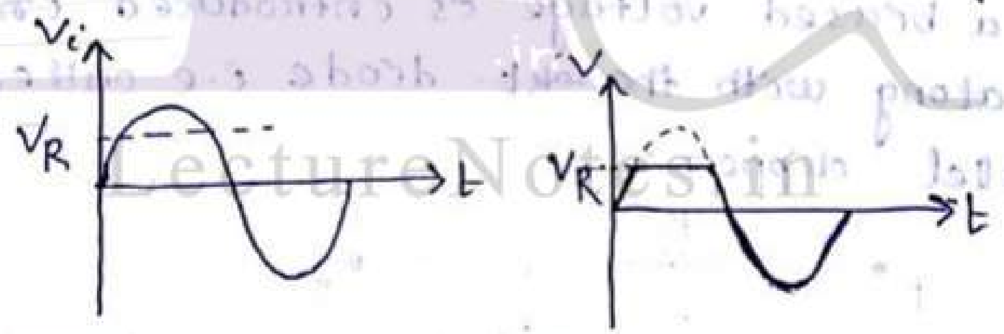
Clipper :

clipper

- Series clipper
  - biased series
- parallel clipper.
  - biased parallel.

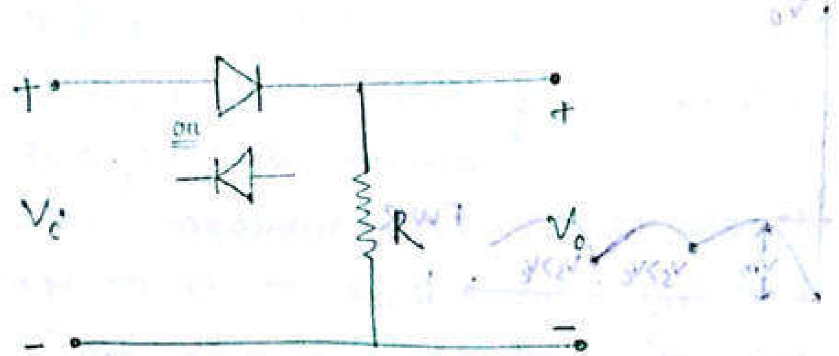
→ A clipper is an electronic ckt which remove or clips off the unwanted portion of the i/p signal.

Ex

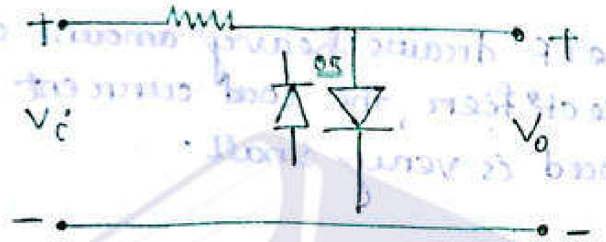


Series clipper :

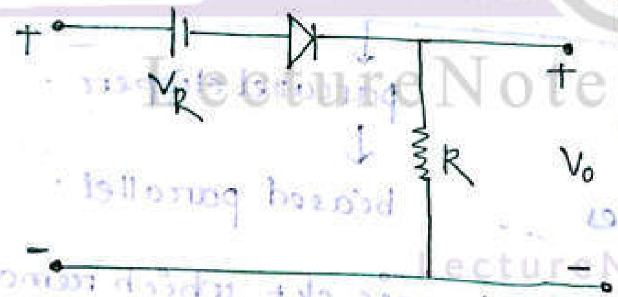
when a diode is connected in series with the o/p, is called series clipper.



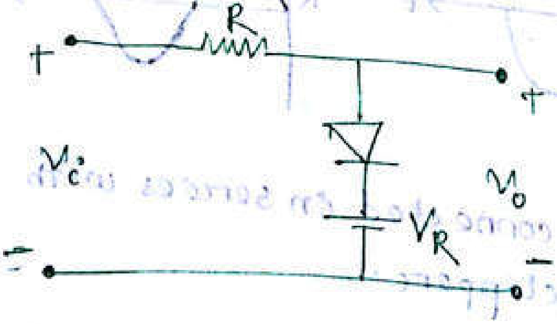
Parallel clipper :
when a diode is connected in parallel with the o/p, is called parallel clipper.



Biased series clipper :
when a biased voltage is introduced in the series ckt along with diode i.e called biased series clipper.

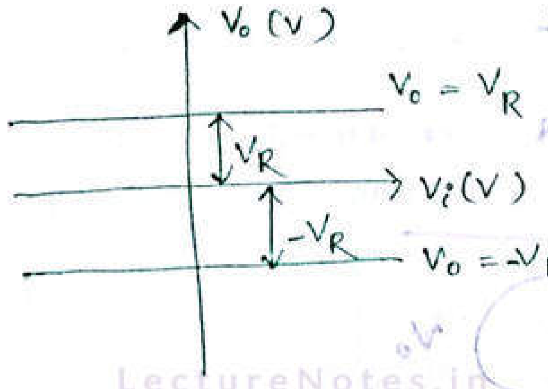


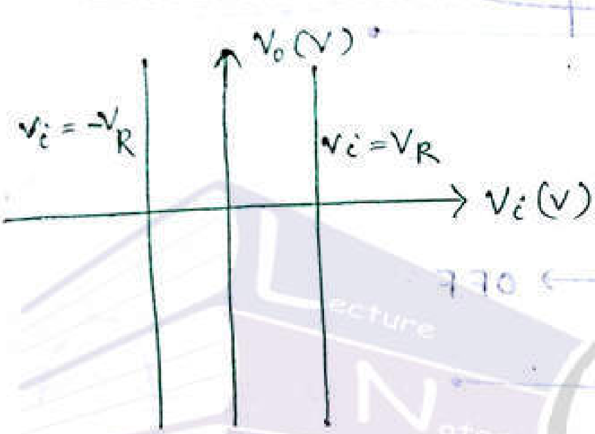
Biased parallel clipper :
when a biased voltage is introduced in the parallel ckt along with the ~~ckt~~ diode i.e called biased parallel clipper.

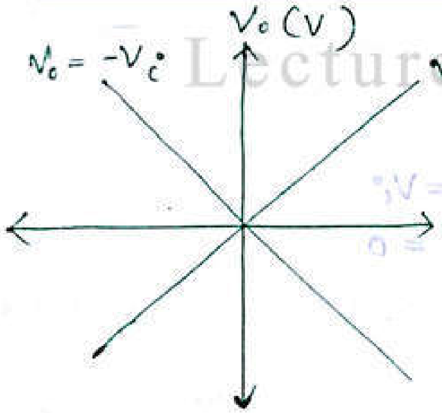


Voltage transfer characteristics (VTC) :

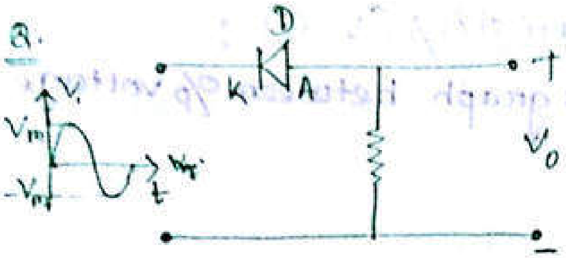
→ It is the characteristics graph between o/p voltage and i/p voltage.



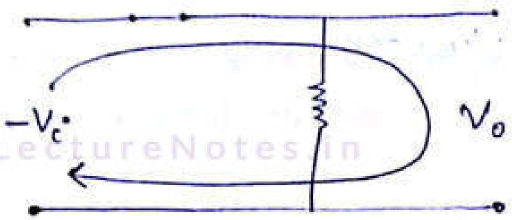




Q.



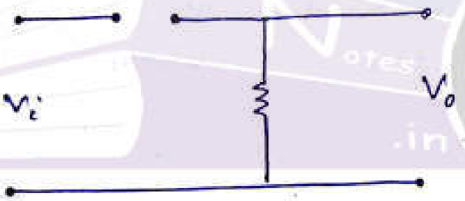
→ when $V_i < 0$, $D \rightarrow ON$



$-V_i + V_o = 0$

$\Rightarrow \boxed{V_o = V_i}$

when $V_i > 0$, $D \longrightarrow OFF$.

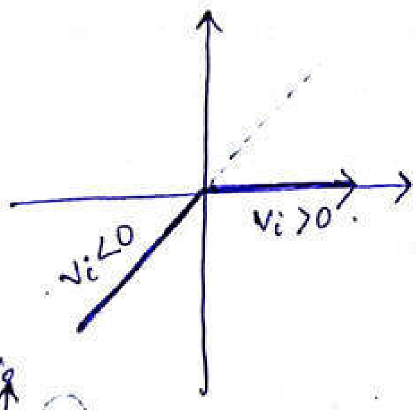


$\boxed{V_o = 0}$

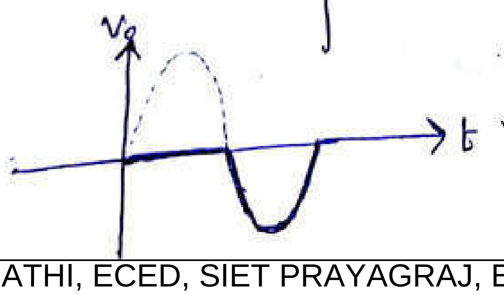
when $V_i < 0$, $D = ON$ $V_o = V_i$

when $V_i > 0$. $D = OFF$ $V_o = 0$

Graph:



O/P:



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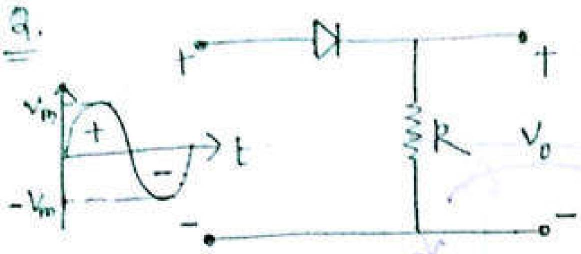
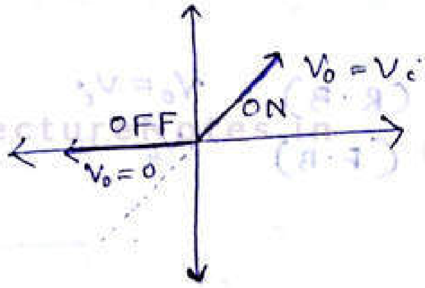
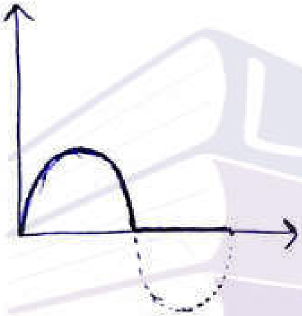


→ $V_i < 0$ D = OFF (RB) $V_o = 0$

$V_i > 0$ D = ON (FB) $V_o = V_i$





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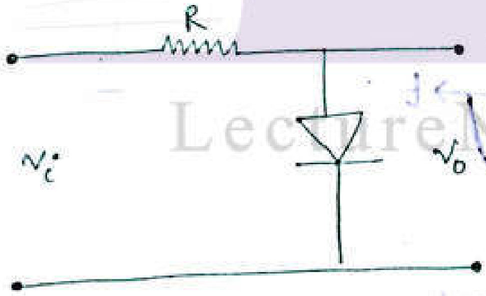
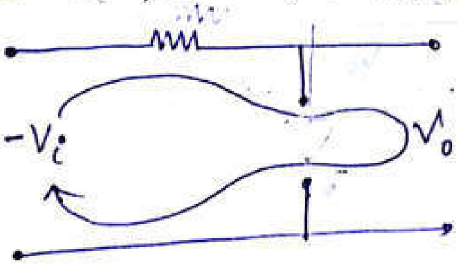


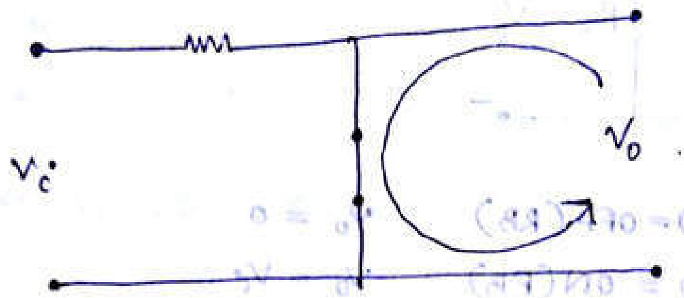
→ when $V_i < 0$ D = OFF (R.B)



$V_o - V_i = 0$

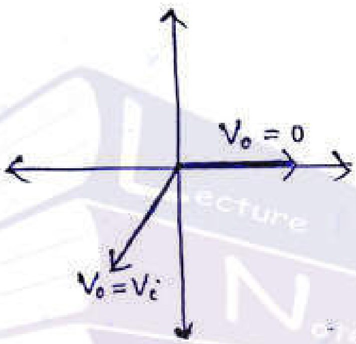
$\Rightarrow \boxed{V_o = V_i}$

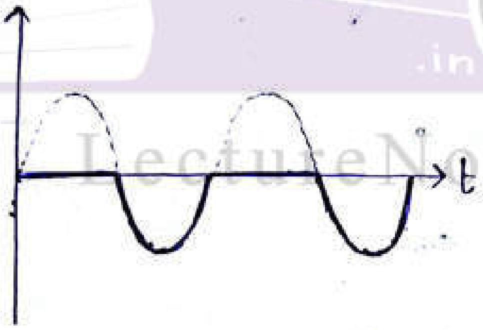
when $V_i > 0$ $D = ON$



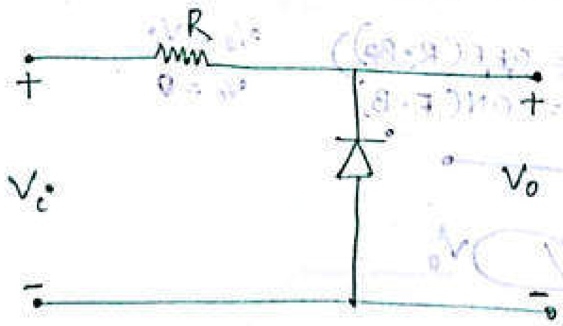
$\boxed{V_o = 0}$

when $V_i < 0$, D = OFF (R·B) $V_o = V_i$
when $V_i > 0$, D = ON (F·B) $V_o = 0$

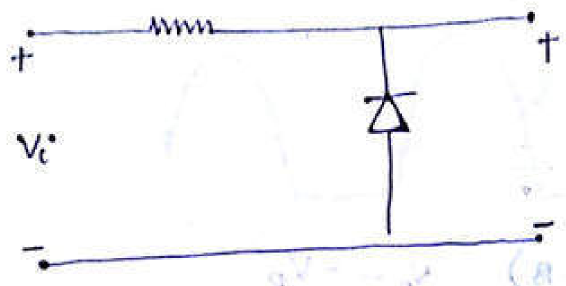




2.

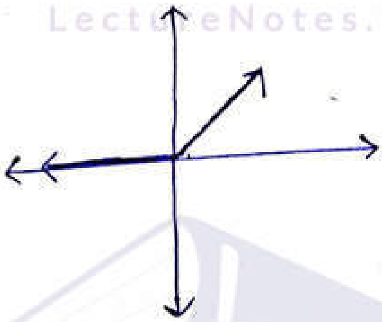


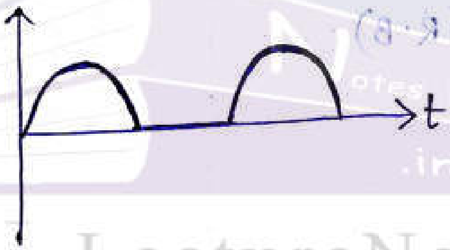
→



$V_i < 0$ $\quad D = ON(F \cdot B)$ $\quad V_0 = 0$

$V_i > 0$ $\quad D = OFF(R \cdot B)$ $\quad V_0 = V_i$





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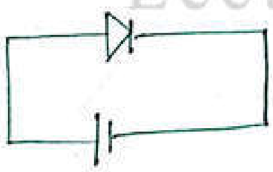
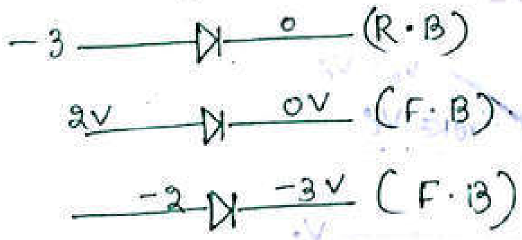


(F · B)



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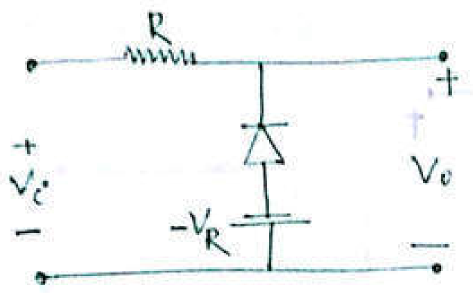
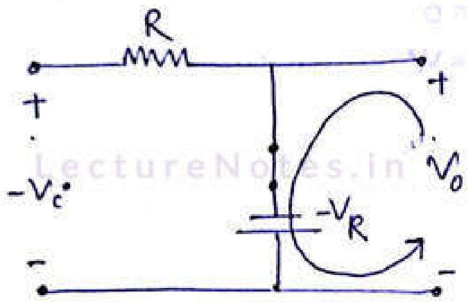
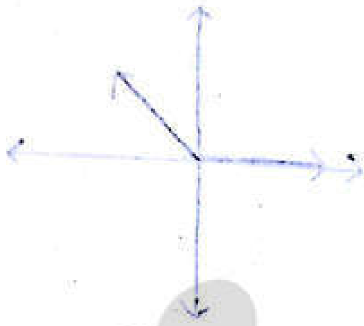


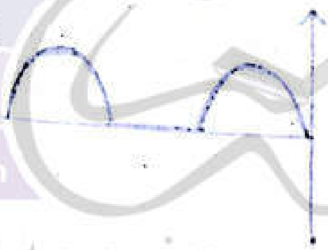
→ $v_i < -V_R$ D = ON (F.B)

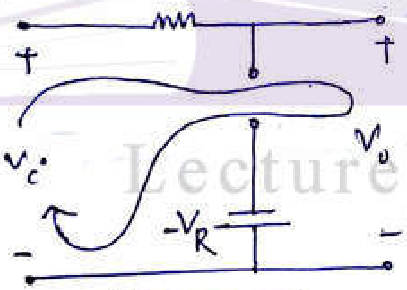




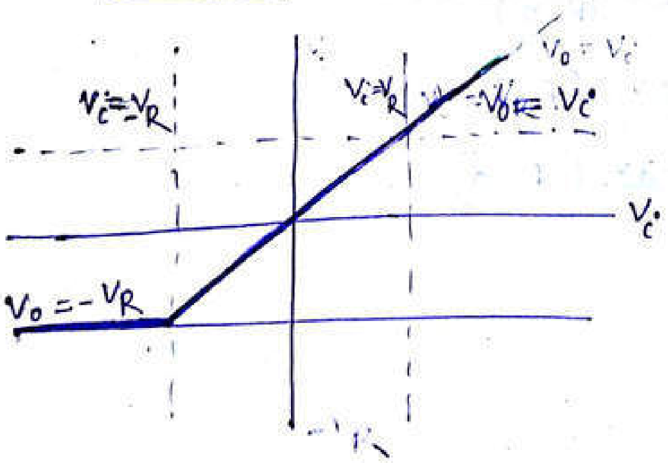
⇒ $\boxed{V_o = -V_R}$

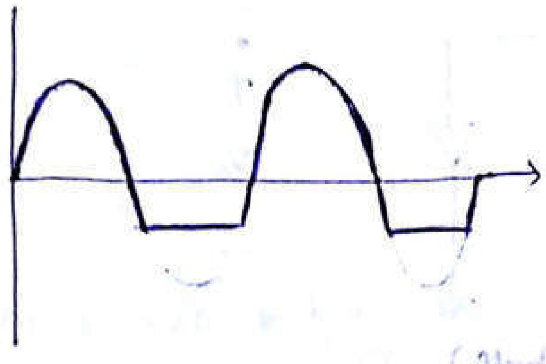
$v_i > -V_R$ D = OFF (R.B)





$\boxed{V_o = V_i}$





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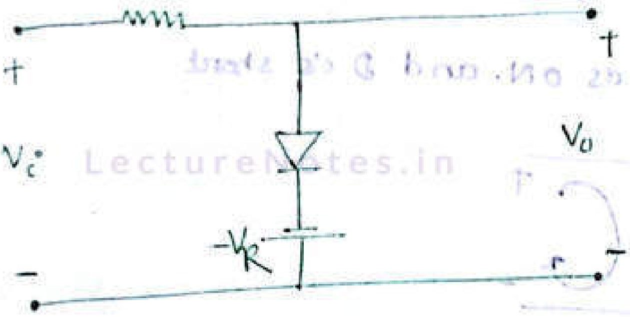
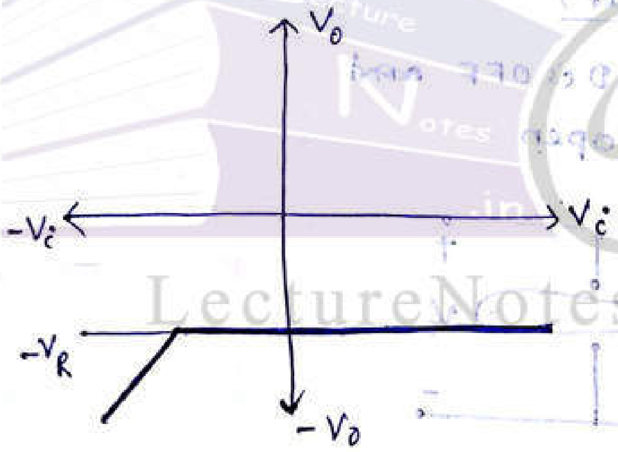
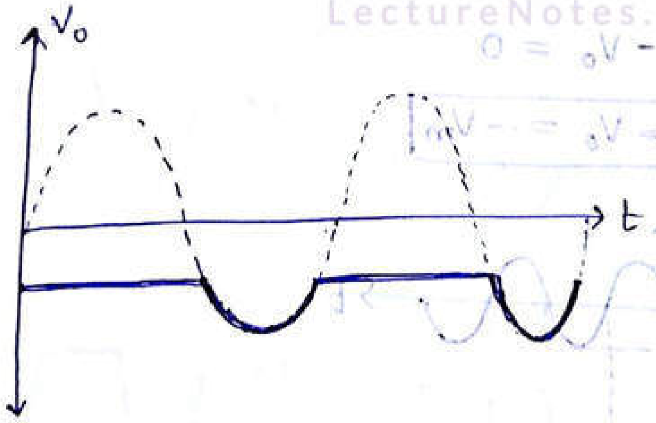


→ $V_i < -V_R$ D = OFF (R·B) $V_0 = V_i$

$V_i > -V_R$ D = ON (F·B) $V_0 = -V_R$





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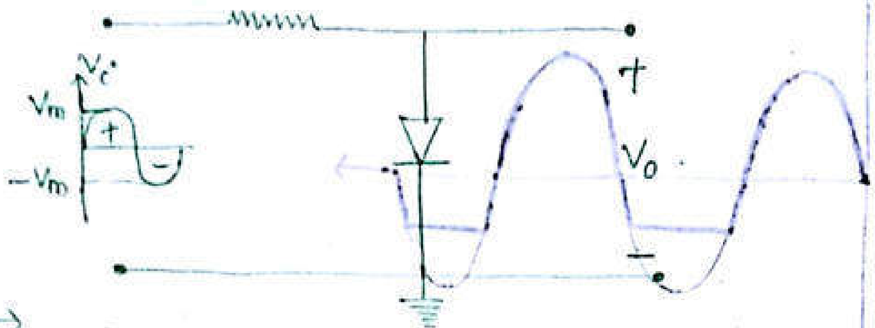
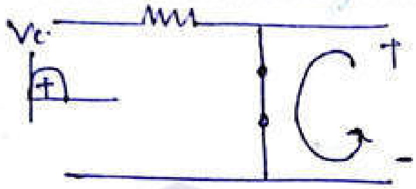


→ $V_i > 0$ (+ve half)

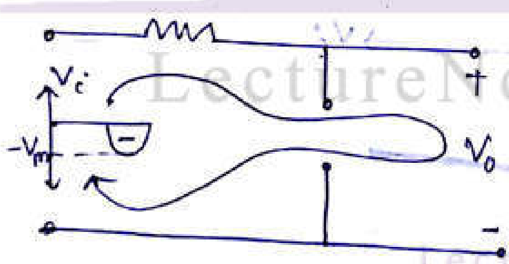
D is FB. So D is ON. and D is short.



$\boxed{V_0 = 0}$

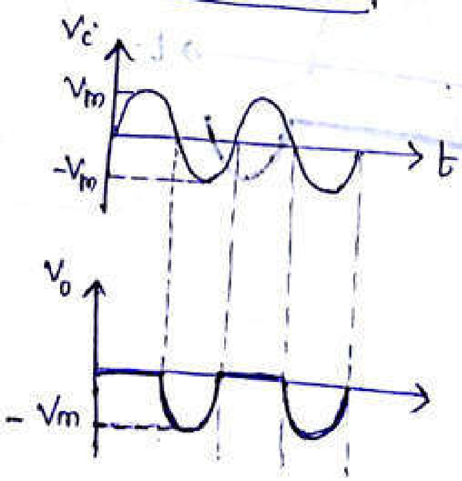
$V_i < 0$ (-ve half)

D is RB. So D is OFF and Hence D is open.



$V_i - V_0 = 0$

$\Rightarrow \boxed{V_i = V_0 = -V_m}$



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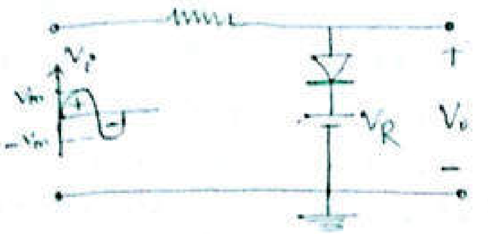
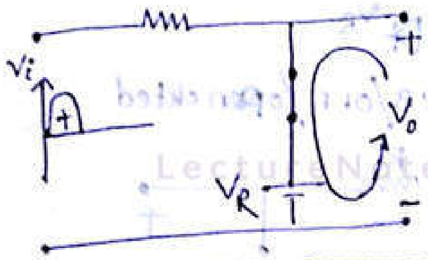


→ $V_i > V_R$

D is FB / D is ON / D is short ckted.

$V_i > V_R$ ▷| V_R

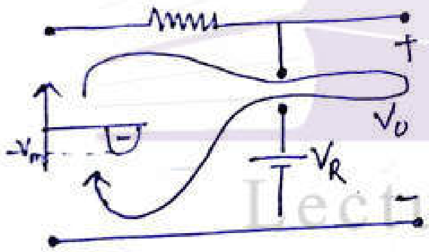


$V_0 - V_R = 0 \Rightarrow \boxed{V_0 = V_R}$

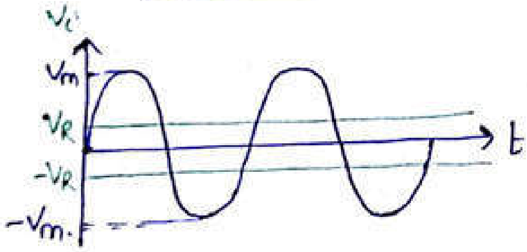
$V_i < V_R$

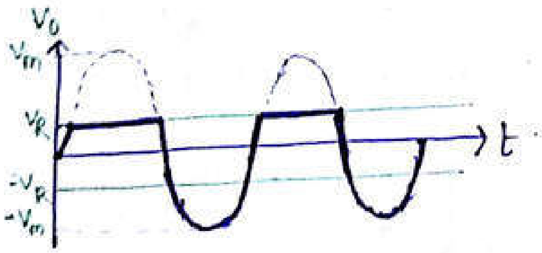
D is RB / D is OFF / D is open ckted

$V_i < V_R$ ▷| V_R

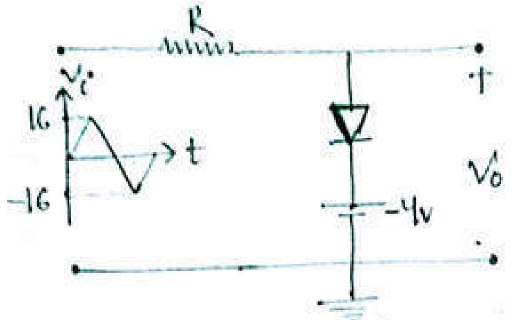


$\boxed{V_0 = V_i = -V_m}$





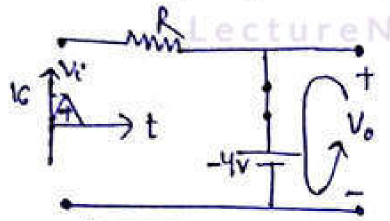
Q.



→ $V_i > V_R$

$V_i > V_R$ V_R

D is FB/ON/shortckted

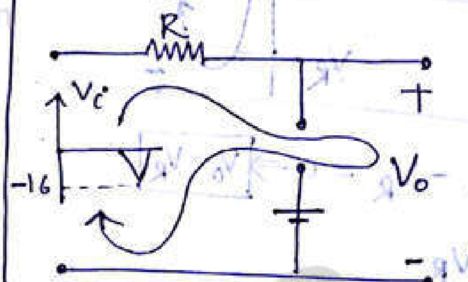


$\boxed{V_o = -4V}$

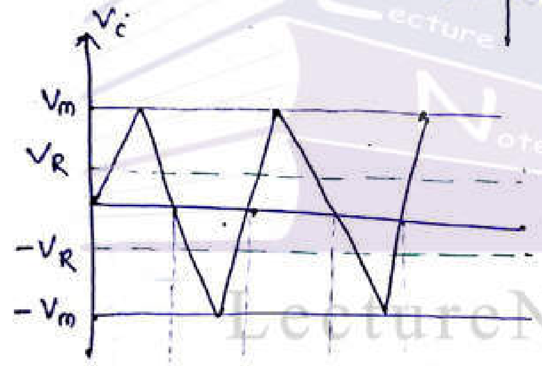
$V_i < V_R$

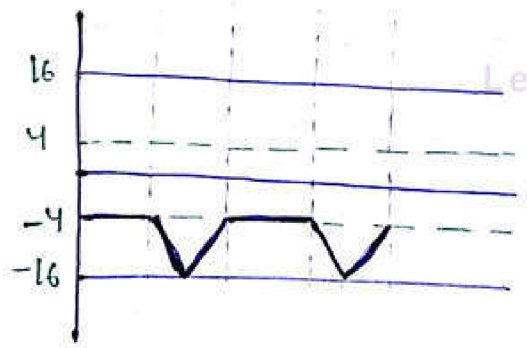
$V_i < V_R$ V_R

D is RB/OFF/openckted



$\boxed{V_o = -16}$





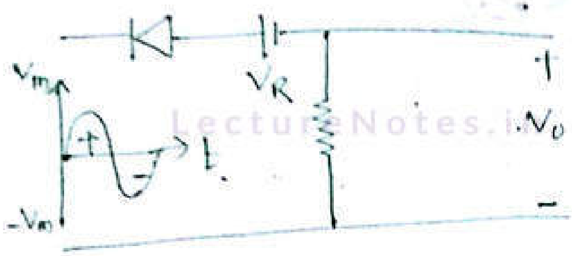
Shortcut Method

→ If anode of the diode is connected at the +ve of o/p either of it is series clipper or parallel clipper, +ve part or the above the reference level will be clipped OFF.

→ If anode is connected at the -ve of o/p either it is series clipper or parallel clipper, -ve part or the part above reference level will be clipped OFF.

Biased Series clipper :

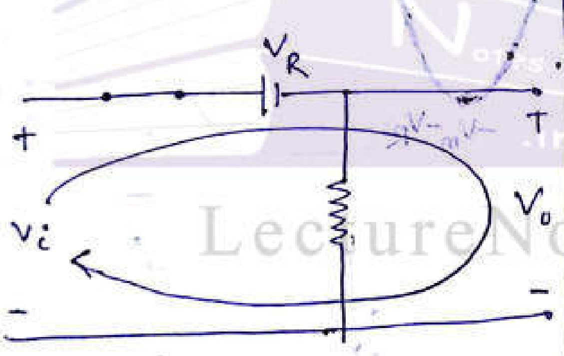
5.



→ $V_i < V_R$ $D = ON (F.B)$ $V_o = V_R$

$V_i > V_R$ $D = OFF (R.B)$ $V_o = 0$.

$V_i < V_R$



V_i	V_o
0	$-V_R$
V_R	0
V_m	$V_m - V_R$ (not considered)
$-V_m$	$-V_m - V_R$

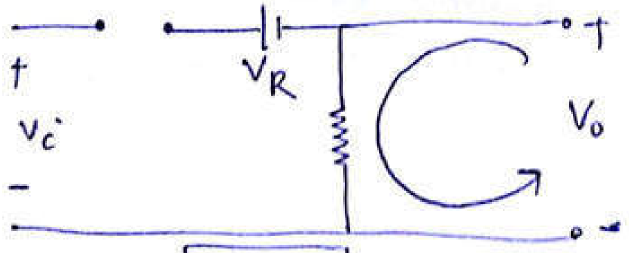
$V_i - V_R - V_o = 0$.

$\Rightarrow V_o = V_i - V_R$

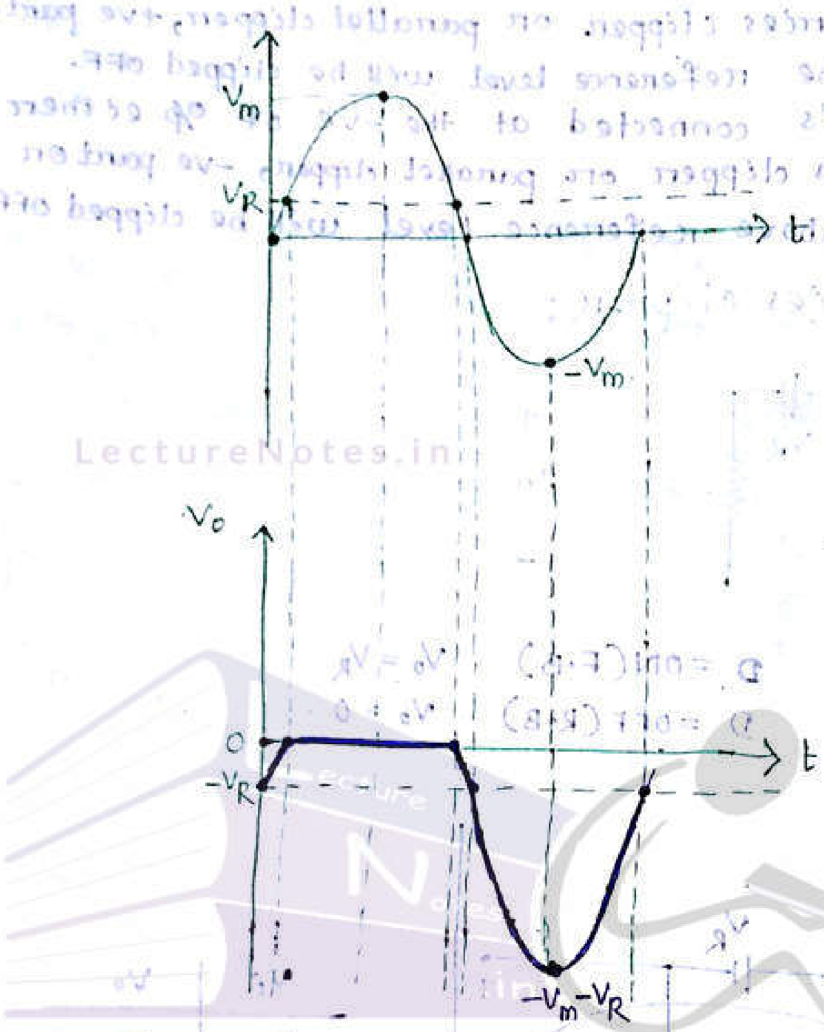
$\Rightarrow \boxed{V_o = -V_m - V_R}$.

$V_i > V_R$

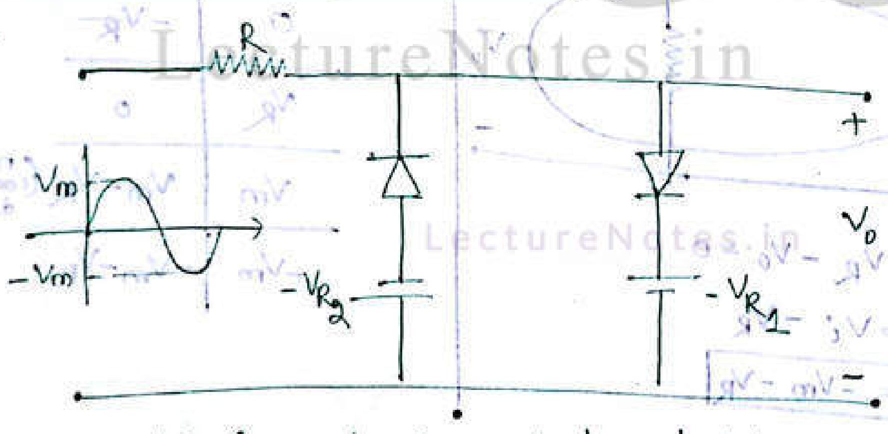
D is RB / OFF / open



$\boxed{V_o = 0}$



Q.



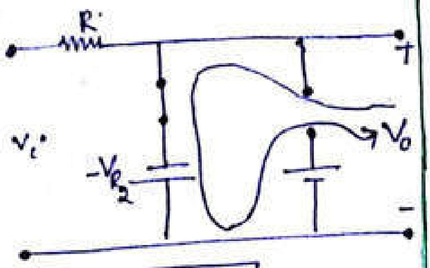
clipping at two independent level

DR. R.R TRIPATHI, ECED, SIET PRAYAGRAJ, EMAIL ID: ramracksha@gmail.com

→ $V_i < -V_{R_2}$

D_2 (F·B)/ON/short

D_1 (R·B)/OFF/open

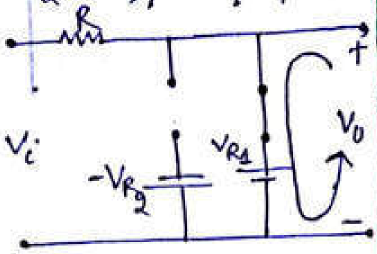


$\boxed{V_0 = -V_{R_2}}$

$V_i > V_{R_1}$

D_1 (F B)/ON/short

D_2 (R B)/OFF/open

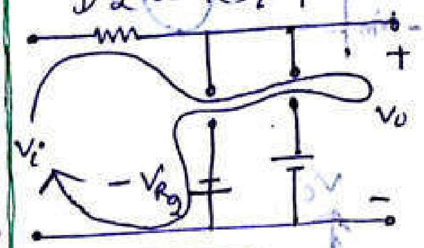


$\boxed{V_0 = V_{R_1}}$

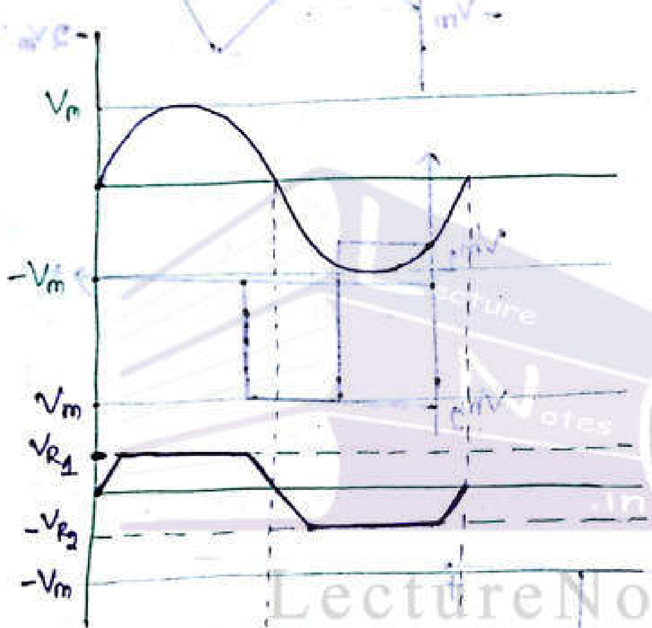
$-V_{R_2} < V_i < V_{R_1}$

D_1 is R·B/open

D_2 is RB/open



$\boxed{V_i = V_0}$



clamper:

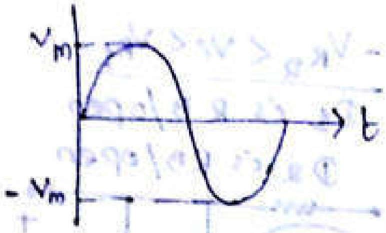
→ A clamper is an electronic ckt which clamps or fixes the extremities of the i/p signal to a new reference level

→ By passing through the clamping ckt the original shape of the i/p signal does not change.

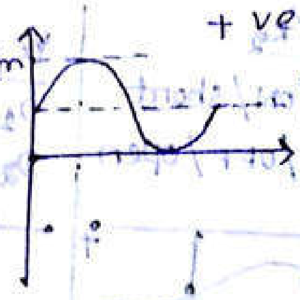
→ clamper are of two types.

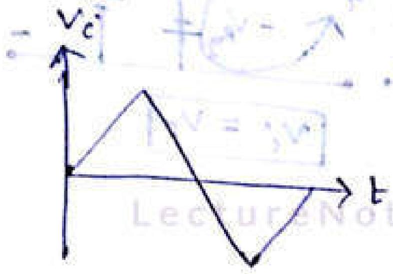
(i) +ve clamper

(ii) −Ve clamper

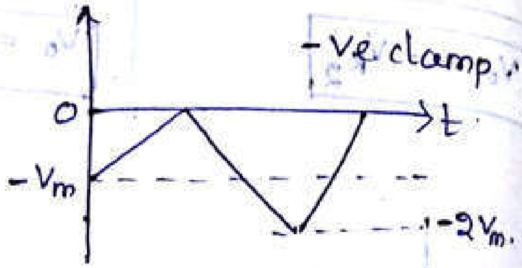


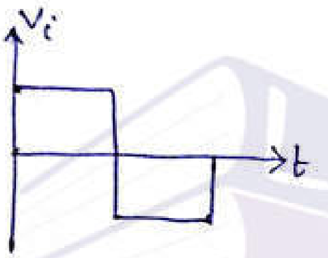
+ ve clamper.

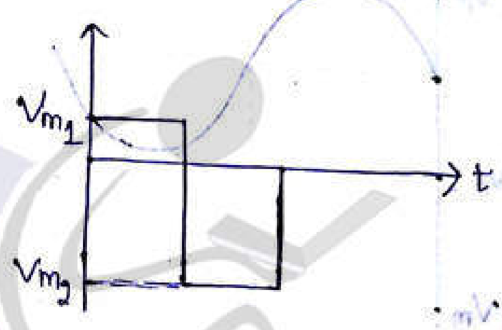




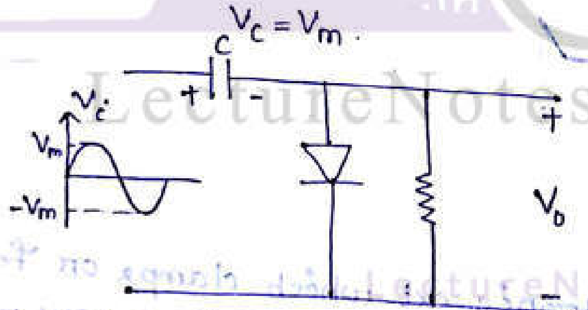
-ve clamp.





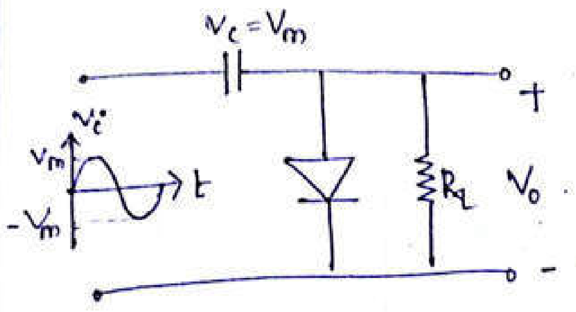


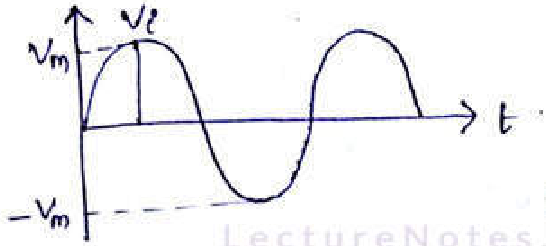
clamper -



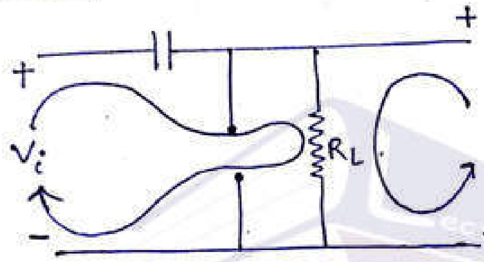
→ During the +ve quater cycle of i/p signal, the capacitor charges to a maximum value V_m with left plate +ve and right plate is -ve. In this period diode is forward biased.

→ As the charging time for capacitor is very less than discharging time through load; in the and quater cycle of the +ve i/p, the capacitor discharges to a negligible value and remains at V_m.





$V_i > 0$



1st: $V_i - V_c - IR_L = 0$

$\Rightarrow V_i - V_c = IR_L$

2nd: $V_o - IR_L = 0$

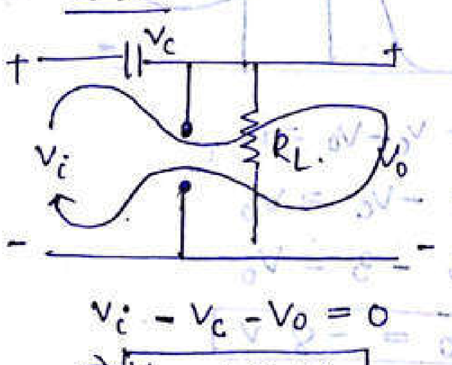
$\Rightarrow V_o = IR_L$

From 1st and 2nd.

$V_i - V_c = V_o$.

or

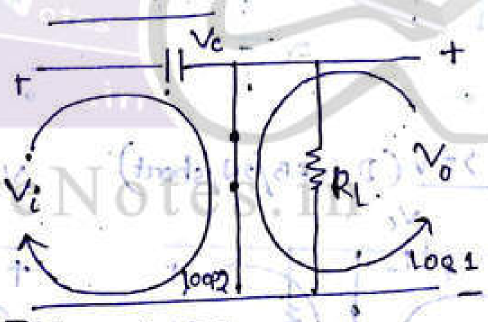
$V_i > 0$



$V_i - V_c - V_o = 0$

$\Rightarrow \boxed{V_o = V_i - V_c}$

$V_i < 0$



From Loop 1

$\boxed{V_o = 0}$.

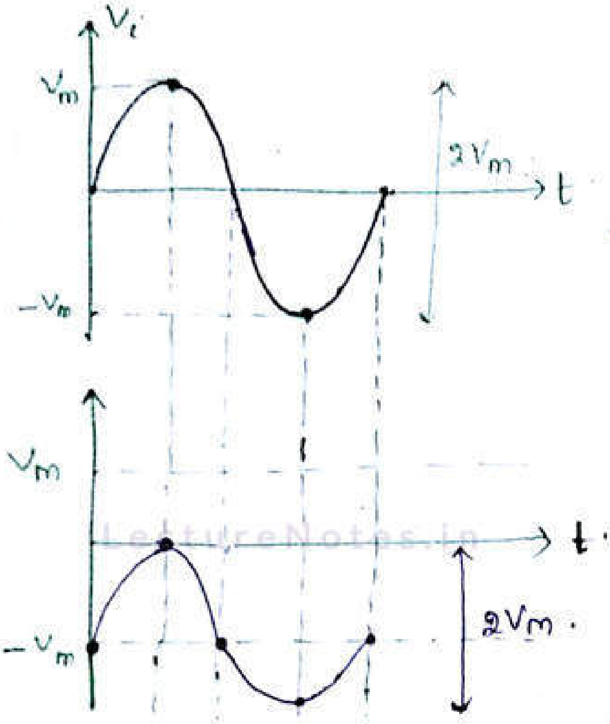
From Loop2

$V_i - V_c = 0$

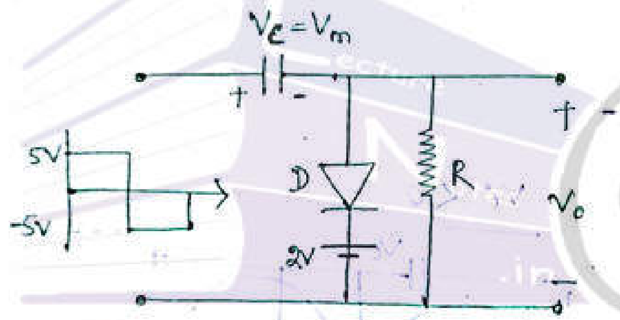
$\Rightarrow V_i - V_c = V_o \; (\because V_o = 0)$

$\Rightarrow V_i - V_m = V_o$.

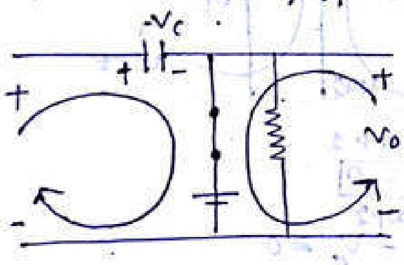
V_i	V_o
0	$-V_m$
V_m	0
$-V_m$	$-2V_m$



Q.



→ $v_i > 2V$ (D is FB/ON/short)

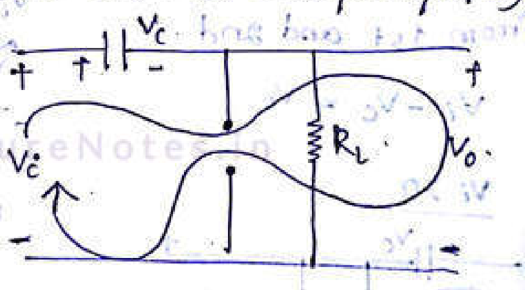


$v_i - V_c - 2 = 0$

$\Rightarrow 5 - 2 = V_c$

$\Rightarrow \boxed{V_c = 3V}$

$v_i < 2V$ (D is RB/OFF/open)

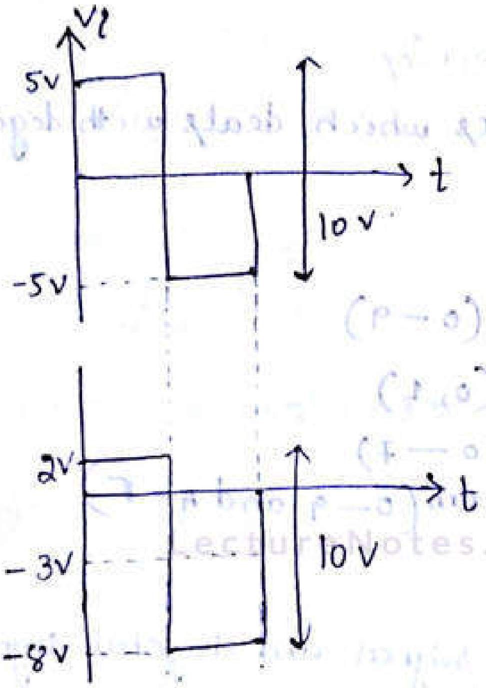


$V_i - V_c - V_0 = 0$

$\Rightarrow V_i - V_c = V_0$

$\Rightarrow -5 - 3 = V_0$

$\Rightarrow \boxed{V_0 = -8 V}$

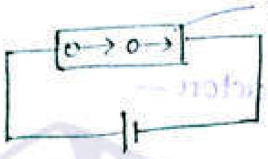

Vi
5v
t
10v
-5v
2v
t
-3v
10v
-8v

Physics of Semiconductor devices:

concept of Diffusion and drift :-

→ The process of movement of charge carriers due to the concentration gradient is called diffusion and the flow of current due to diffusion is called as diffusion current.

→ The process of movement of charge carriers due to application of electric field is called drift and the current flow due to drift is called drift current. The velocity due to drift is called drift velocity.



$V_d \propto E$

$\Rightarrow V_d = \mu E$

$\Rightarrow V_d = \mu_n E$

$\Rightarrow V_d = \mu_p E$

$V_d \rightarrow$ drift velocity

$E \rightarrow$ electric field.

$\mu \rightarrow$ mobility

$\mu_n \rightarrow$ mobility of e^-

$\mu_p \rightarrow$ mobility of holes.

Mobility:

The ability of movement of charge carriers (e^-s and holes) is called mobility.

$$\boxed{\mu = \frac{V_D}{E}}$$

Unit of mobility $= \frac{m/s}{V/m} = m/s \times m/V = m^2/V\text{-}s$.

Conductivity (σ):

→ The ability of conduction of charge carrier is called conductivity.

→ conductivity is the reciprocal of resistivity.

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

→ conductivity is the multiplication of concentration, charge and mobility :

$\boxed{\sigma_p = \mu q p}$ or $\boxed{\sigma_p = \mu e p}$

$\boxed{\sigma_n = \mu q n}$ or $\boxed{\sigma_n = \mu e p}$

$p \rightarrow$ concentration of hole

$n \rightarrow$ concentration of e^-

$\sigma_p = \mu_p e p$ —— (1)

$\sigma_n = \mu_n e n$ —— (2)

$\sigma = \sigma_p + \sigma_n$

$= \mu_p e p + \mu_n e n$

$\Rightarrow \boxed{\sigma = e(\mu_p p + \mu_n n)}$

In case of intrinsic semiconductor —

$\boxed{n = p = n_i}$

n_i = intrinsic concentration

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

$\boxed{\sigma = e n_i (\mu_p + \mu_n)}$ → conductivity of an intrinsic semiconductor.

Some Important terms related to semiconductor physics:

$n \rightarrow$ electron concentration

$p \rightarrow$ hole concentration

$n_i \rightarrow$ intrinsic carrier concentration

$\sigma_n \rightarrow$ conductivity of e^-

$\sigma_p \rightarrow$ conductivity of holes

$e = q \rightarrow$ electronic charge.

$\mu_n \rightarrow$ mobility of e^-s

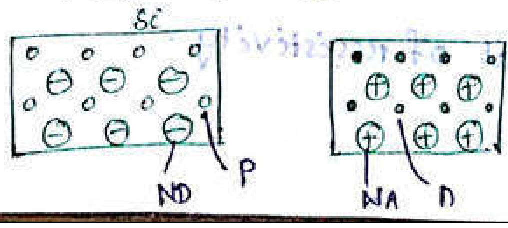
$\mu_p \rightarrow$ mobility of holes.

$N_A \rightarrow$ Acceptor ion concentration

$N_D \rightarrow$ Donor ion concentration

Law of neutrality :

$n + N_A = p + N_D$.



Note :

For an intrinsic semiconductor

$n = p = n_i$

$\boxed{n \times p = n_i^2}$ (mass action law)

Mass Action law:

The product of electron concentration and hole concentration is constant at thermal equilibrium. This is called Mass Action law

N-type:

$N_D = 0$

$n >> p$

P-type:

$N_A = 0$

$p >> n$

$n + N_A = p + \cancel{N_D}^{0}$; $n + \cancel{N_A}^{0} = p + N_D$

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

N-type:

$n + N_A = p$

$\Rightarrow n_i + N_A = n_i \; (\because n = p = n_i)$

$\Rightarrow N_A = 0$

$n + N_A = p + N_D$

$\Rightarrow n + 0 = \cancel{p}^{0} + N_D \; (\because n >>> p)$

$\Rightarrow \boxed{n = N_D}$

P-type:

$p + N_D = n$

$\Rightarrow n_i + N_D = n_i \; (\because n = p = n_i)$

$\Rightarrow N_D = 0$

$n + N_A = p + N_D$

$\Rightarrow \cancel{n}^{0} + N_A = p + 0 \; (\because p >>> n)$

$\Rightarrow \boxed{p = N_A}$

* $n \times p = n_i^2$

$\Rightarrow n \times N_A = n_i^2 \; (\because p = N_A)$

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

* $n \times p = n_i^2$

$\Rightarrow N_D \times p = n_i^2 \; (\because n = N_D)$

$\Rightarrow \boxed{p = \frac{n_i^2}{N_D}}$

According to the law of neutrality the total concentration of e^- and charge carriers in N-side must be equal to total concentration of hole and the total charge carriers in the p-side.

Current density :

→ current density can be calculated due to the diffusion of holes and due to the diffusion of e^-s and can be represented with J_p and J_n respectively.

→ current density for e^- = the multiplication of charge. diffusion constant for e^- and concentration gradient for e^-

$$\boxed{J_n = q \times D_n \times \frac{dn}{dx}}$$

D_n = Diffusion constant for e^-

$\frac{dn}{dx}$ = concentration gradient for e^-

→ The current density for hole is the production of -ve of charge, concentration gradient of hole and diffusion constant for hole.

$$\boxed{J_p = -q \times D_p \times \frac{dp}{dx}}$$

D_p = diffusion constant for hole.

$\frac{dp}{dx}$ = concentration gradient for hole.

→ As the mobility and diffusion are statistical phenomena it is not surprising that they obey Einstein relation

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

D_n = diffusion constant for e^-

D_p = diffusion constant for hole.

μ_n = mobility of ~~ho~~ e^-

μ_p = mobility of hole.

K = Boltzman constant

T = Temperature

q = charge