BASIC ELECTRONICS

UNIT 1.

Introduction of Semiconductor Material

Conductor : The term conductor is applied to any material, that will support a generous flow of charge. When a voltage source is applied to its terminal.

Example: copper ($\rho = 10^{-6}\Omega$-cm)

Insulator: It offers very low level (negligible) conductivity when voltage is applied.

Example: Mica ($\rho = 10^{12}\Omega$-cm → Resistivity)

Semiconductor : The conductivity of this material somewhere lie between the extremes of an insulator or conductor.

Example: Si, Ge

Si → ($\rho = 50 \times 10^{3}\Omega$-cm)

Ge → ($\rho = 50\Omega$-cm)

Classes of Semiconductor:

Semiconductor material falls into one of two classes.

1) Single crystal SC 2) Compound crystal SC.

1) Single crystal semiconductor: These type of semiconductors have repetitive crystal structure.

Example :- Silicon (Si) and germanium (Ge)

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Covalent Bond in semiconductors:-

In Covalent bond, bonding is done by sharing electrons.
In a pure Si or Ge crystal the four valance electron of one atom form bonding arrangement with four adjoining atoms.

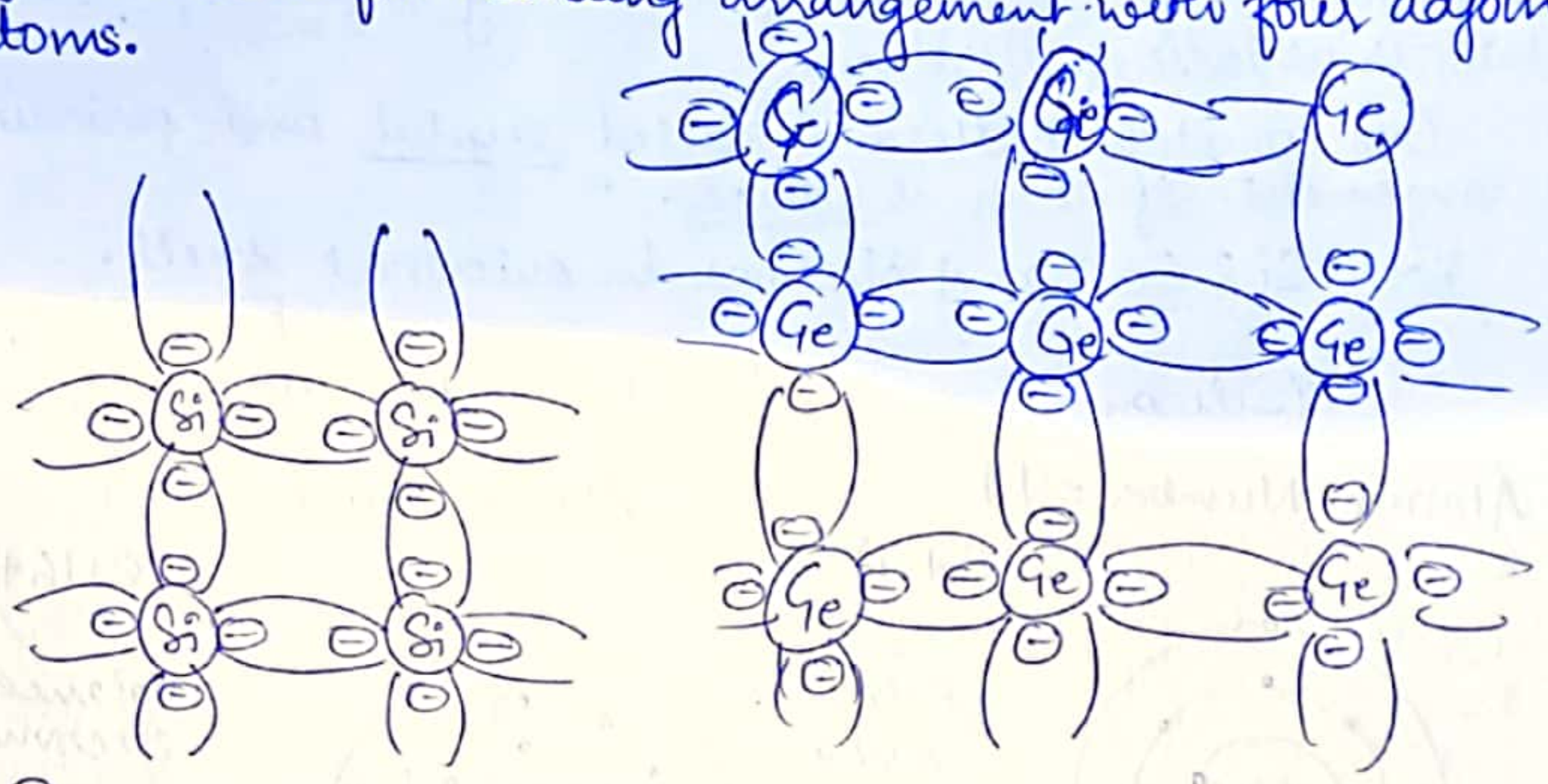

fig: Covalent Bonding of Si Atom & Ge Atom.

Because GaAs is compound semiconductor, their is sharing between two different atoms. Each atom Ga or Arsenic is surrounded by atom of complementary type Five electrons are provided by Arsenic and three by Ga atom.

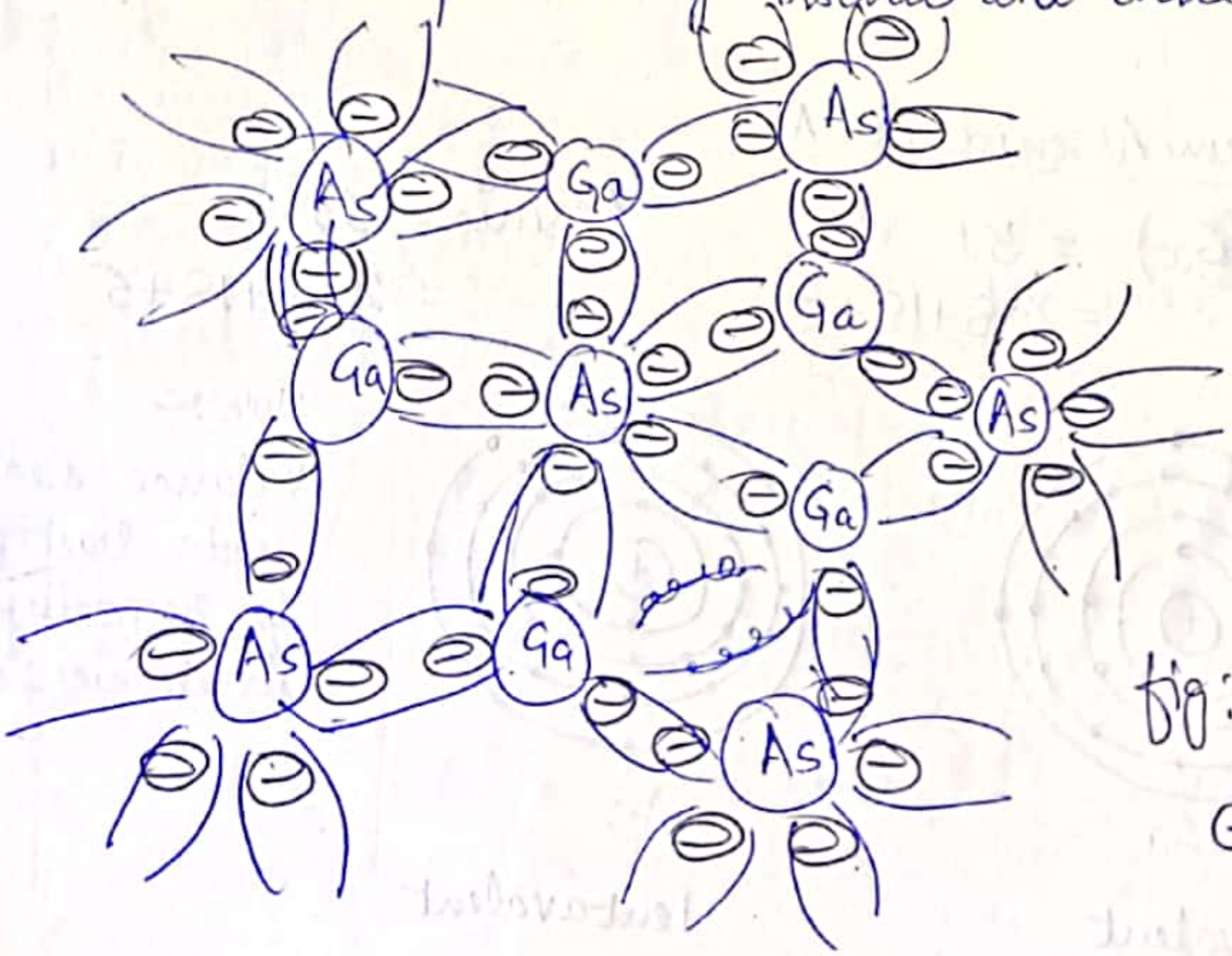

fig:- Covalent Bonding of GaAs crystal.

* Although the covalent bond will result in a stronger bond between valance electron and their parent atom. it is still possible for the ~~par~~ valance $\bar{e}$ to absorb kinetic energy and causes to break covalent bond.

* The term free is applied to any electron that has separated from free lattice structure. It is very sensitive to external electric field.

* Intrinsic semiconductor:-
Any SC material that has been carefully refined to reduce the number of impurities to a very low level. (as pure as can be made available through modern Technology).

* Intrinsic carrier:-
Free electron in material due only to external causes.
~~Unit:-~~

* Relative Mobility:-
The ability of free carrier to move throughout the material

Semiconductor	Intrinsic Carriers	Mobility Factor (μ_n)
Si	1.7×10^{6} (cm^{-3})	1500 cm^2/VS
Ge	1.5×10^{10} (cm^{-3})	3900 cm^2/VS
GaAs	2.5×10^{13} (cm^{-3})	8500 cm^2/VS

Energy levels:-

→ Only specific energy levels can exist for the electrons in atomic structure of an isolated atom.

→ The farther an $\bar{e}$ is from the nucleus, the higher is the energy state and any electron that has left its parents atom has higher energy state than any electron in atomic structure.

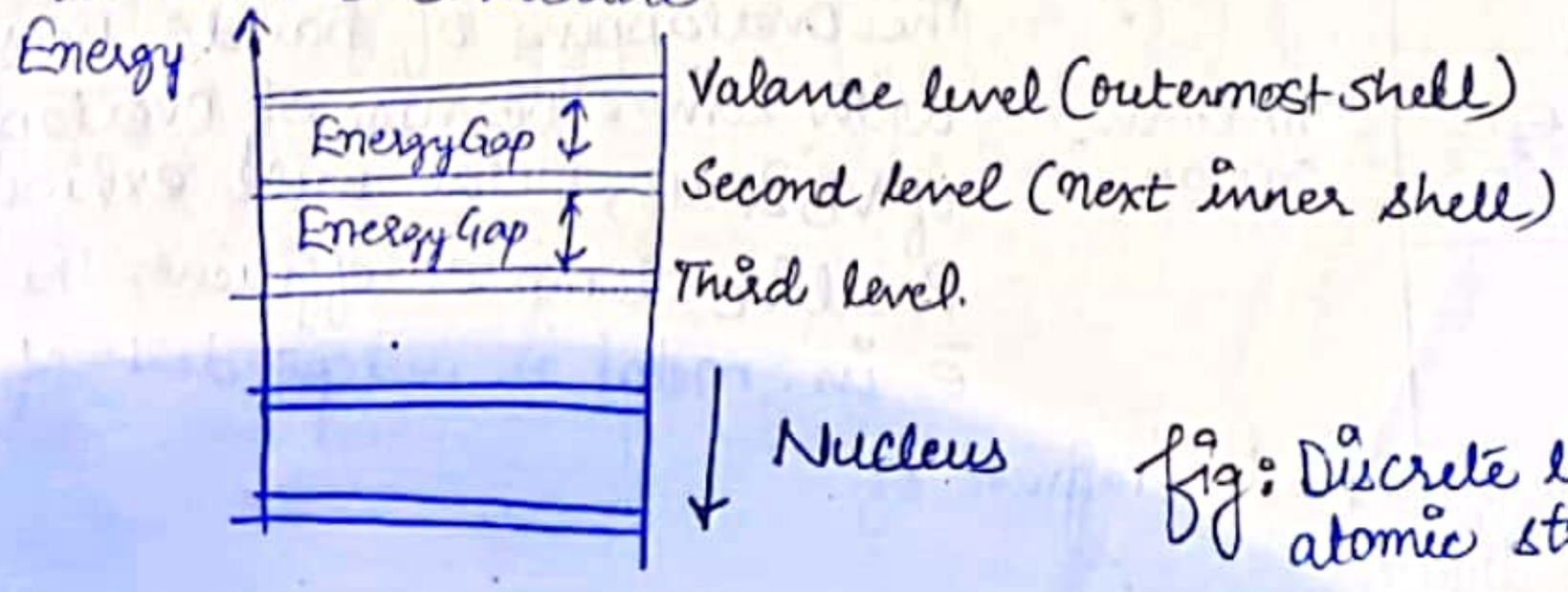

fig: Discrete levels of isolated atomic structure.

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Energy Band Gap or Forbidden Band :-

This is the area where carriers are not permitted.

~~In Metal~~. In Insulator :- $E_G \rightarrow$ large $\rightarrow$ 5ev to 15ev.

No electron can jump from Valance Band to Conduction Band. Hence CB is empty. Carrier Concentration in CB is zero. which results zero conductivity. Hence all insulators are bad conductor of current within normal working temperature.

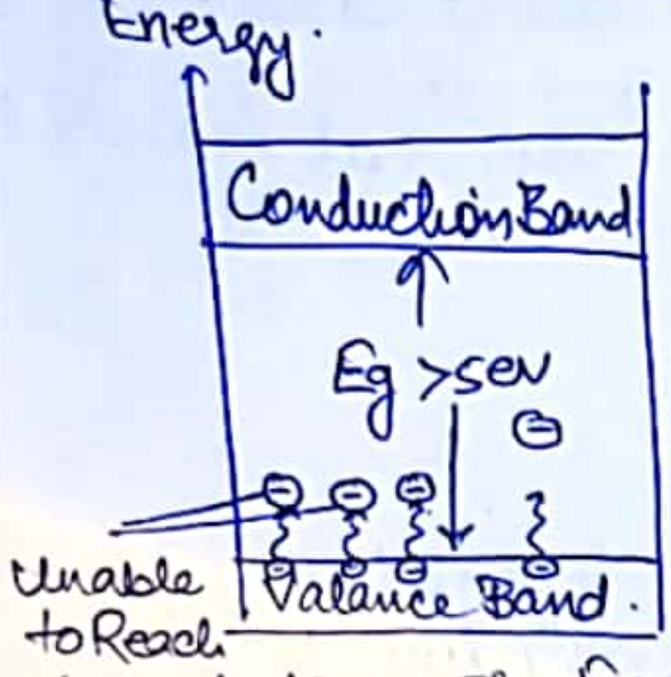

Fig: Energy Band diagram Insulator

In Semiconductor. $E_G \rightarrow$ Small $\rightarrow \simeq 1ev$.

$E_g = 0.67ev$ (Ge)
$E_g = 1.12ev$ (Si)
$E_g = 1.43ev$ (GaAs).

at $t = 0K = -273°C$,
Conduction band is Empty hence conductivity = 0. It behaves like insulator.

at $t = 300K = 27°C$ (Room Temp).
As shown in diagram that min energy level of associated with electron in CB and max energy level of Valance Band and b/w the two is energy gap.
($\bar{e}$ in VB must overcome the energy of free band)
(Negative temp Coefficient.

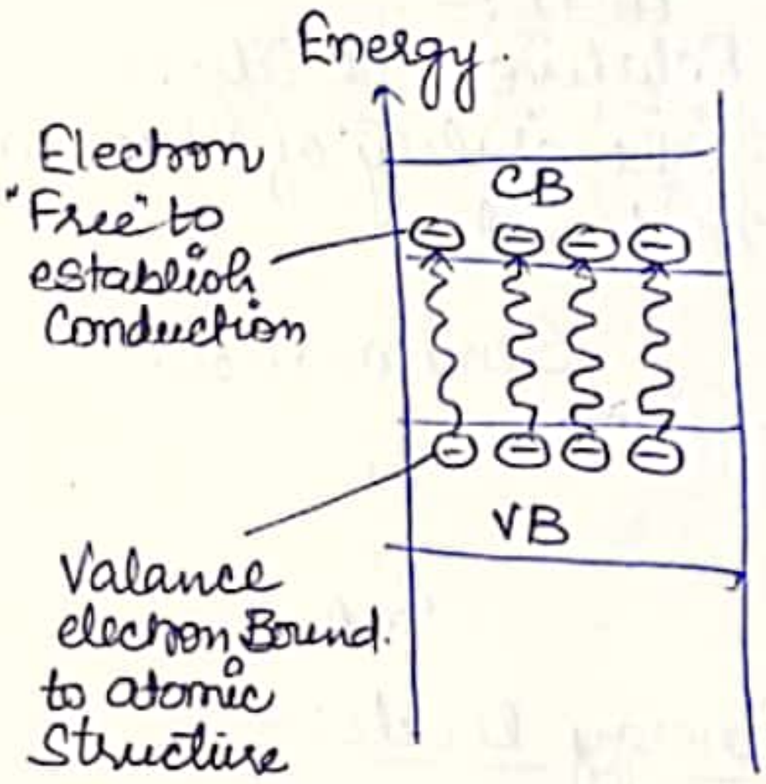

Fig: Energy Band diagram of ~~Insulator~~ Semiconductor

In Conductor:- (Metals)

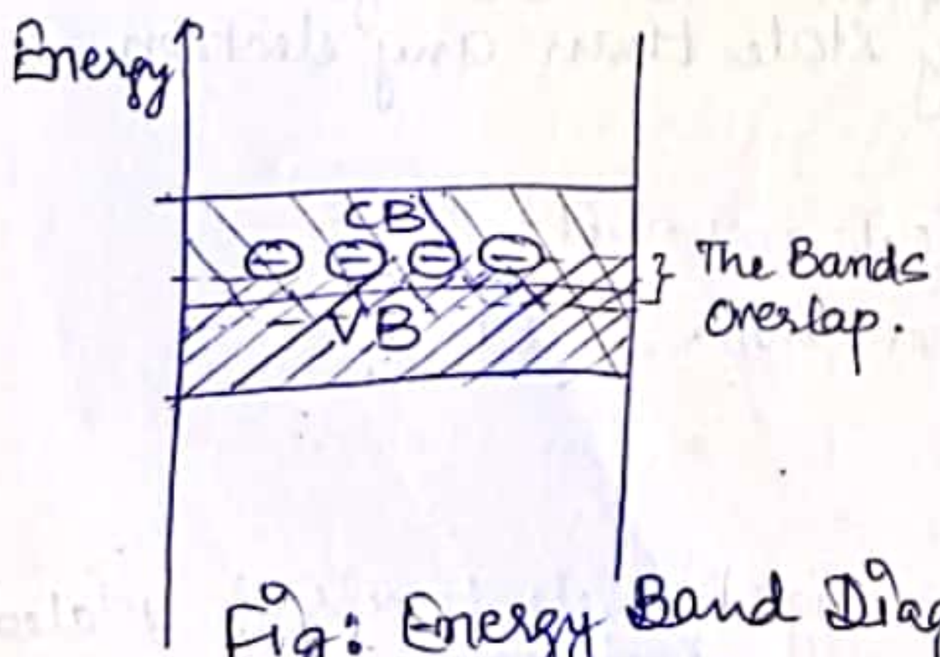

Fig: Energy Band Diagram of Conductor.

Free electrons are always available in conductor even at 0K.
The overlapping of Bands increases with temp. Because of overlapping of VB & CB, Metal will exhibits Positive temp co-efficient. The free $\bar{e}$ in metal is independent of Temp.

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Extrinsic Material:-

The characteristic of any SC material can be altered by adding specific amount of impurity atoms to relatively pure SC Material. These impurities, although added only at 1 part in 10 million, can alter the band structure sufficiently.

There are two types of extrinsic SCs:

1) n-type 2) p-type.

n-type semiconductor or Donor

n-type material is formed by adding predetermined number of impurity atom that have five valance electrons (Pentavalent) to a silicon base. Such pentavalent impurities are: eg. Antimony, arsenic, phosphorus. These are group 5 elements

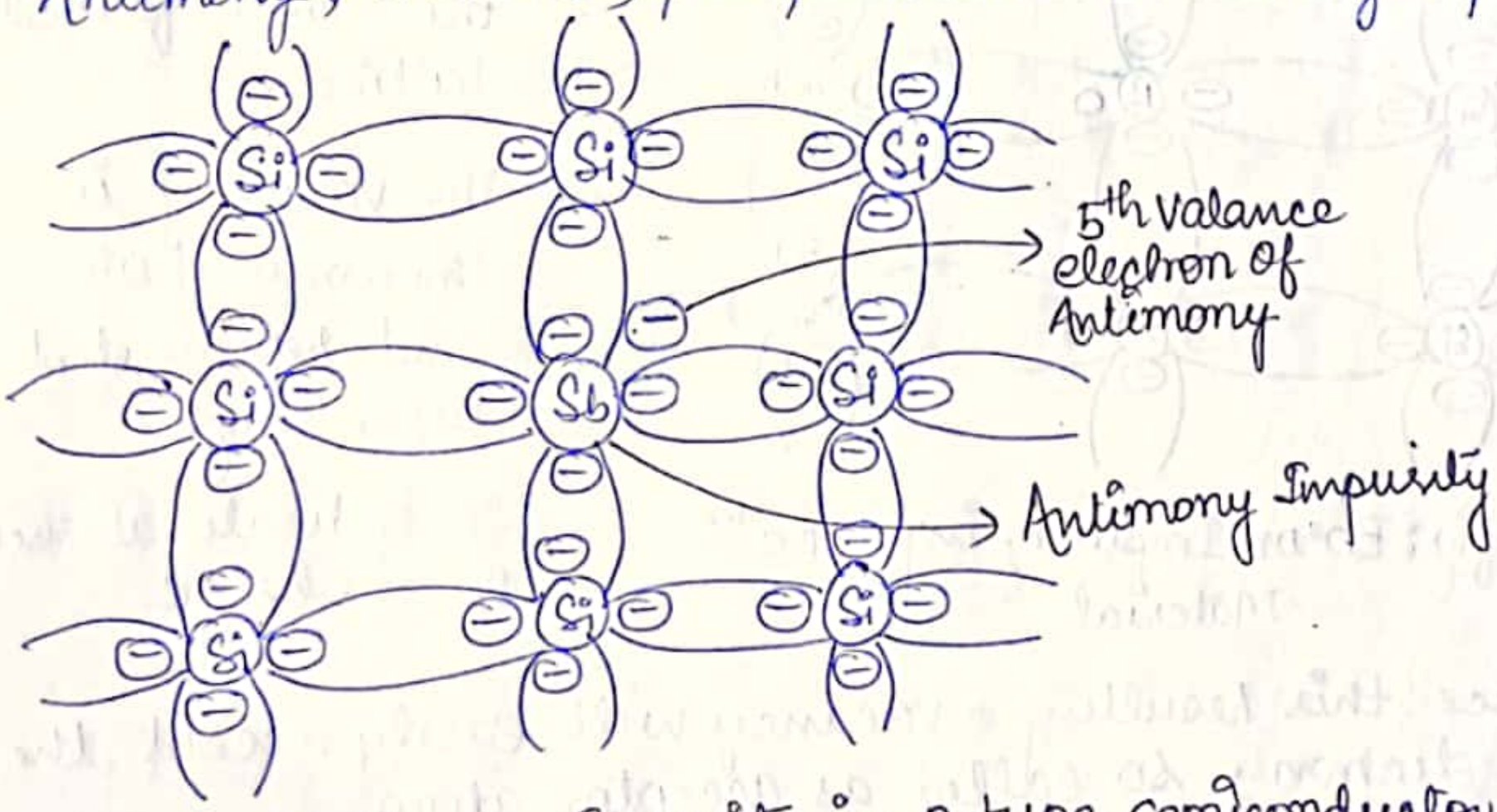

fig: Antimony Impurity in n-type semiconductor.

In n-type SC, four covalent bonds are present with additional fifth electron due to impurity. which is unassociated with any covalent bond. This electron is free to move.

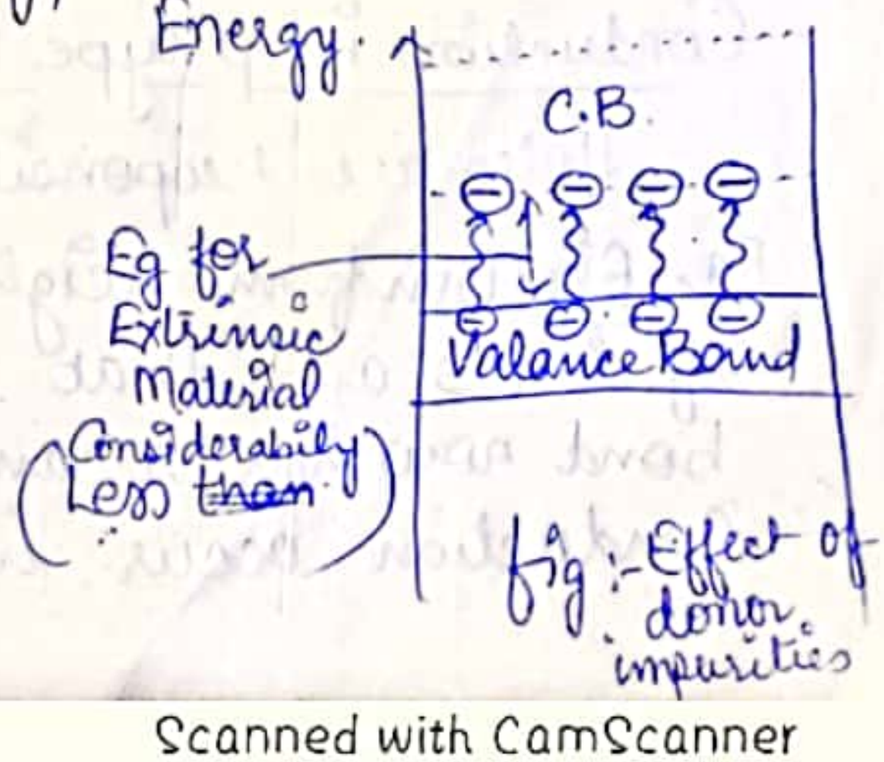

fig:- Effect of donor impurities

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This free electron is diffused impurity with five valance electrons are called <u>donor atom.</u>

Due to doping the energy band gap Eg appears significantly less than that of the ~~extrinsic~~ intrinsic material

Free electron due to added impurity sit at this energy level and have less difficulty absorbed by conduction band. There are large number of carriers in conduction level hence conductivity of material increases significantly.

P-type Material :-

The p-type material is formed by doping a pure Germanium or Si crystal with impurity atom having three valance electron. Materials are, Boron, Gallium, Indium. These elements are Group III element

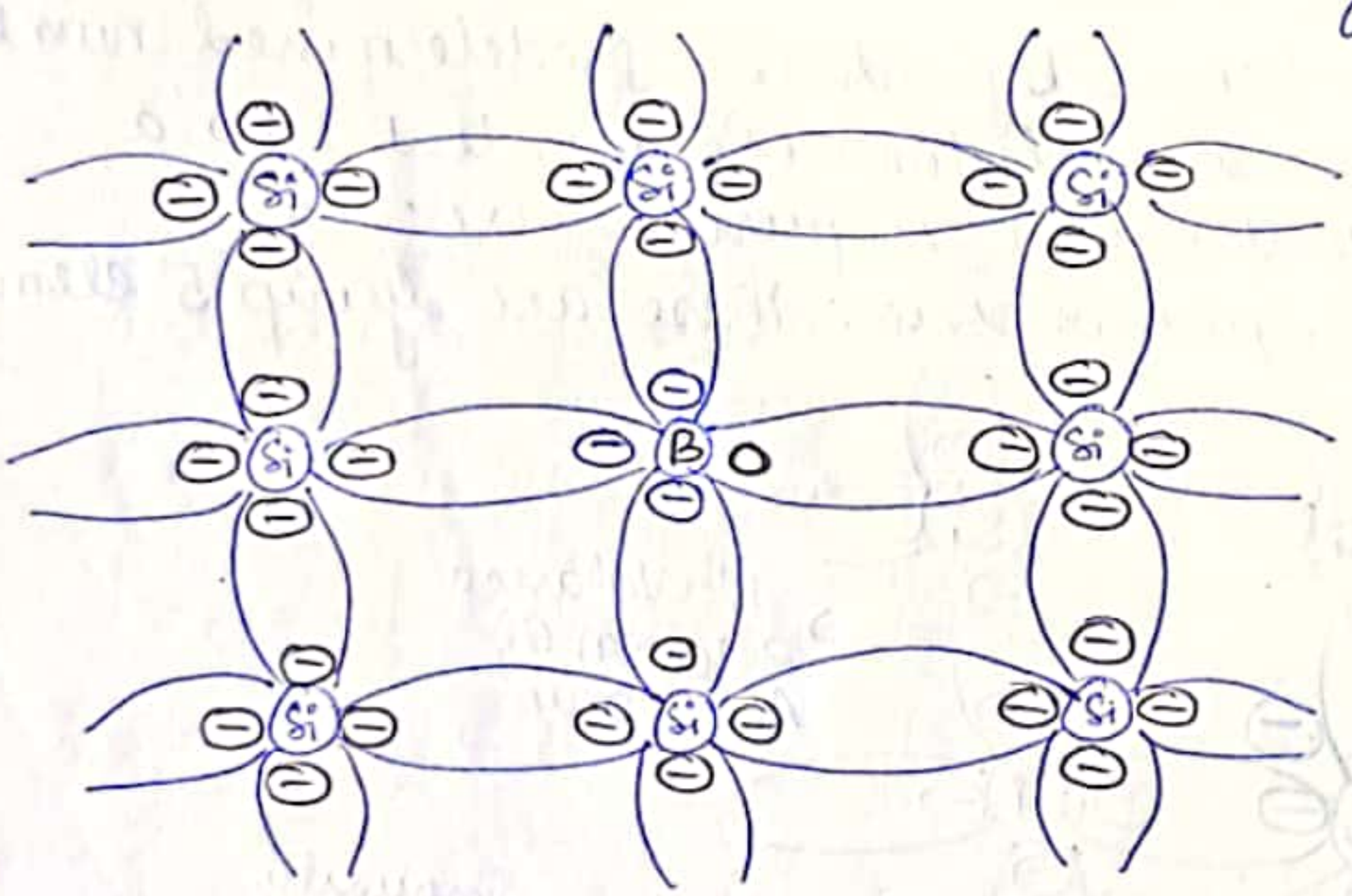

fig: Boron Impurity in p-type Material

Now there is an sufficient number of electrons to complete the newly formed lattice.

The vacancy is known as hole and represented by 'O' sign.

It indicate absence of '−' charge.

Since this resulting vacancy will easily accept the free electron, so called as <u>acceptor atom.</u>

Conduction in p-type Material :-

Holes are responsible for the conduction of Material by holes and that atom which break covalent bond now has vacancy called as hole. This way Conduction occur in this.

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Majority carriers :-

The more abundant charge carriers which are primarily responsible for ~~co~~ current transport in semiconductor material is called as majority carrier.

Example :- In n-type material → electrons
In p-type material → holes.

Minority carriers :-

The less abundant charge carrier is called minority carrier

Example :- In n-type → holes
In p-type → electron.

Note :- In an intrinsic SC, which does not contain any impurity the conc^n of both ~~materials~~ carriers are equal.

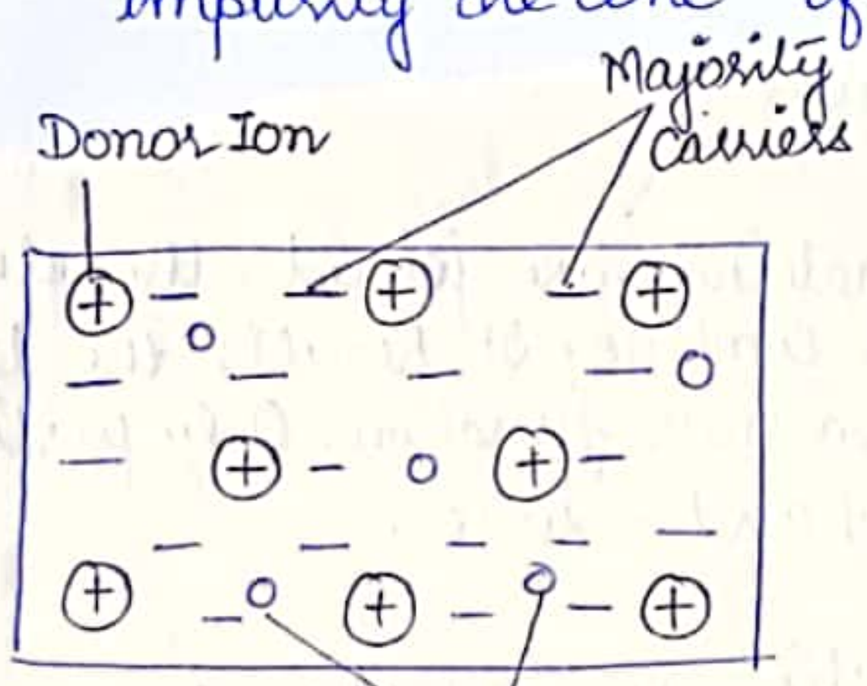


fig: n-type

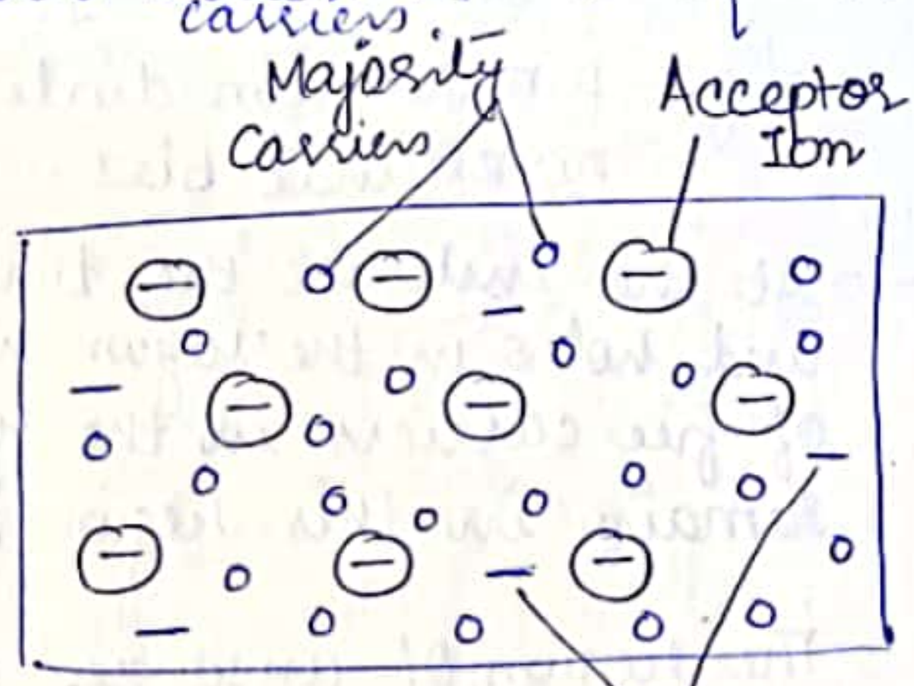
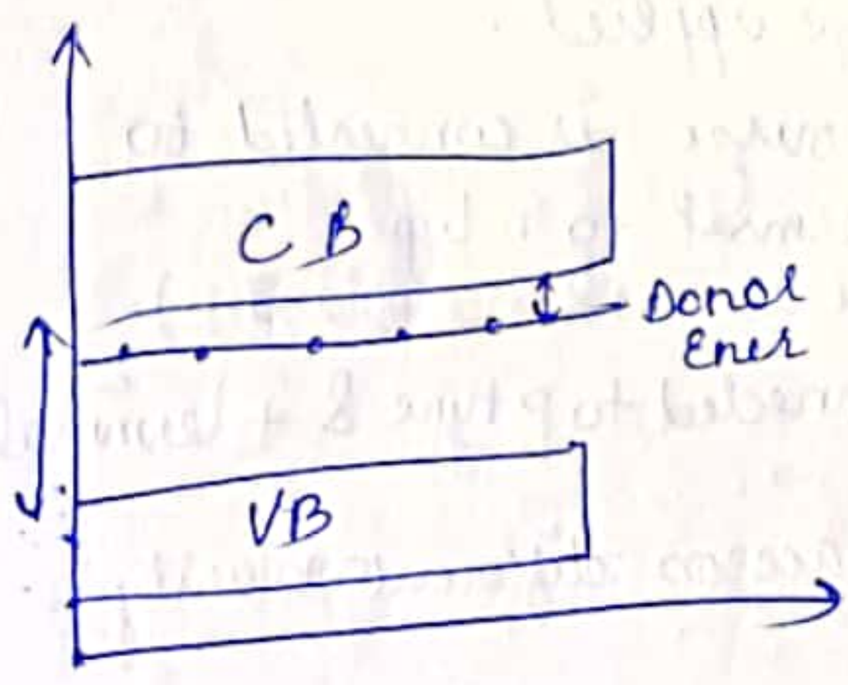
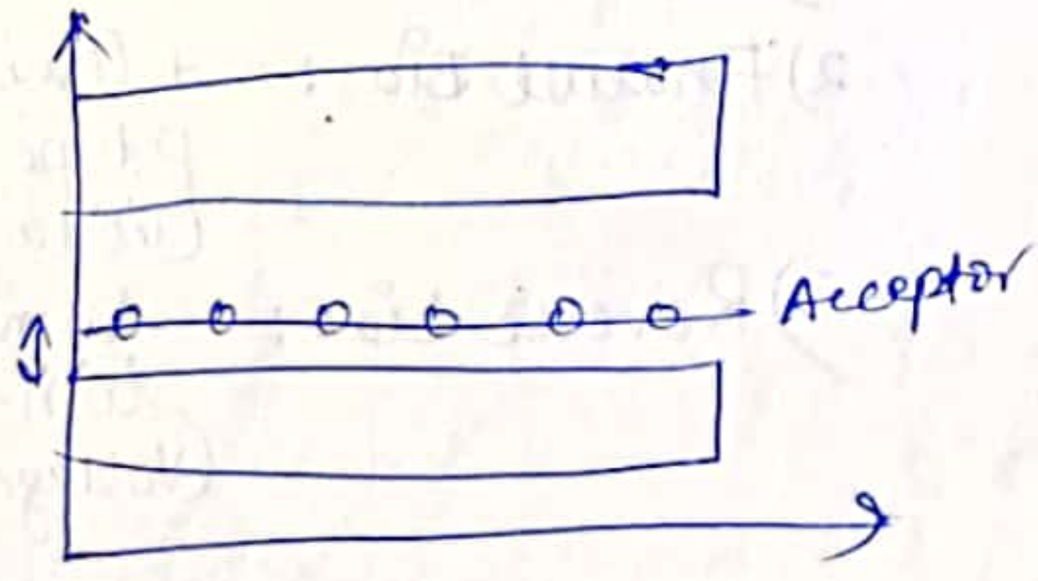


fig: p-type



n-



p-

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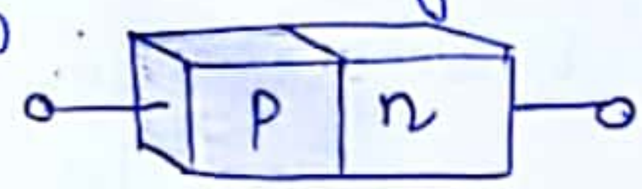
Depletion Layer Formation in p-n Junction diode:-

P-n Junction is most fundamental and the simplest electronic device. It has a characteristic of passing current in one direction only. P-n Junction diode is made by simply joining n-type & p-type materials.



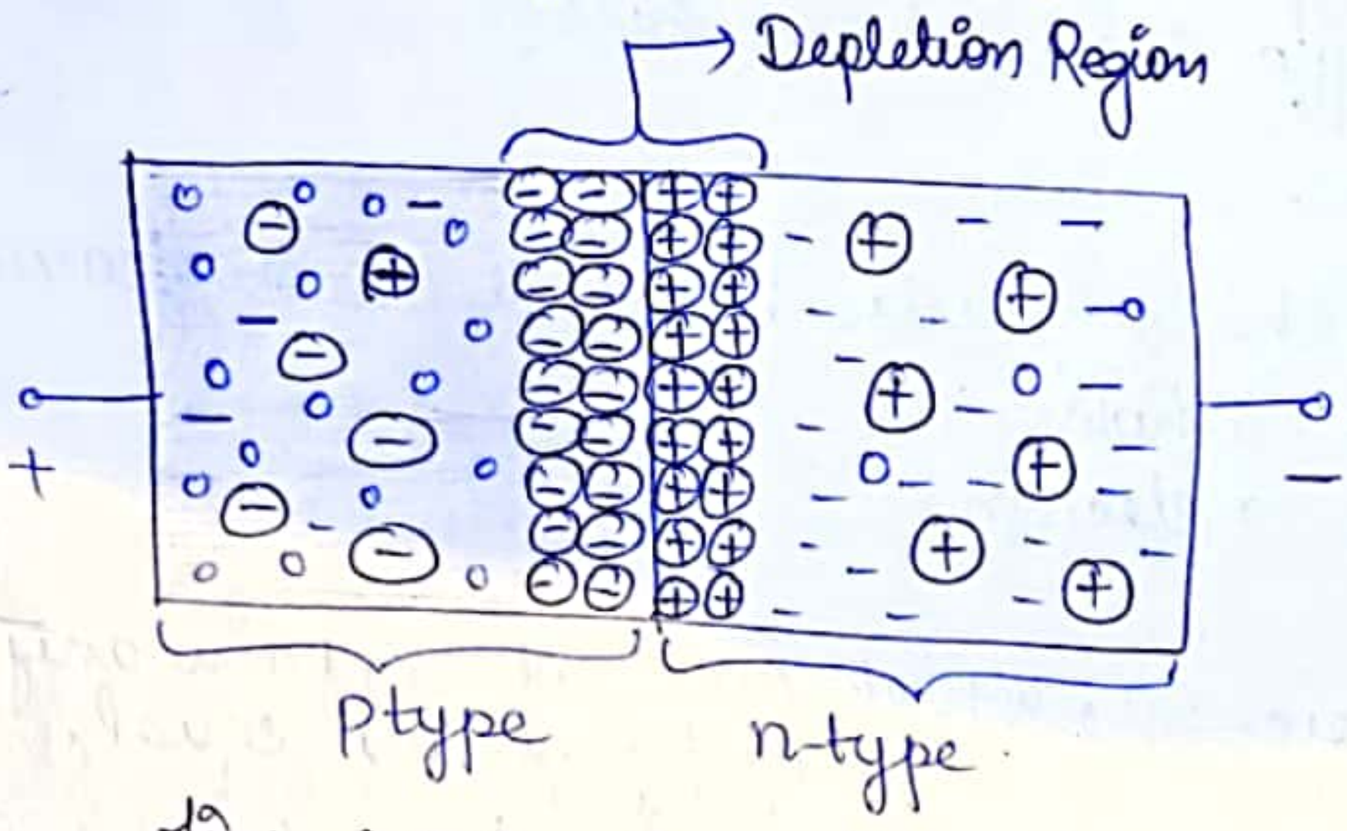


fig:- p-n Junction diode with no external bias.

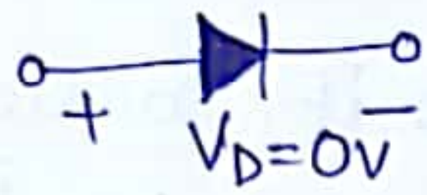


fig: Symbol of diode

→ It is a two terminal device

→ At the instance the two materials are joined, the electron and holes in the region will combine. It results the lacking of free carriers in the region near junction. Only particals remain in this region is + and − ions.

The region of uncovered positive and negative ion is called as depletion region, due to the depletion of free carriers in this region.

Bias:- Application of External Voltage between two terminals

The Three bias are available

1) No bias:- No external voltage applied.
2) Forward Bias:- + terminal of source is connected to p-type and − terminal to n type (Voltage applied accross same polarity)
3) Reverse bias:- − terminal is connected to p-type & + terminal to n-type. (Voltage applied accross different polarity).

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The majority carriers ($\bar{e}$) of n-type overcome the attraction force of ⊕ ion and negative ion in depletion region at p-type migrate those $\bar{e}$ to p-type material. which causes majority carrier flow of n-type

Minority carrier of this side passes the kinetic energy to pass through the depletion region and causes minority carrier flow of n-type.

Same type of carrier flow is applied to p-type as shown in fig:

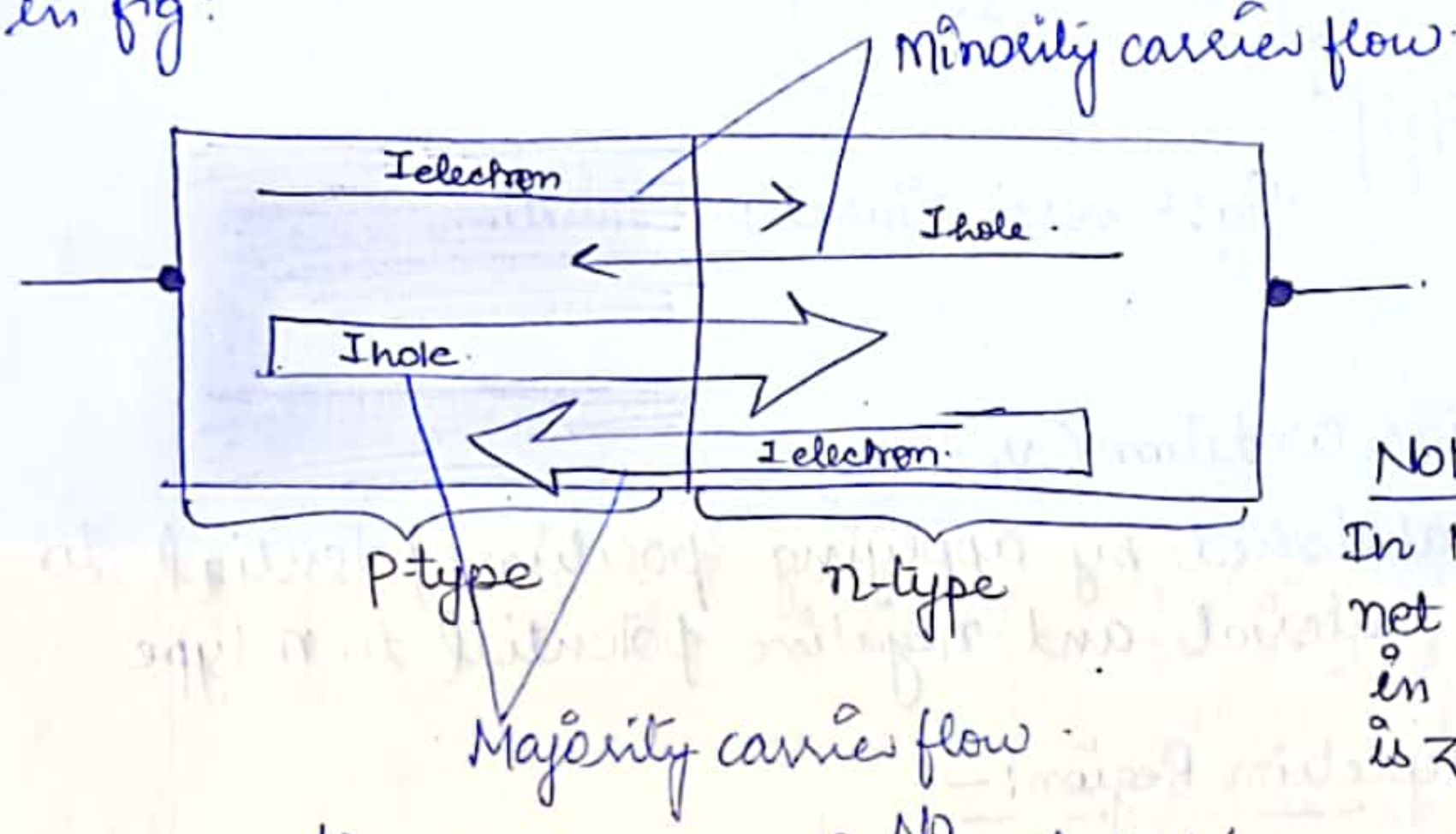

fig: Carrier flow in No applied bias.

Note:-
In No bias; the net flow of charge in one direction is zero.

Reverse Bias Condition:-

If External potential applied accross the p-n junction such that the positive terminal is connected to n-type material and negative terminal is connected to p-type. This bias condition is reverse Bias.

(The number of positive ion in depletion region of the n-type material will increase due to large no. of free electron. Similarly no. of uncovered negative ion increased in p-type material. hence depletion region is widen)

→ (The widening of depletion region create to great barrier for majority carriers and it reduce to zero.)

However no. of minority carrier will not change. hence minority carrier flow in same way as in no bias conditions

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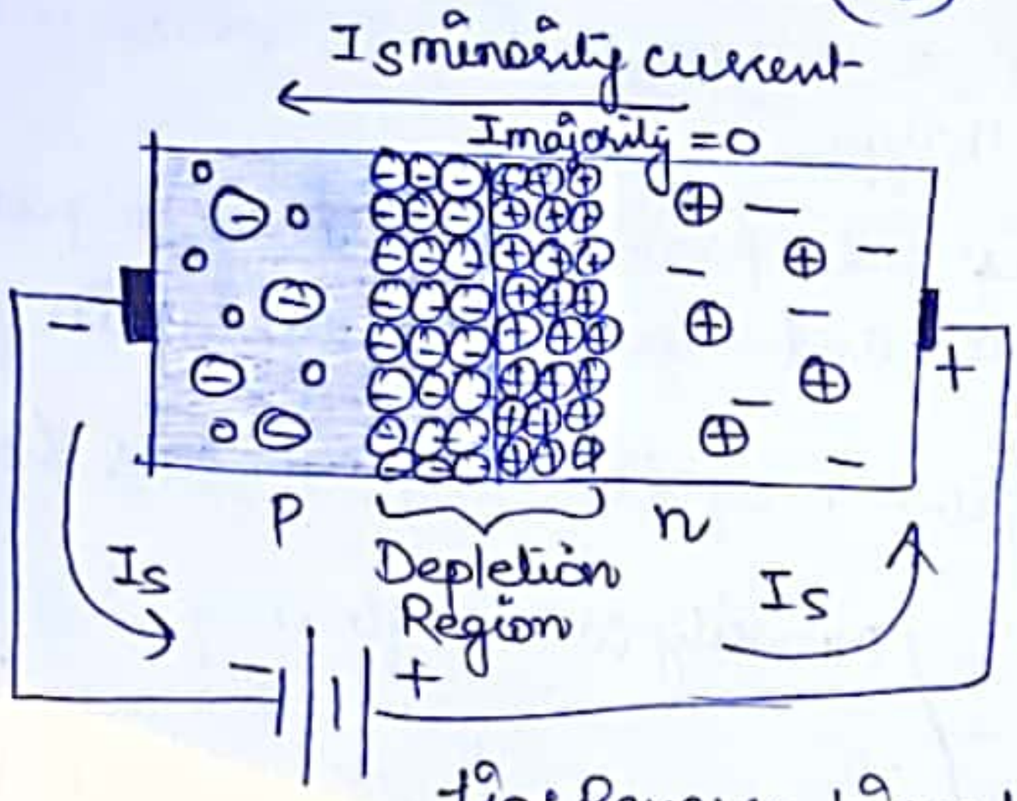
→ The current that exists in Reverse bias ~~region~~ cond^n is called as reverse saturation current (I_S).



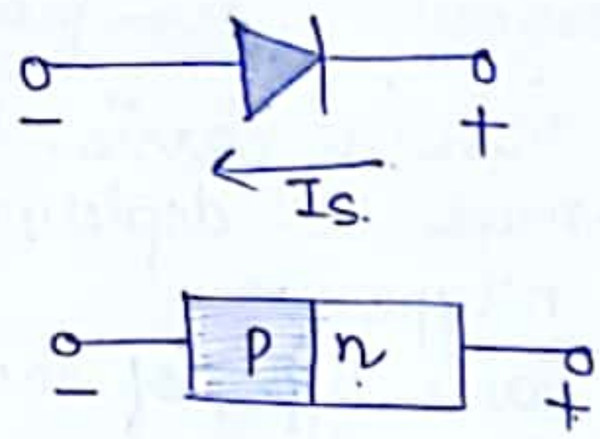


fig: Reverse-biased p-n Junction

Forward bias condition ($V_D > 0V$)

→ It is established by applying positive potential to the p-type material and negative potential to n-type material.

→ Effect on depletion Region:-

The majority carriers of both sides are combined with respective ions near depletion region and due to this width of depletion region get reduced.

Reduction in the width of depletion Region cause heavy flow of ~~minority~~ majority carriers accross the junction

→ Due to reduced barrier at junction electron from n-side feel strong ~~attac~~ attraction for positive potential applied ~~accross~~ to p-side.

→ As applied bias increased in magnitude, depletion Region will continue to decrease until flood of electron passing through the junction.

→

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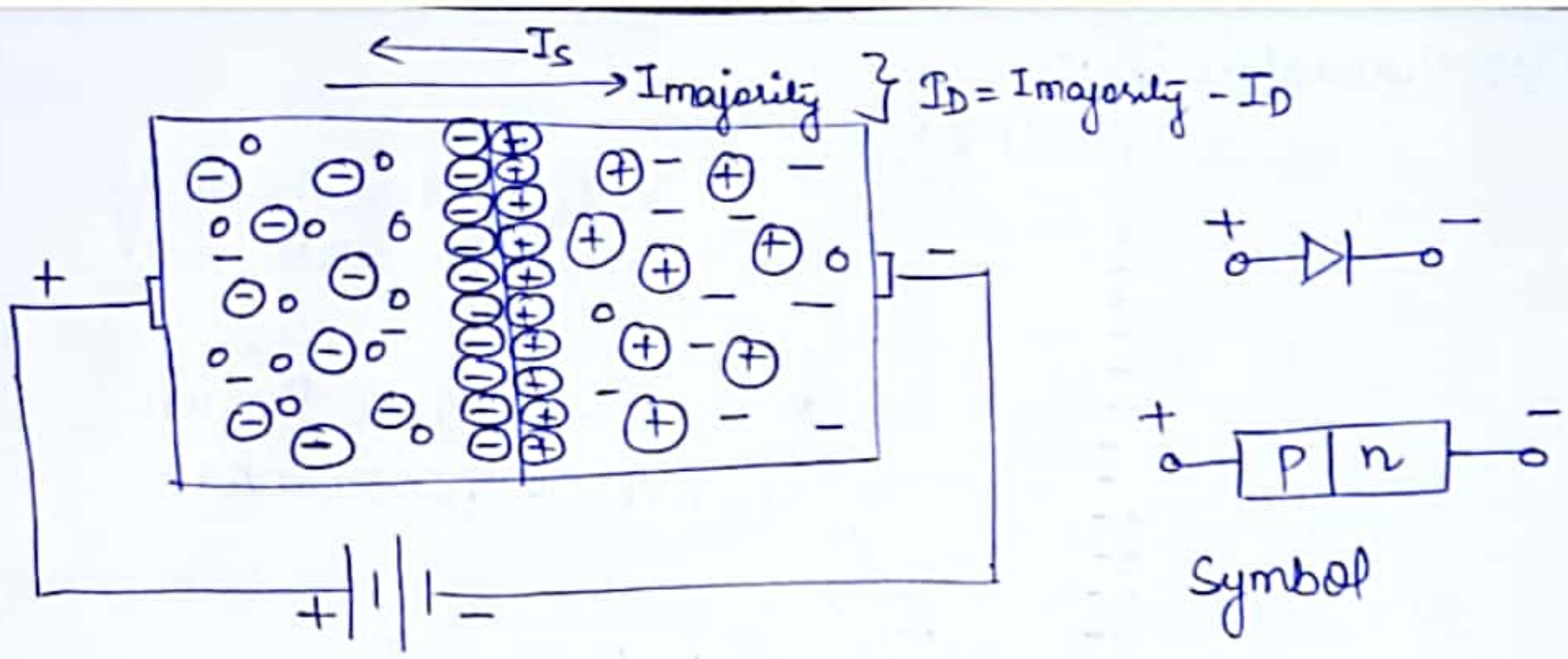

fig:- Internal Charge distribution in F.B.

<u>Note</u> :- Direction of current for positive voltage region matches the arrowhead in diode symbol.

Comparision of Si and Ge diode:-

Parameter	Si Diode	Ge Diode
Cut-in Voltage	0.7V	0.3V.
Reverse Sat Current	In nA	In μA
Effect of Temp.	Less	More
Breakdown Voltage	Higher	Lower
Applications	Rectifiers Clippers, Clampers etc.	Low Voltage Low Temp Applications

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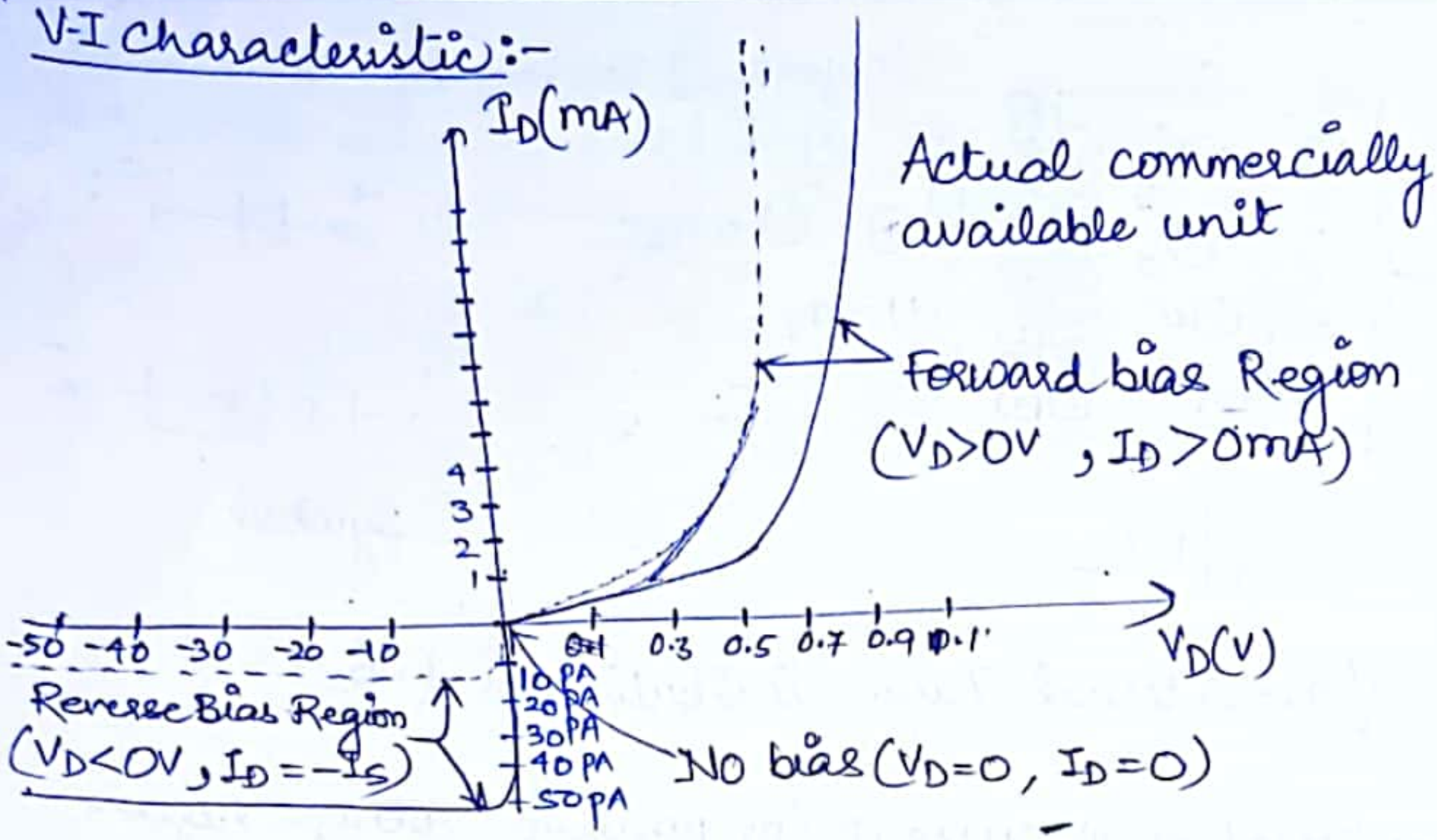
V-I Characteristic :-



In F.B :- Due to decrease in depletion width majority carries flow increased exponentially. Current rises beyond knee curve. As applied bias increases flood of majority carriers passes through the junction and current increased.

In graph. Forward Voltage has max value = 1V.

General Characteristic of Semiconductor diode defined by Shockley's Equation, for Forward & Reverse Region:

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

$I_S \rightarrow$ Reverse Saturation

$V_D \rightarrow$ Applied forward bias voltage

$n \rightarrow$ Identity factor

$V_T \rightarrow$ Thermal Voltage ; $V_T = \frac{kT}{q}$.

$\eta = 1 \rightarrow$ Germanium Diode.

$= 2 \rightarrow$ Si Diode.

- k; Boltzmann's constant $= 1.38 \times 10^{-23}$ J/K.
- $T_K \rightarrow$ Absolute Temp (in K).
- q = Magnitude of ~~electric~~ electronic charge 1.6×10^{-19}C.

In R.B :-

The current exists under reverse bias condition is called as reverse saturation current. (I_S).

The term saturation indicate that it reachs its maximum level quickly and doesnot change significantly with increase in reverse potential.

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From Schockely's equation, $I_D = I_S(e^{+V_D/nV_T} - 1)$

In F.B, $V_D = +ve$.

$\therefore$ 1st term grows quickly and $\boxed{I_D \cong I_S e^{V_D/nV_T}}$ → (V_D positive)

In R.B, $V_D = -ve$, Exponential term drops quickly below 1

hence $\boxed{I_D \cong -I_S}$ → (V_D Negative)

<u>Reverse Saturation current</u>:—(I_S or I_{sat})

The current exists under reverse bias condition due to minority carrier is called as reverse saturation current. (I_S)

Factors for generation of I_S;

1) Leakage currents
2). Generation of carriers in depletion region
3). higher doping level.
4) Sensitive to intrinsic level of carriers.
5) Double the area of junction, the reverse current would be double.
6). <u>Temperature Sensitivity</u>:— Very sensitive to temp. thats why it is also known as "<u>Thermally Generated current</u>".

→ I_D doubles for every 5°C temp rise.

→ I_S doubles for every 10°C temp increase.

<u>Breakdown Region</u>:—(In Reverse bias diode)

Breakdown:- It is area in R.B Region, where p-n junction Breake down with sudden rise in reverse I.

It occurs at ~~at~~ a very large reverse voltage. The breakdown in reverse bias diode can takes place due to following effect:

1) Avalanche Effect 2) Zener Effect.

1) Avalanche Breakdown:-

→ Due to large reverse voltage, the velocity of minority carriers will increase to greater extent.

→ Kinetic energy associated with them also increases.

→ While travelling these minority carrier collied with the stationary atoms and impart some of the kinetic energy to valence electron present in the covalent bonds.

→ Due to this additionally aquired energy; these valance $\bar{e}$ will break the covalent bonds and jump into conduction

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Now these free electrons will accelarate and knock out some more valance electron by means of collisions. This chain-reaction is called as 'Avalanche Effect'.

Large V_R → Large I_R → Large Power dissipation accross diode.

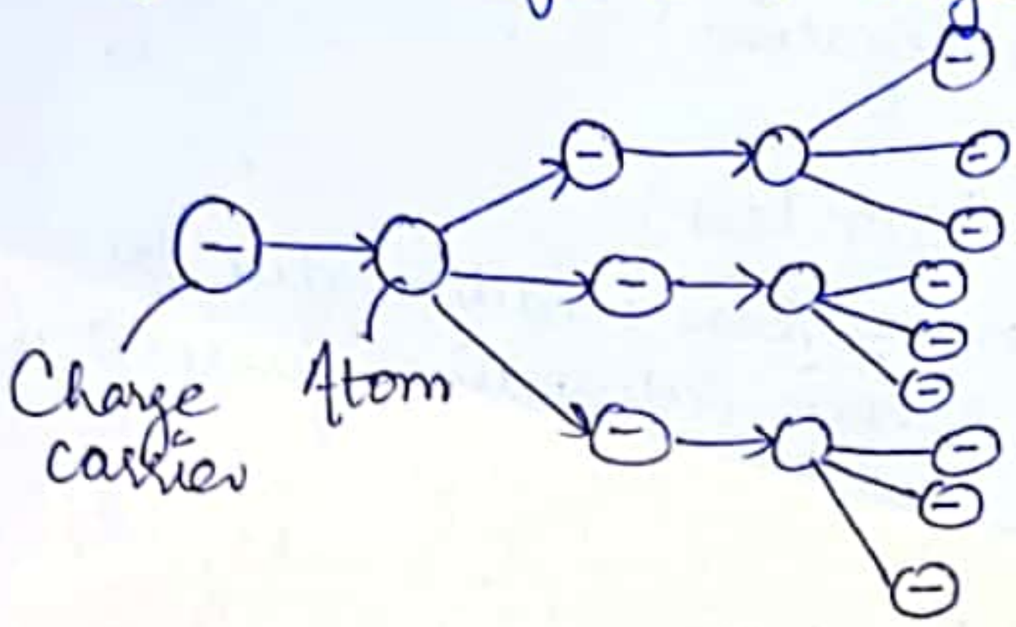

fig: Due to high velocity carrier collied with atom, generates charge carriers.
→ Avalanche Multiplication or Chain Reaction

PIV (Peak Inverse Voltage) :- The maximum reverse bias potential that is applied to pn junction before entering into breakdown region is called as peak inverse voltage.

Knee Voltage or cut in voltage :- In F.B, pn junction a very little current flows until forward voltage exceeds the junction barrier potential. The forward voltage at which the current through the junction starts increasing rapidly, is known as <u>knee voltage</u> or <u>cut-in-voltage</u>.

Quiescent Point or Operating point :-
(Still or constant)

Question :- A diode is operating at 300°K has 0.4V accross it when the current through it is 10mA and 0.42V when current is twice as large. Find the value of I_0 and η.

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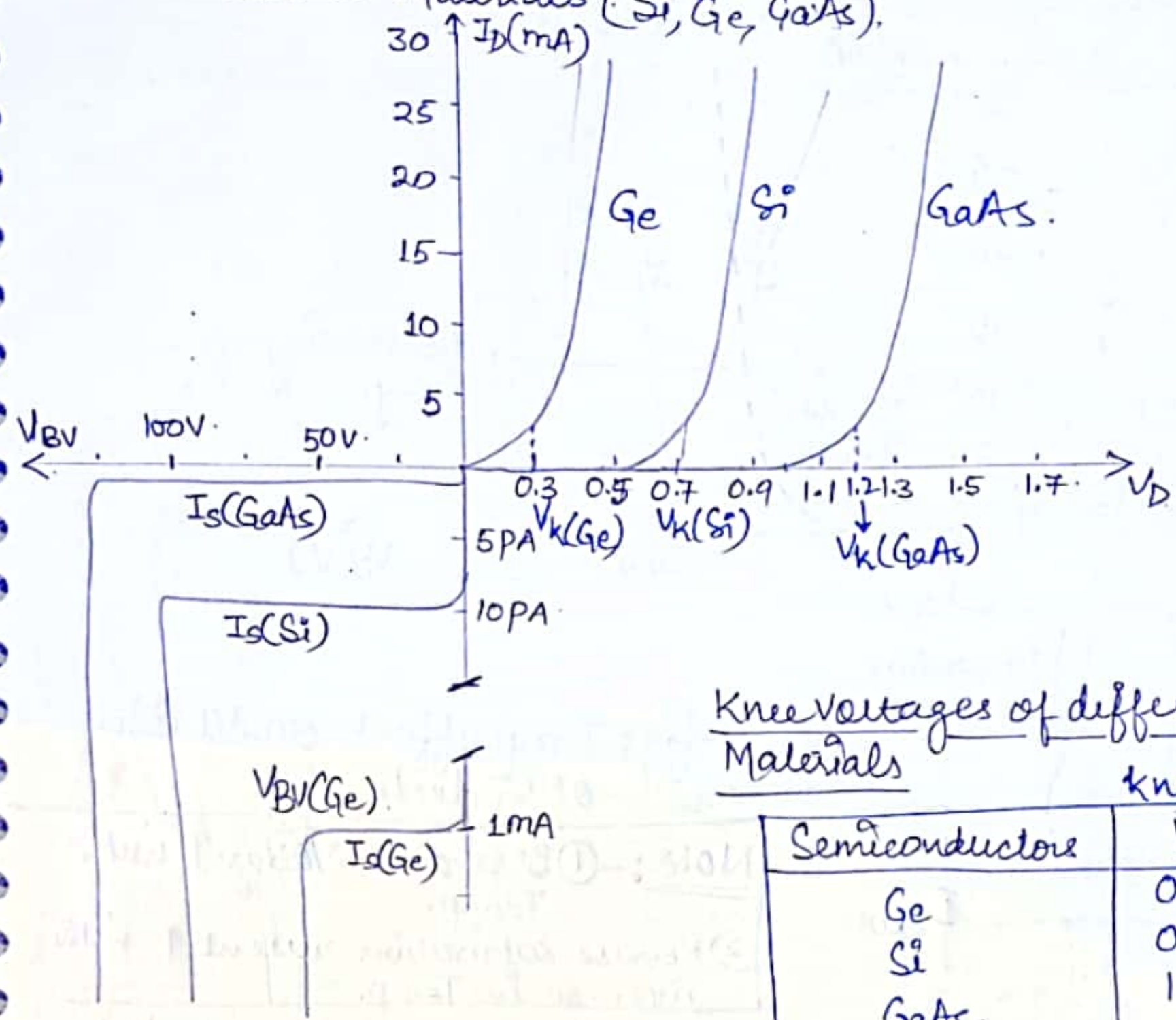
Comparisons of VI Characteristics of different SCs.
Semiconductor Materials (Si, Ge, GaAs).



Knee Voltages of different SC Materials

Semiconductors	Knee Voltage V_K(V)
Ge	0.3V
Si	0.7V
GaAs.	1.2V.

Reverse saturation current :-

Semiconductor	I_{sat} or I_s
Ge	1 μA
Si	10PA
GaAs.	1pA

GaAs has highest knee voltage; minimum reverse saturation current and maximum breakdown level. It has mobility factor 5 times of Si.

GaAs and Ge is used for high speed operations.

However through proper design, careful control of doping levels Si can also be used for frequencies upto GHz.

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h- Temperature effect on VI Characteristics :-

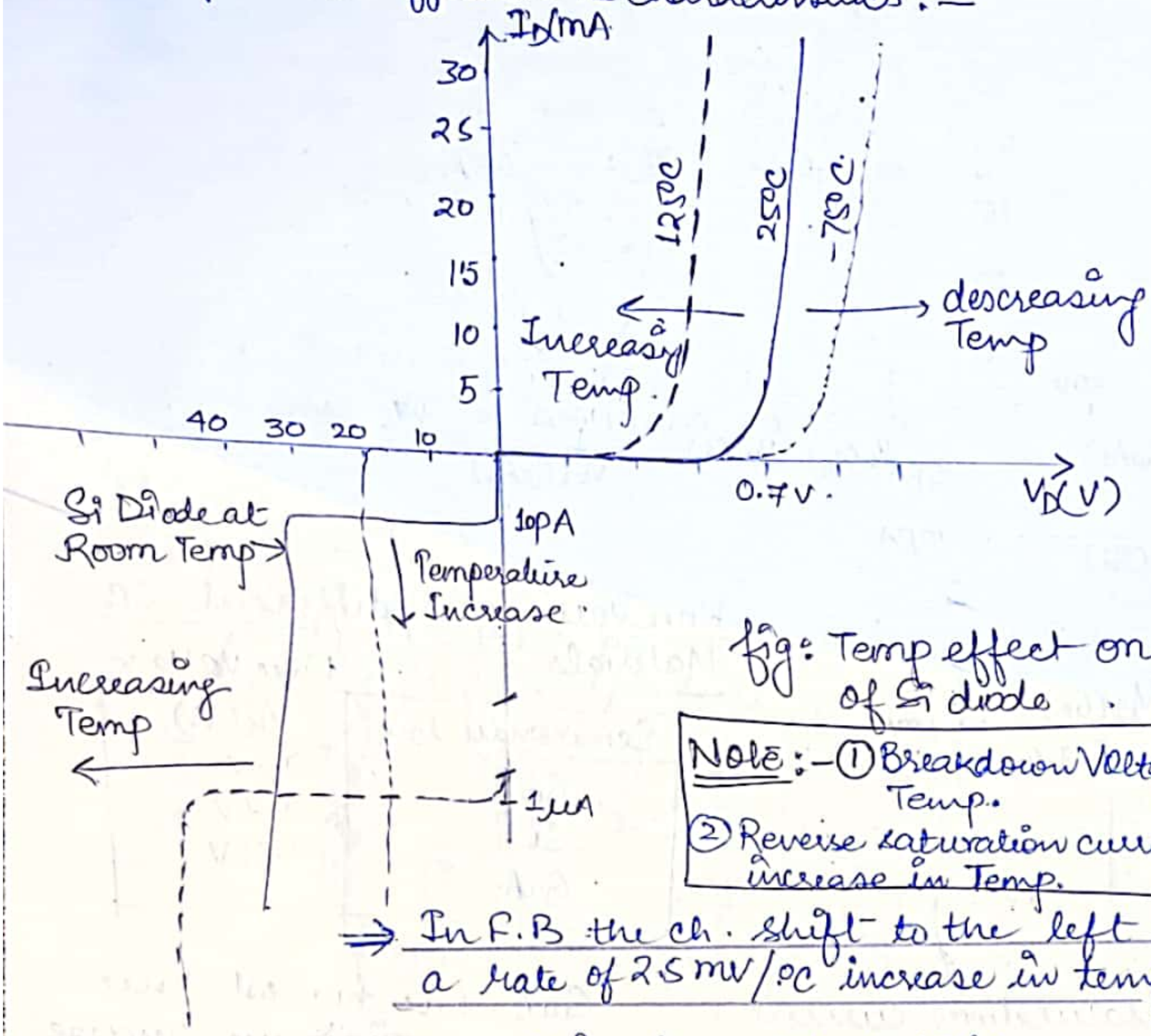

fig: Temp effect on VI Ch. of Si diode.

Note:- ① Breakdown Voltage ↑ with Temp.
② Reverse saturation current ↑ with increase in Temp.

⇒ In F.B the ch. shift to the left at ~~the~~ a rate of 2.5mV/°C increase in temp.

Ex:- Temp Raise from 20°C to 100°C.
Then Voltage drop = 80 × 2.5mV. ⇒ 200mV or 0.2V.
≠ (It is significant value)

decrease in ~~voltage~~ temp has reverse effect.

⇒ In R.B reverse current of Si diode doubles for every 10°C rise in temp.

Change from 20°C to 100°C, Is increases from 10nA to 2.56μA.

SC	Temperature Range
Ge	-60°C to 75°C
Si	-60°C to 175°C
GaAs	-200°C to 200°C

⇒ Breakdown voltage decrease with temp. even if initial ~~zero~~ V_{BR} = 5V.

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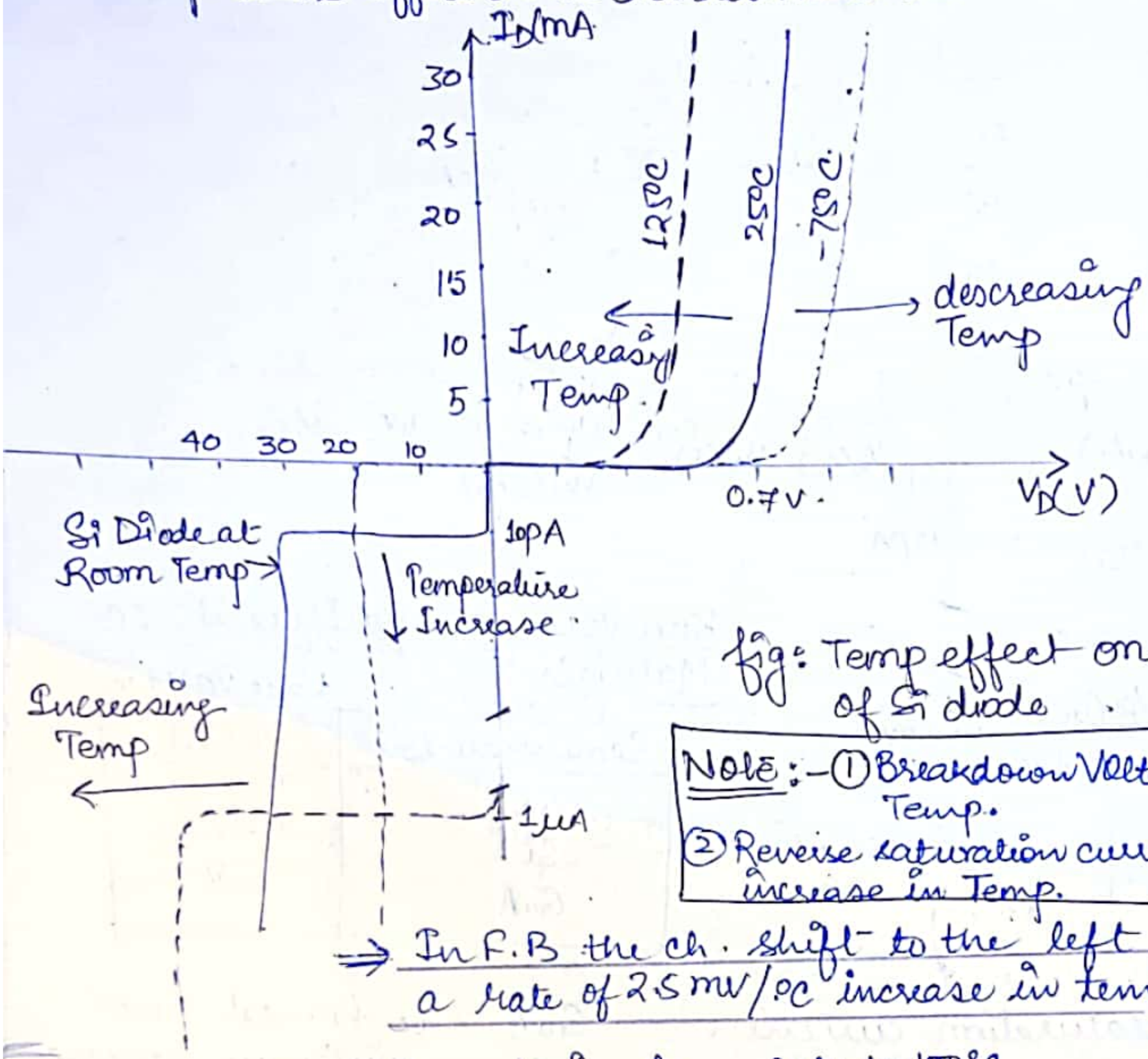
b- Temperature effect on VI Characteristics :-



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⇒ Breakdown voltage decrease with temp even if initial V_{BR} = 5V.

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Ideal Vs Practical VI-Ch.:-

The behaviour of SC diode is like mechanical switch.

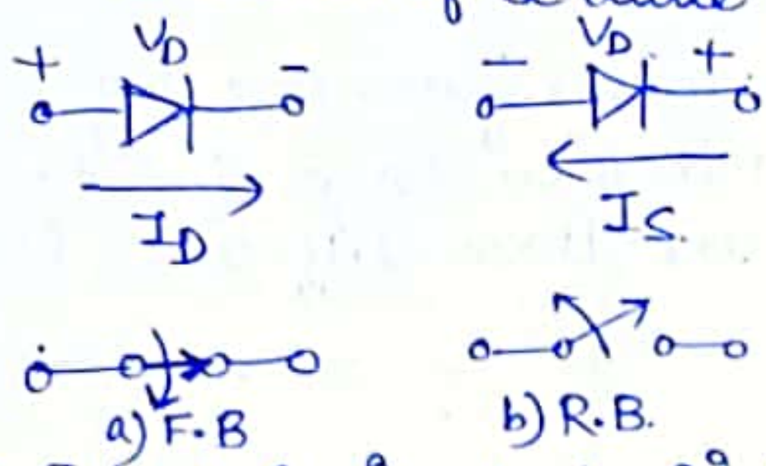

fig: Ideal Semiconductor Diode.

A SC diode is different from mechanical switch in the sense when the switch is closed it will permit current to flow in one direction.

Ideally, if SC diode is behave like a closed switch in ~~the sense~~ F.B the resistance of diode = 0Ω.

$R_{F.B} = 0\Omega$, $R_{R.B} = \infty\Omega$.

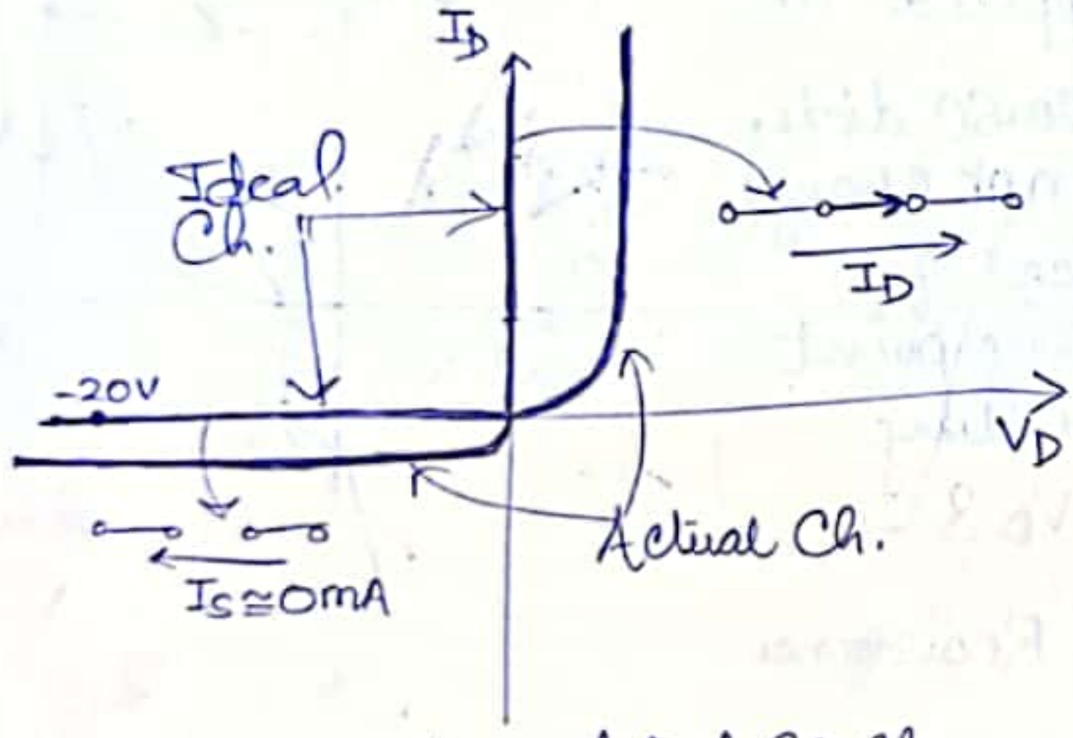

fig: Ideal Versus Actual SC Ch.

~~When device~~

When switch is closed.

Diode current $I_D = 5mA$.

& Diode Voltage $V_D = 0V$.

Diode Resistance $R_F = \frac{V_D}{I_D}$

$$R_F = \frac{0V}{5mA} = 0\Omega$$

$\boxed{R_F = 0}$ → (S/ckt Equivalent)

When switch open,

Diode current = 0mA

$V_D = 20V$

$$R_R = \frac{20}{0} = \infty\Omega.$$

$\boxed{R_R = \infty\Omega}$ → (O/ckt equivalent)

At vertical in voltage accross Ideal diode is 0V and Resistance = 0Ω

At Horizontal line, because current is 0mA. Resistance is consider to be infinite (∞).

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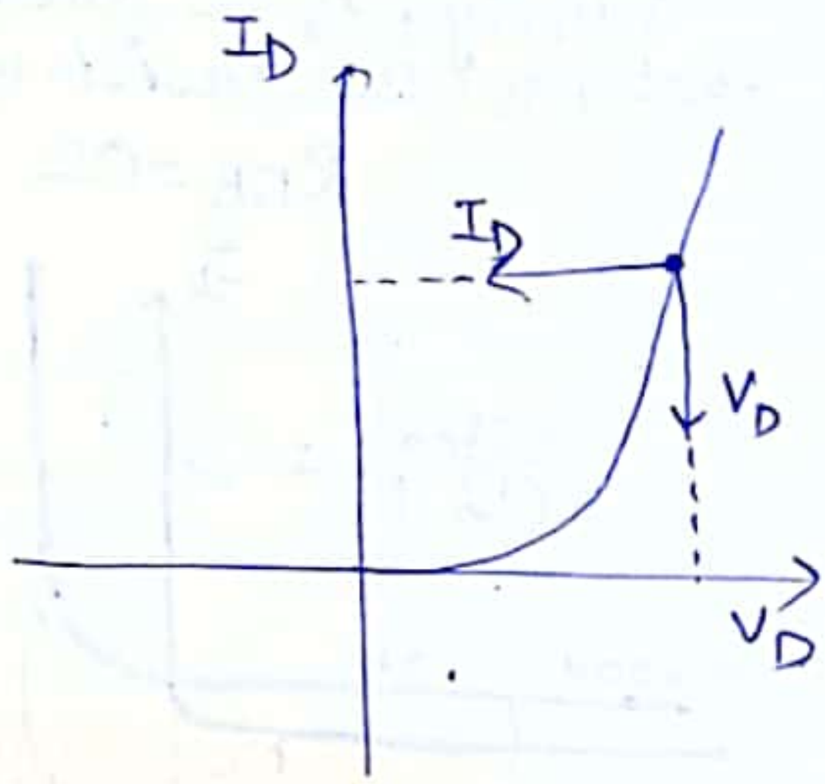
RESISTANCE LEVELS:-

As the operating point of diode moves from one region to another the resistance of diode will also change due to non-linear characteristic. There are three different levels of Resistance.

1) DC or Static Resistance
2) AC or Dynamic Resistance
3) Average AC Resistance.

1) DC or Static Resistance:

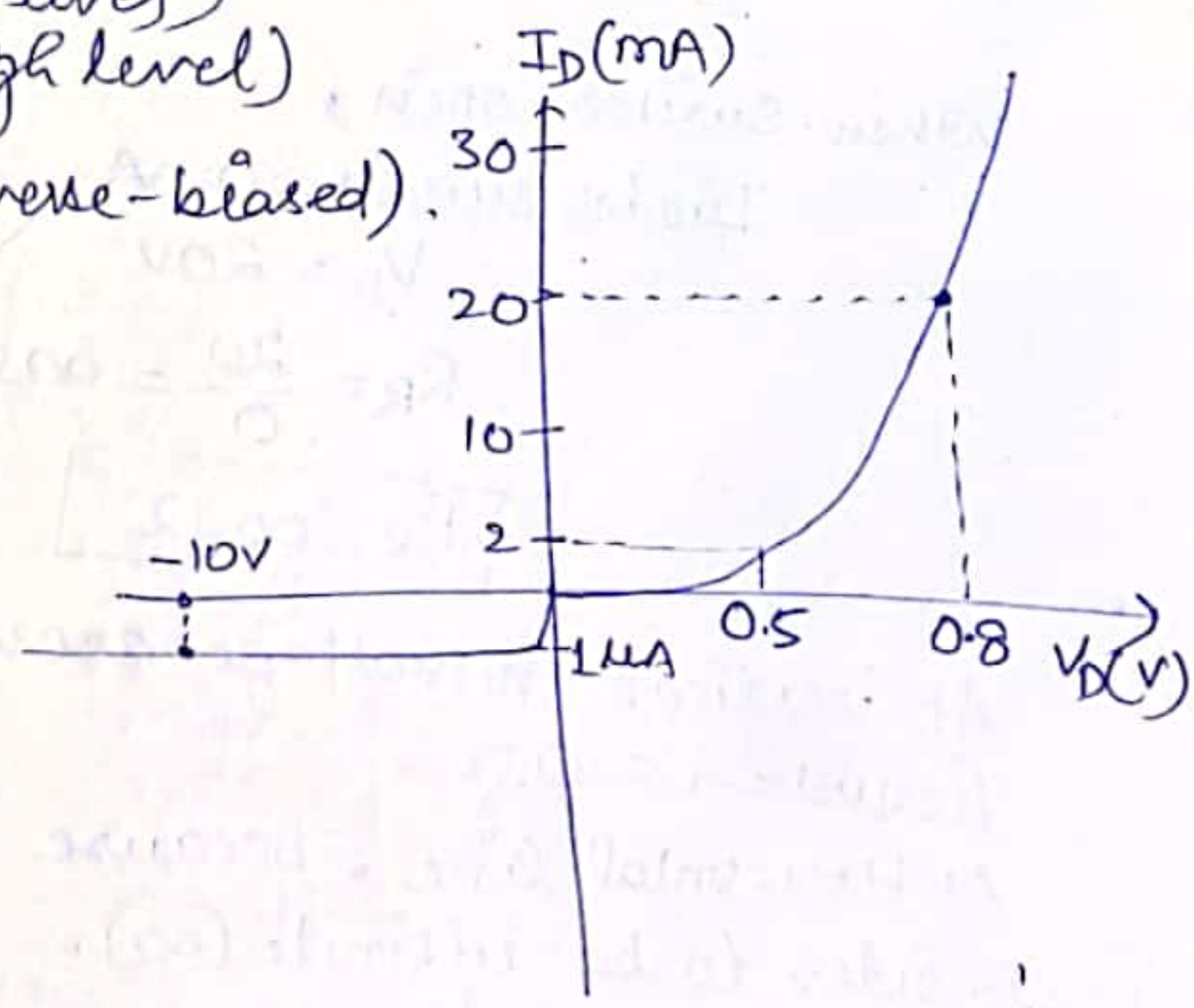
When DC voltage is applied to the circuit containing ~~co~~ SC diode, the operating point will not change with time. The resistance of the diode at ~~ed~~ operating point can be determined by finding corresponding levels of V_D & I_D.



$$\boxed{R_D = \frac{V_D}{I_D}} \rightarrow \text{dc Resistance}$$

Numerical 1:- Determine the resistance level of diode

a) $I_D = 2mA$ (low level)
b) $I_D = 20mA$ (high level)
c) $V_D = -10V$ (Reverse-biased).



a) $R_D = \frac{0.5}{2mA} = 250\Omega$

b) $R_D = \frac{0.8}{20mA} = 40\Omega$

c) $R_D = \frac{10}{1\mu A} \Rightarrow 10M\Omega$

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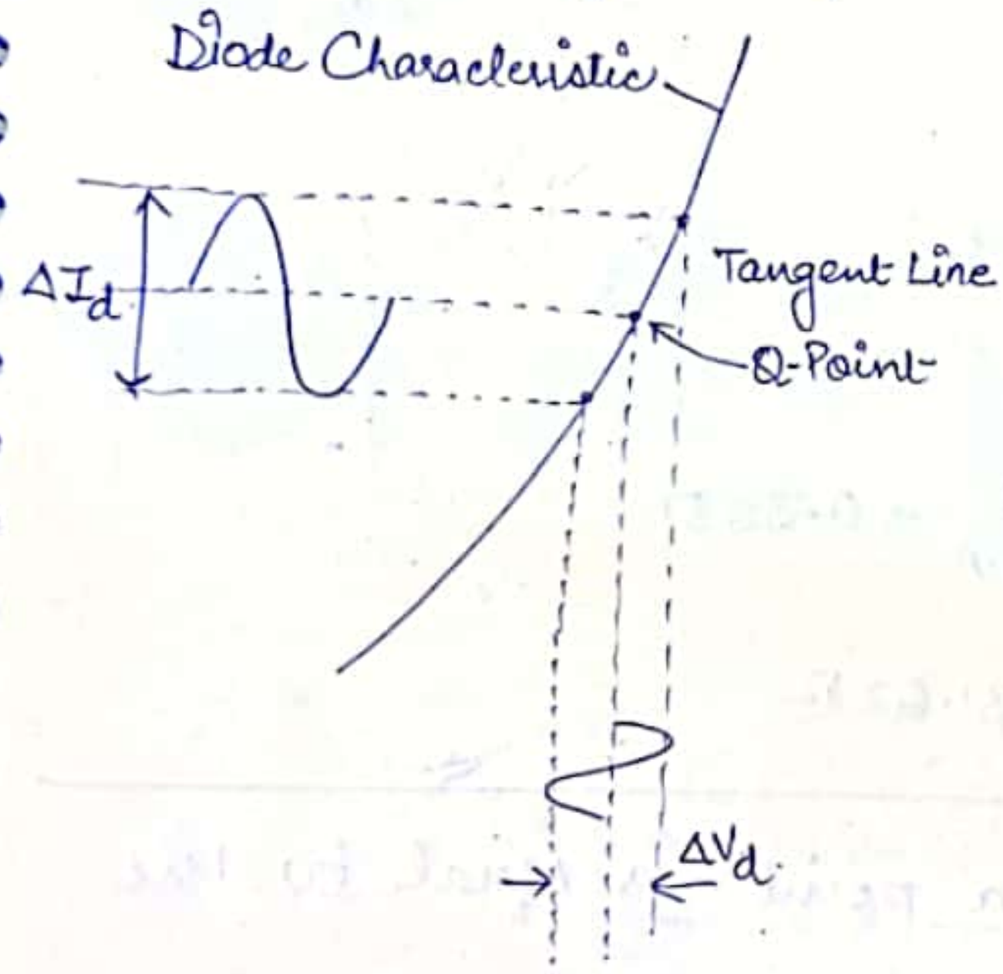
AC or Dynamic Resistance :-

If a sinusoidal voltage applied, then this varying i/p will move the instantaneous operating point up & down region of Characteristics..

A straight line drawn tagent to the curve through the Q-Point will define a particular change in voltage and current can be determined as ac or dynamic resistance

Keep the change in voltage & current as small as possible and equidistant to either side of the Q-point.



Dynamic resistance can ~~be defined by changing~~ Ratio be determined by Change in voltage & current in diode characteristic to either side of Q-point

$$r_d \cong \frac{\Delta V_d}{\Delta I_d}$$

$\Delta \rightarrow$ finite change in quantity.

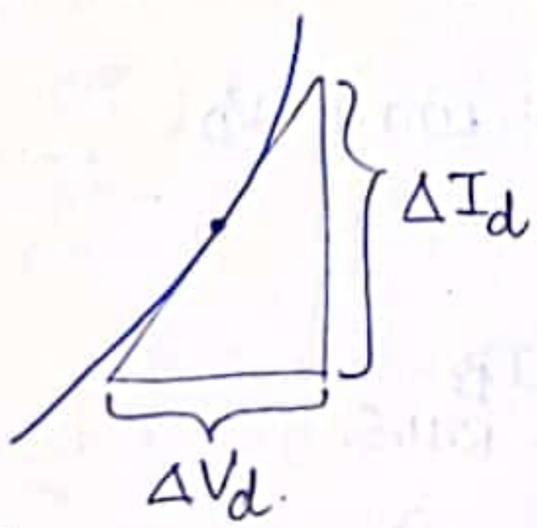


fig:- Defining Dynamic resistance at Q-Point.

→ AC resistance in vertical region is very small.

AC resistance is higher for lower current levels.

Note

The lower the Q-Point of operation, the higher is the ac resistance.

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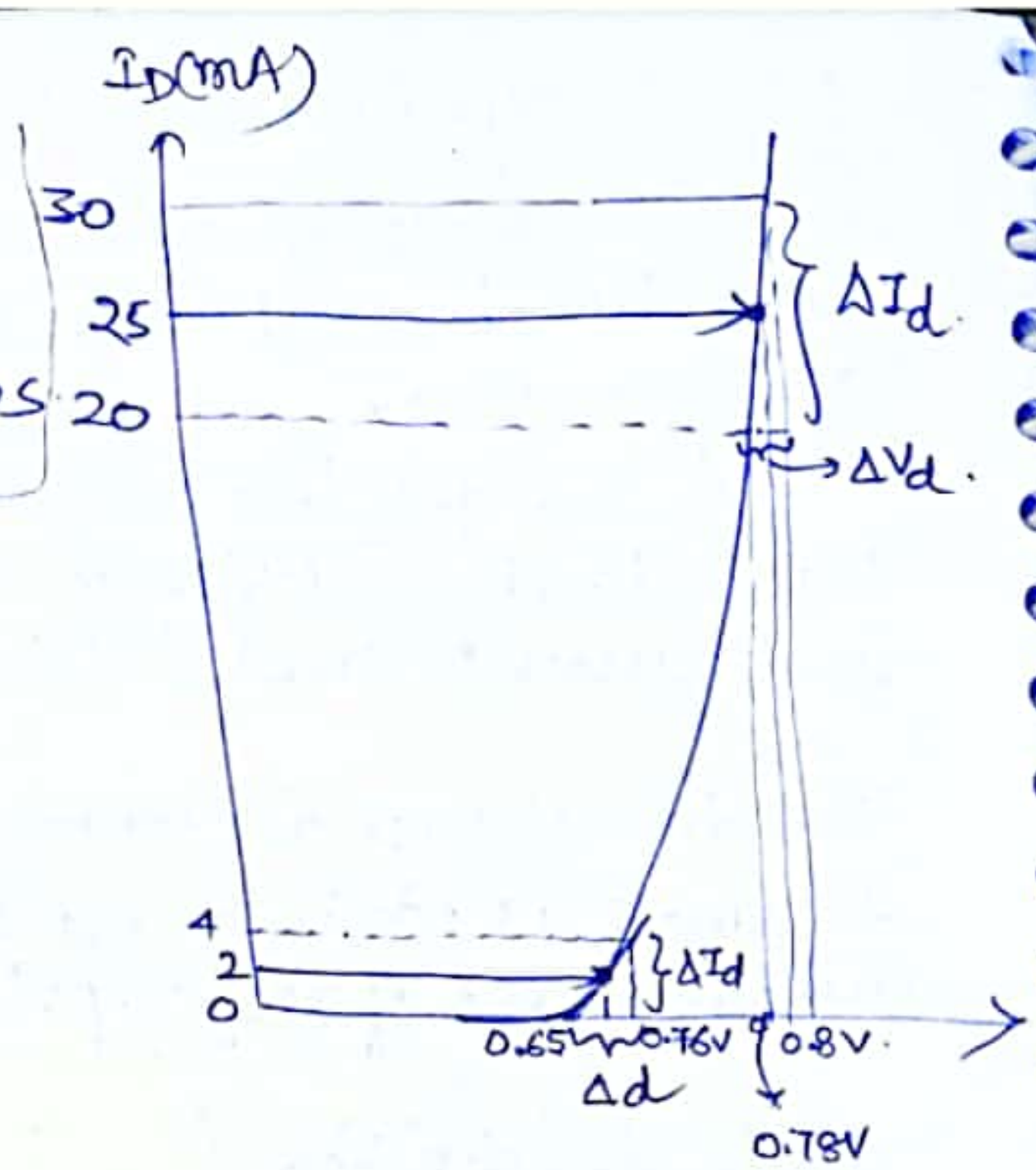
Numerical 2: For the ch. determine
a) ac Resistance at $I_D = 2mA$
b) ac Resistance at $I_D = 25mA$
c) Compare both to dc resistances at each current level.



a) $\Delta V_d = 0.76 - 0.65 \Rightarrow 0.11V$.
$\Delta I_d = 4mA$

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.11}{4mA} \Rightarrow 27.5\Omega$$

b) $\Delta I_d = 30mA - 20mA = 10mA$
$\Delta V_d = 0.8 - 0.78 = 0.02V$.

$$r_d = \frac{\Delta V_d}{\Delta I_d} = \frac{0.02V}{10mA} = 2\Omega.$$

c) $R_D = \frac{V_D}{I_D}$ at 2mA.

$$R_D = \frac{0.7}{2mA} \Rightarrow 0.35\Omega.$$

at 25mA

$$R_D = \frac{0.79}{25} = 31.62\Omega.$$

The derivative of a f^n at a point is equal to the slope of tangent line.

Diode Equation $I_D = I_S(e^{V_D/\eta V_T} - 1)$

take derivative of above equation w.r.t. V_D.

$$\frac{dI_D}{dV_D} = I_S \frac{d}{dV_D}(e^{V_D/\eta V_T} - 1)$$

$$\frac{dI_D}{dV_D} = I_S \frac{1}{\eta V_T}(e^{V_D/\eta V_T})$$

$\Rightarrow$ add +1 & -1 at R.H.S.

$$= I_S \frac{1}{\eta V_T}(e^{V_D/\eta V_T} - 1 + 1)$$

$$= \frac{1}{\eta V_T}[I_D + I_S]$$

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If $I_D >> I_S$

$$\frac{dI_D}{dV_D} \cong \frac{I_D}{\eta V_T}$$

Flip the result,

$$\boxed{\frac{dV_D}{dI_D} \cong \frac{\eta V_T}{I_D}} = r_d.$$

Dynamic Resistance can be found by substituting Q-Value of Diode Current.

Note :-

Various r_d varies with different values of I_d, the formula may be differs.

→ r_d is accurately calculated only at vertical rise of the curve.

→ For lesser values of I_D r_d will be multiplied by 2.

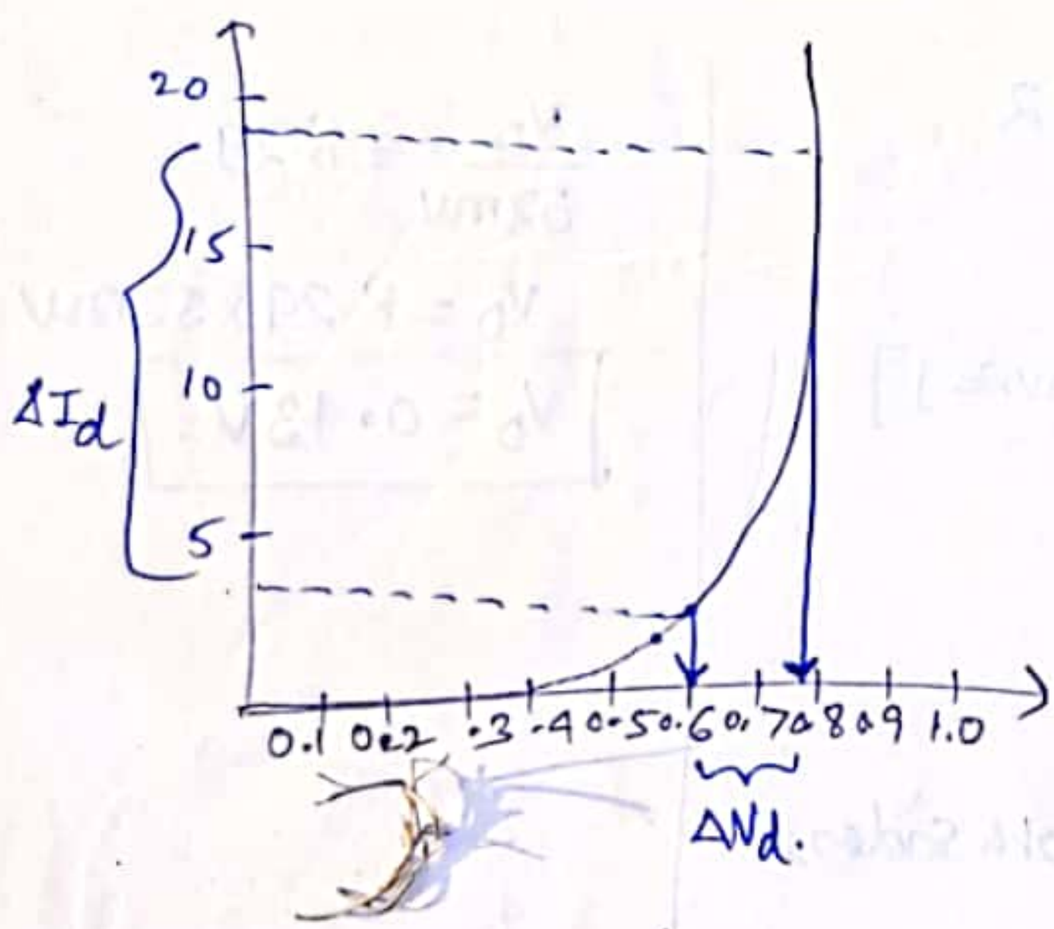
Ac resistance of a diode in active region = 1Ω to 100Ω.

Average AC Resistance :-

If I/P ~~Resistance~~ signal is sufficiently large to produce broad swing, then associated resistance for that region is called as average ac resistance.

This resistance is determined by straight line drawn between two intersections established by maximum and minimum values of I/P voltage.

$$\boxed{r_{av} = \frac{\Delta V_d}{\Delta I_d}}$$



$\Delta V_d = 0.725 - 0.65 \Rightarrow 0.075V$

$\Delta I_d = 1mA$

$r_{av} = \frac{\Delta V_d}{\Delta I_d} = 5\Omega$

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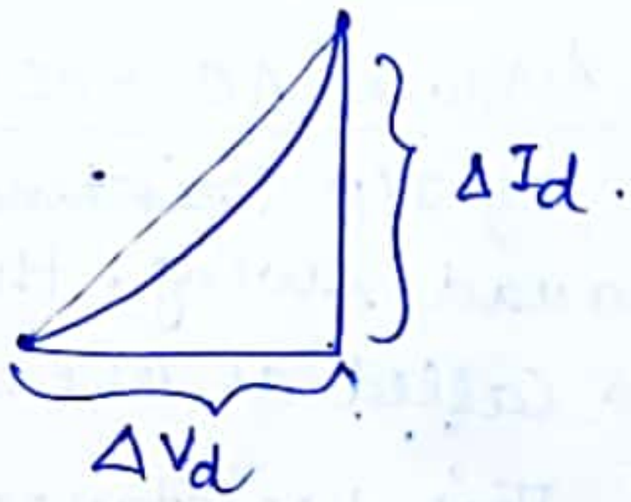
Summary Table of Diode Resistance.

Types.	Equations.	Special Characteri	Graphical determinations
1) DC or Static Resistance	$R_D = \frac{V_D}{I_D}$	Defined at point on Ch.	
2) AC or Dynamic Resistance	$r_d = \frac{\Delta V_d}{\Delta I_d}$.	Defined by tangent of the line	
3) Average AC	$r_{av} = \frac{\Delta V_d}{\Delta I_d}$ | pt to pt.	Defined by straight line b/w limit of operations.	

Numerical:—

$\eta = 1$

1. Determine the forward bias voltage applied to a silicon diode to produce a forward current of 10 mA and reverse saturation current $I_0 = 25 \times 10^{-7}$ A at room temperature. [Ans. 0.4 Volt]
2. A germanium diode draws 50 mA with a forward bias of 0.27 V. The junction is at room temperature of 27°C. Determine the reverse saturation current of the diode. [Ans. 1.545 μA]
3. Determine ac resistance for a semiconductor diode with a forward bias of 0.25 V. Reverse saturation current at room temperature is of 1.2 μA. [Ans. 1.445 Ω]

(1)

$I_d = 10mA$ $\qquad \eta = 2$

$I_S = I_0 = 25 \times 10^{-7} A$.

$I_d = I_0 [e^{V_D/\eta V_T} - 1]$

$10 \times 10^{-3} = 25 \times 10^{-7} [e^{V_D/26mV \times 2} - 1]$

$\frac{10 \times 10^4}{25} = [e^{V_D/26mV \times 2} - 1]$

$4000 + 1 = e^{V_D/52mV}$

take natural log on both sides,

$\ln(4001) = \frac{V_D}{52mV}$.

$\frac{V_D}{52mV} = 8.29$

$V_D = 8.29 \times 52mV$

$\boxed{V_D = 0.43V}$

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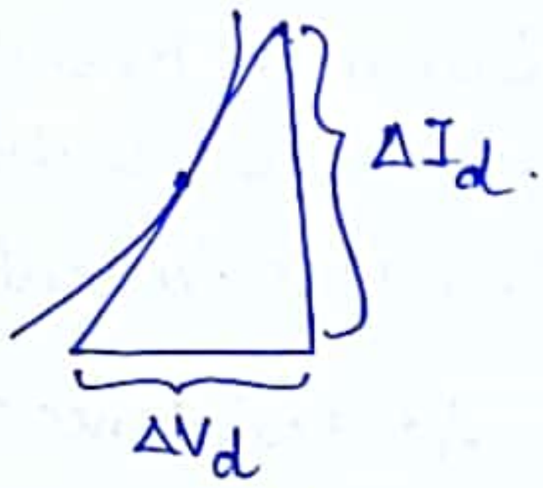
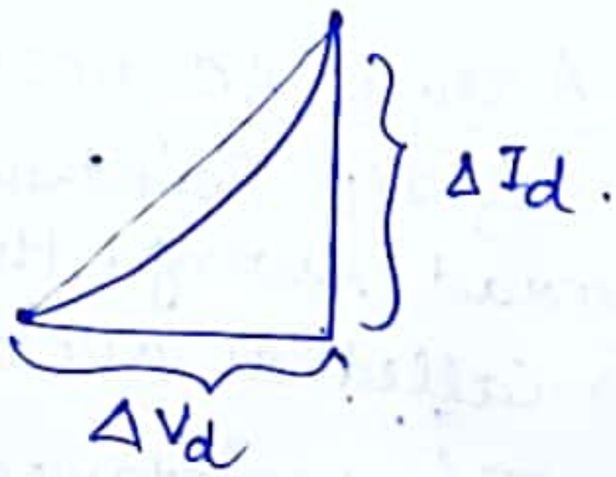
2) AC or Dynamic Resistance	$r_d = \frac{\Delta V_d}{\Delta I_d}$.	Defined by tangent of the line	
3) Average AC	$r_{av} = \frac{\Delta V_d}{\Delta I_d}$ | pt to pt.	Defined by straight line b/w limit of operation.	

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3. Determine ac resistance for a semiconductor diode with a forward bias of 0.25 V. Reverse saturation current at room temperature is of 1.2 μA. [Ans. 1.445 Ω]

① $I_d = 10mA$

$\eta = 2$

$I_S = I_0 = 25 \times 10^{-7} A$.

$I_d = I_0 [e^{V_D/\eta V_T} - 1]$

$10 \times 10^{-3} = 25 \times 10^{-7} [e^{V_D/26mV \times 2} - 1]$

$\frac{10 \times 10^4}{25} = [e^{V_D/26mV \times 2} - 1]$

$4000 + 1 = e^{V_D/52mV}$

take natural log on both sides,

$\ln(4001) = \frac{V_D}{52mV}$.

$\frac{V_D}{52mV} = 8.29$

$V_D = 8.29 \times 52mV$

$V_D = 0.43V$

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(2) $I_D = I_0(e^{V_D/\eta V_T} - 1)$

$I_D = 50mA$ $T = 27°C$

$V_D = 0.27V$

$\eta = 1 \rightarrow$ Ge.

$50mA = I_0[e^{0.27/0.026} - 1]$

$I_0 = \frac{50mA}{32209-1}$

$\boxed{I_0 = 1.552\,\mu A}$

(3) $V_T = 26mV$

$V_D = 0.25V$

$I_0 = 1.2\,\mu A$

$T = 26mV$

$I_D = I_0[e^{0.25/0.026} - 1]$

$\boxed{I_D = 17.991\,mA}$

$\boxed{r_d = \frac{26mV}{I_D}}$

$r_d = \frac{26mV}{17.991\,mA}$

$\boxed{r_d = 1.445\Omega}$

Resistance

(4) The I_0 for Ge Diode is $1\mu A$ at a reverse voltage of $-0.52V$. Calculate the values of FWD and ~~Rw~~ reverse dynamic resistance. Assume the FWD voltage to be $+0.52V$ at room temp.

R.B

$I_D = 1\mu[e^{-0.52/0.026} - 1]$

$\boxed{I_D = -0.999\mu A}$

$r_R = \frac{26 \times 1000}{0.999}$

$\boxed{r_R = 26K\Omega}$

F.B

$I_D = 1[e^{0.52/0.026} - 1]$

$= 4.85 \times 10^8 \times 10^{-6}$

$= 485.16\,A$

$\boxed{r_f = 0.053m\Omega}$

(5) Determine the dynamic resistance of a P-N junction diode at a FWD current of 2mA. assume $\frac{KT}{q} = 25mV$.

$I = 2mA$ $V_T = 25mV$.

$r_f = \frac{\eta V_T}{I_D} = \frac{25}{2}\Omega \Rightarrow 12.5\Omega$

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(6) A p-n Junction diode has a Temp of 125°c and a ~~reverse~~ $I_o = 30\mu A$. At a temp 125°C find the dynamic resistance for 0.2V Bias in the FWD and Reverse direction.

$I_{o(125)} = 30\mu A$

$V_D = 0.2V$.

$T = 125°c = 125+273 = 398K$.

$V_T = \frac{T}{11600} = \frac{398}{11600} = 0.0343$
$= 34.3mV$

F.B

$I_D = 30[e^{0.2/0.0343} - 1]$
$= 30[340.7 - 1]$
$I_D = 30 \times 339.67$
$= 10.19mA$

$r_D = \frac{\eta V_T}{I_D}$

$= \frac{1 \times 34.3}{10.19}$

$r_D = 3.37\Omega$

R.B

$I_D = 30[e^{0.20/0.0343} - 1]$
$= 30[0.558 - 1]$
$= -13\mu A$

$I_D = -13\mu A$

(7) Find a.c resistance for a SC diode having a F.B 200mV. and reverse sat $I_o = 1\mu A$ at room temp.

$V_T = 26mV$.

$V_F = 200mV = 0.2V$.

$I_o = 1\mu A$

$I_D = 1\mu A[e^{0.2/0.026} - 1]$
$= 1\mu A[2185]$
$= 2.185mA$

$r_F = \frac{\eta V_T}{I_D}$

$= \frac{1 \times 26}{2.185} = 11.89\Omega$

$r_F = 11.89\Omega$

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Questions Related to Diode Current :-

① The FWD through Si diode is 10 mA at room temp 27°C. The corresponding $V_F = 0.75V$. Calculate the I_0.

Solⁿ $I_D = I_0(e^{V_D/\eta V_T} - 1)$

$I_D = 10mA$
$V_D = 0.75V$
$V_T = 0.026V$
$\eta = 2$

$$I_0 = \frac{10mA}{(e^{0.75/0.025\times2} - 1)}$$

$$I_0 = \frac{10\times10^{-3}}{1.83\times10^{6}}$$

$$\boxed{I_0 = 5.46nA}$$

② ~~Explain the effect of temp on p-n Junction diode.~~ Determine FWD current for Ge diode at room temp when voltage accross it is 0.3V. T = 27°C, $I_0 = 1nA$

$I_0 = 1nA$
$V_T = \frac{27}{11600} = 26mV$
$\eta = 1$
$V_F = 0.3V$

$I_D = I_0[e^{0.3/0.026} - 1]$
$= 1n[e^{11.53} - 1]$
$= 1n[101721]$

$$\boxed{I_D = 0.103 mA}$$

③ A diode at operating temp 300°K has $V_D = 0.4V$ accross it when the current through it is 10mA and 0.42V when the current is twice as large. What is the value of I_0 and η allow the diode to be modelled by diode eqⁿ ?

$$V_T = \frac{300}{11600} = 25.86mV$$

$$\boxed{V_T = 26mV}$$

$V_D = 0.4V$. $I_D = 10mA$
$V_D = 0.42V$ $I_D = 20mA$

$10mA = I_0(e^{0.4/0.026\eta} - 1)$ ①
$20mA = I_0(e^{0.42/0.026\eta} - 1)$ ②

$$\frac{1}{2} = \frac{e^{0.4/0.026\eta} - 1}{e^{0.42/0.026\eta} - 1}$$

~~$e^{0.42/0.026\eta} = 2e^{0.4/0.026\eta}$~~

~~$e^{0.42/0.026\eta}$~~ take natural log on both side

$$0.693 = \frac{0.42}{\eta\times26\times10^{-3}} - \frac{0.4}{\eta\times26\times10^{-3}}$$

$\eta\times0.693\times26\times10^{-3} = 0.02$

$$\boxed{\eta = 1.11}$$

Place this value in eqⁿ ①

$10mA = I_0[e^{0.4/1.11\times0.026} - 1]$

$$\boxed{I_0 = 9.56nA}$$

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Diode Equivalent circuit :-

An equivalent circuit is a combination of elements properly choosen to best represent the actual terminal Ch. in partical operating cond^n.

There are three equivalent circuits for two terminal diode :

1) Piecewise linear Equivalent circuit
2) Simplified Equivalent circuit
3) Ideal Equivalent circuit

1) Piecewise Linear Equivalent Ckt :-

In this we take approximate Ch. of diode by straightline segment. This equivalent circuit is called as piecewise Ckt.

The straight line segment is not exact duplicate of actual Ch. especially near knee region but it is sufficiently close to the actual curve.

Diode is replaced by a battery which specifies voltage accross the device must not be greater than threshold voltage and resistance which is average resistance value.

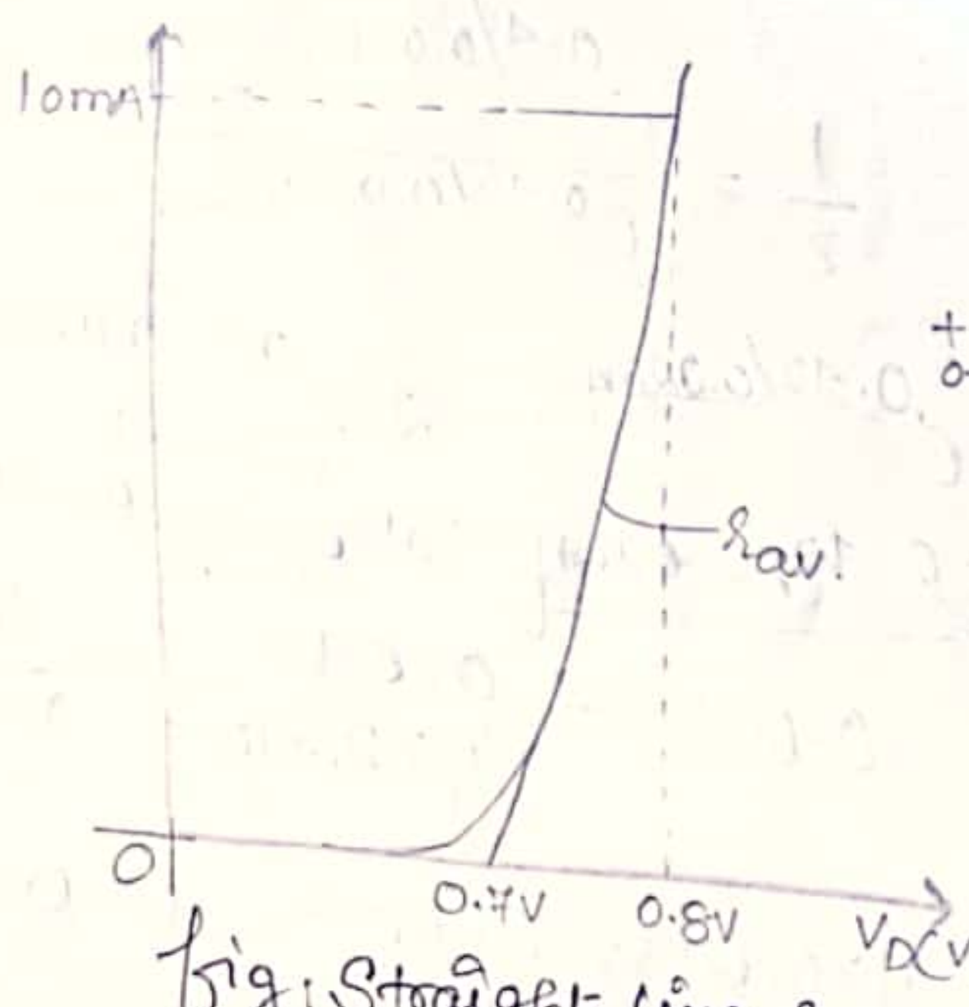

fig: Straight line segment to approximate the ch. curve.

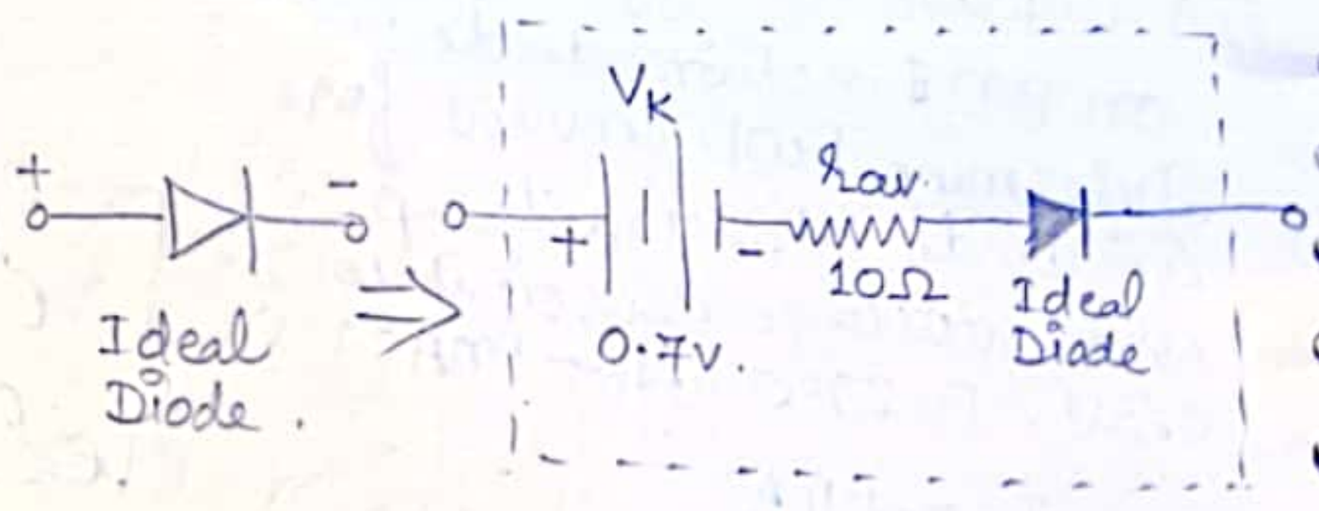

fig: Piecewise equivalent circuit

→ V_K → It is not an Idependent Voltage Source.
It represent horizontal offset of characteristic.

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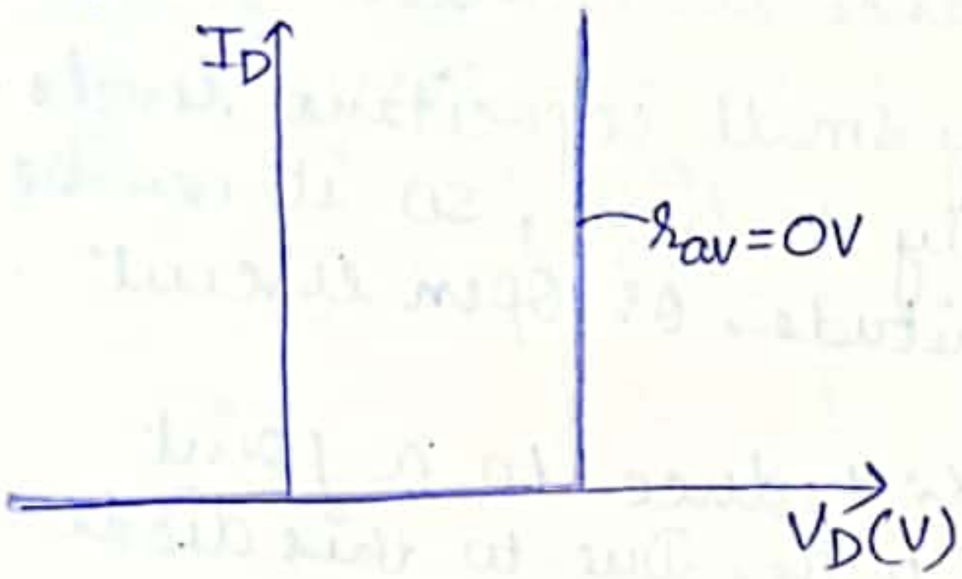
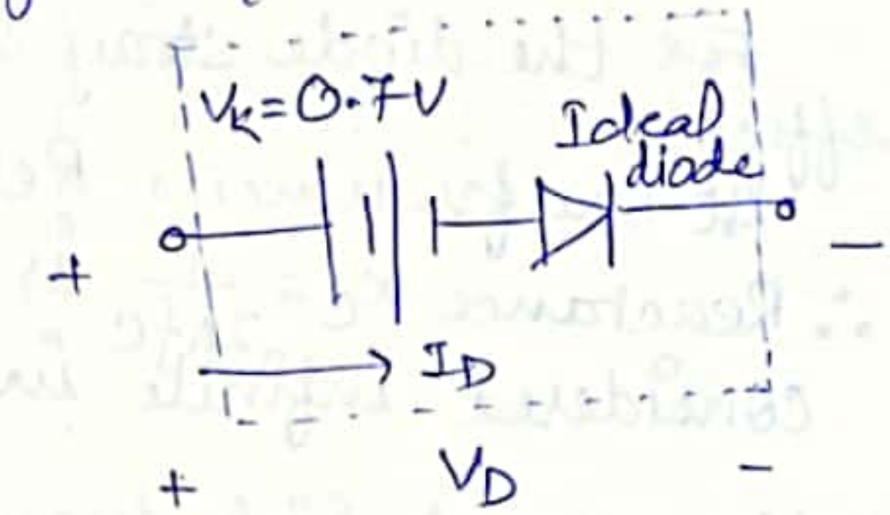
$$r_{av} = \frac{0.8V - 0.7V}{10mA - 0} \Rightarrow 10\Omega.$$

If specification sheet is not avaiable the r_{av} can be approximated ~~to~~ by ac resistance r_d.

Simplified Equivalent Circuit :-

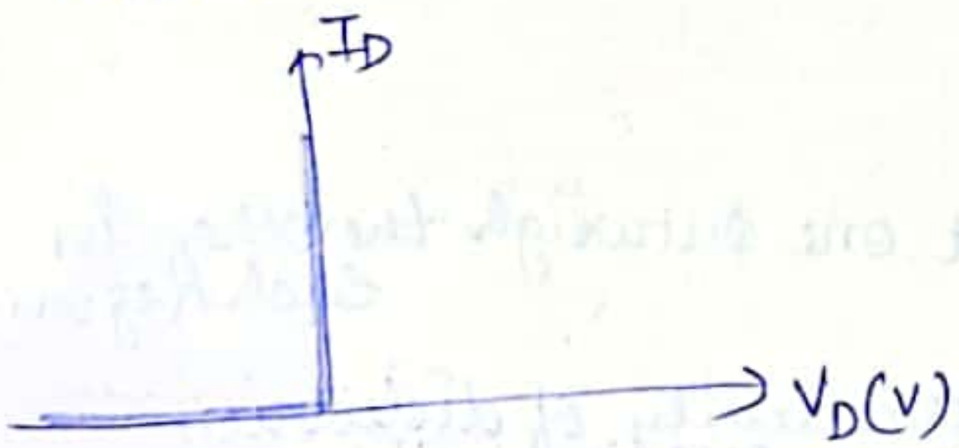
In most applications r_{av} is very small. So can be simply ignored in comparision to the elements of n/w. This reduced equivalent ckt is called as simplified equivalent ckt.

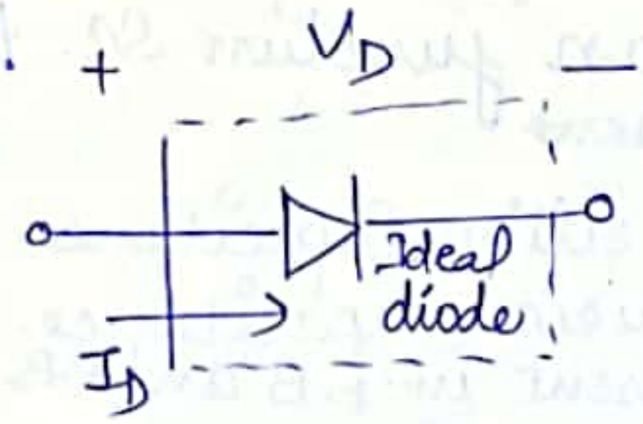


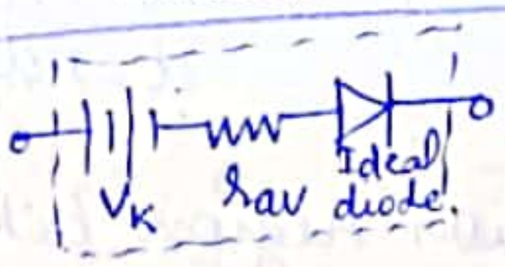
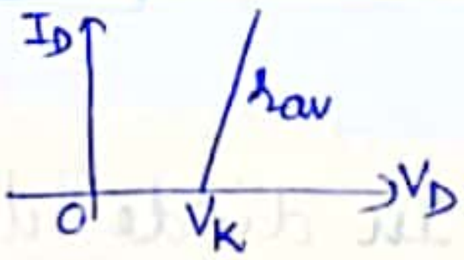
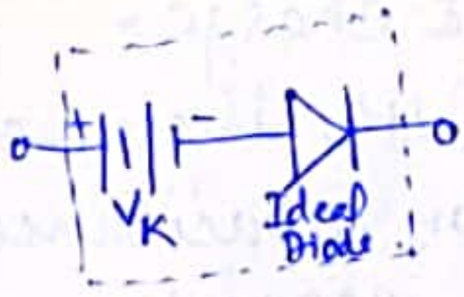
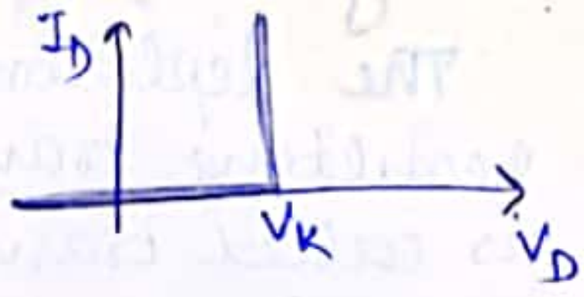
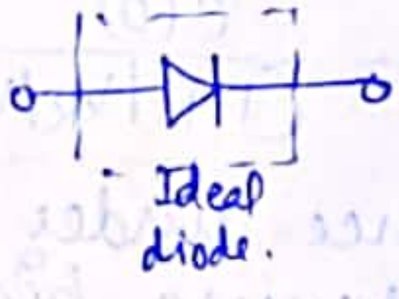
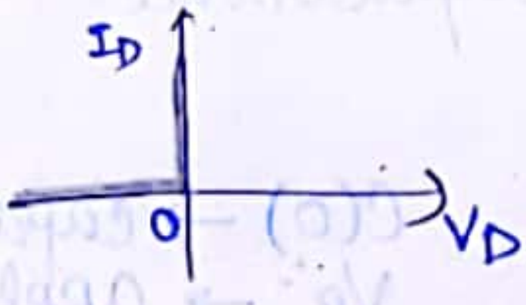


Ideal Equivalent Circuit :-

In case of Ideal diode, in F.B condition current flows and in reverse bias it is 0.





Type	Cond^n	Model.	Ch.
1) Piece-wise Model			
2) Simplified Model.	$R_{N/W} >> r_{av}$		
3) Ideal device	$R_{N/W} >> r_{av}$ $E_{N/W} >> V_K$		

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Transition & Diffusion capacitance :-

EVERY ELECTRONIC OR ELECTRICAL DEVICE IS FREQUENCY SENSITIVE.

At low ~~of~~ to mid frequency the device may have fixed parameters (resistance) but at high frequency, stray capcitive & Inductive effects affect the total impedance of device.

For the diode stray capacitance levels have greatest effect.

At low frequencies, Relatively small capacitance levels. ∴ Reactance $X_C = \frac{1}{2\pi fC}$ is usually so high, so it can be considered infinite in magnitude. or open circuit.

However at high frequencies X_C reduce to a point where it introduce "shorting" path. Due to this diode is unaffected by other elements of N/w.

In a p-n junction SC there are two Capacitive effects: ~~present~~

1) Transition Capacitance
2) Diffusion capacitance.

both are present in F.B and R.B but one outweigh the other in each Region.

1) Transition Capacitance :-

$$C = \frac{\varepsilon A}{d}.$$

$\varepsilon \rightarrow$ permittivity of dielectric
$A \rightarrow$ Area
$d \rightarrow$ distance seperate by plates

In diode depletion region behaves like insulator b/w the layers of opposite charge.

The depletion width ~~increase~~/decrease in R.B then resulting transition capacitance also decrease. This cap is called transition capacitance (C_T); or depletion region capacitance.

$$C_T = \frac{C(0)}{(1 + |V_R/V_K|)^n}$$

$C(0) \rightarrow$ capacitance under no-bias condition.
$V_R \rightarrow$ applied reverse bias voltage.
$V_K \rightarrow$ diode ~~cu~~ threshold.

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$n \rightarrow 1/2$ or $1/3$ depending on manufacturing process of diode
~~for 1/2 step~~ 1/2 for step graded junction 1/3 → linearly graded junction

This capacitive effect is also present in F.B but it is negligible before diffusion capacitance in F.B.

Diffusion capacitance:-(or Storage capacitance)

This capacitance occur due to transport of Charge carrier between two terminals of the device. It directly depends on the rate at which charge is injected into the region just outside the depletion region. Due to that diode current increases which further increase level of diffusion capacitance.

Rate of change of injected charge carriers with applied voltage is cap. $C = \frac{dQ}{dV_D}$

C_D can be demonstrated by the following equation:

$$\boxed{C_D = \left(\frac{\tau_r}{V_K}\right) I_D}$$

$C = \frac{dQ}{dV_D}$

$dV_D \uparrow \rightarrow dQ \uparrow$

$\tau_r \rightarrow$ The minority carrier life-time ($\tau = RC$)

$V_K \rightarrow$ ~~Threshold~~ Knee Voltage

$I_D \rightarrow$ Diode Current.

$C_D = \frac{\tau I_D}{\eta V_T}$

This capacitance play important role in high-speed application.

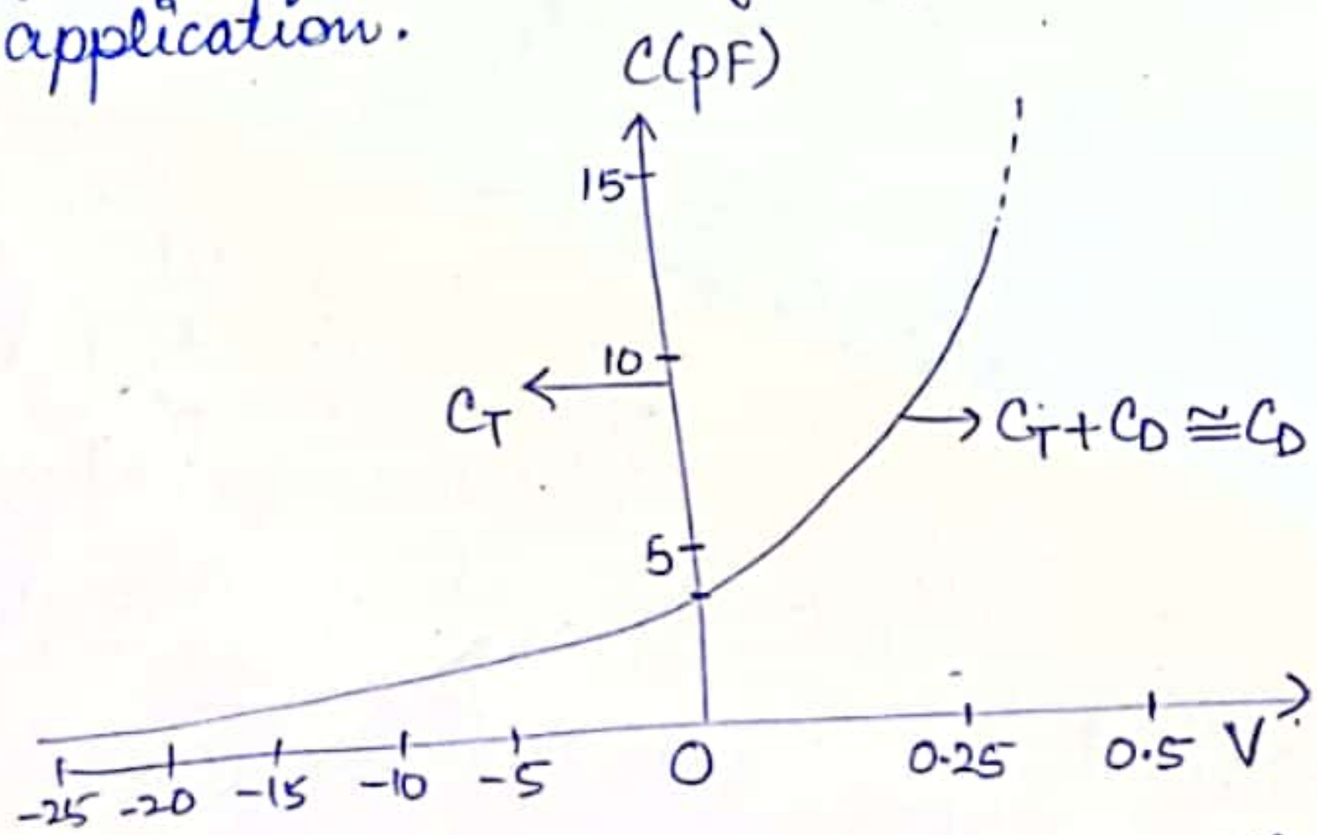
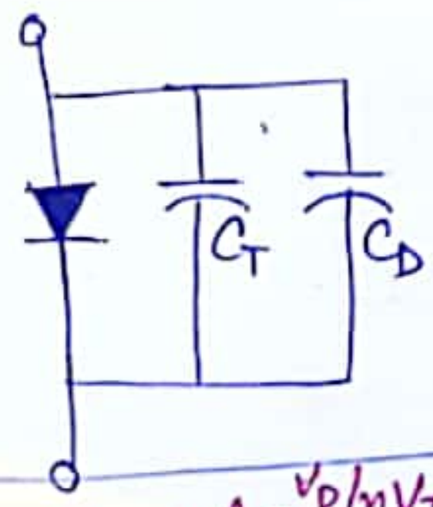


fig: Effect of C_T and C_D due to applied bias



Note:- C_T is predominant in R.B
C_D is predominant in ~~R.B~~ F.B.

Now $C_D = \frac{dQ}{dV_D} = \frac{d}{dV_D}\left[I_0 e^{V_D/\eta V_T} \tau\right]$

$= \frac{I_0 \tau}{\eta V_T} e^{V_D/\eta V_T} \Rightarrow \frac{\tau (I_0 e^{V_D/\eta V_T})}{\eta V_T} \Rightarrow \frac{\tau I_D}{\eta V_T}$

$I = I_0 (e^{V_D/\eta V_T} - 1)$

$= I_0 e^{V_D/\eta V_T} - I_0$

$I_0 << I_0 e^{V_D/\eta V_T}$

$\therefore I = I_0 e^{V_D/\eta V_T}$

we know that $Q = I\tau$

$\tau \rightarrow$ Mean life time of carrier

$Q = I_0 e^{V_D/\eta V_T} \cdot \tau$

F.B → nF to μF
R.B → pF

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Why Si is preferred over Germanium:-

(1) Reverse saturation current of Si diode (in nA) is much lower than Ge diode (in mA).

(2) Suitable for low temp as well as high temp application

	Temp Range
Si	-60°C to 175°C
Ge	-60°C to 75°C.

(3) Si is suitable for high power handling

(4) Easy Availability of Si

(5) Favourable property of fromation of SiO_2.

Only Disadvantage

→ Conductivity of Si is less than Ge.

Explain the effect of temperature on conductor & ~~Temp~~ SC ?
PTC. NTC.

NTC w.r.t resistor → SC

PTC " " → Conductor

Conductor has huge no. of free $\bar{e}$. So when temp is increased vibrations in atom also increased which further ~~decrease~~ restrict the free flow of $\bar{e}$. hence conductivity ↓.

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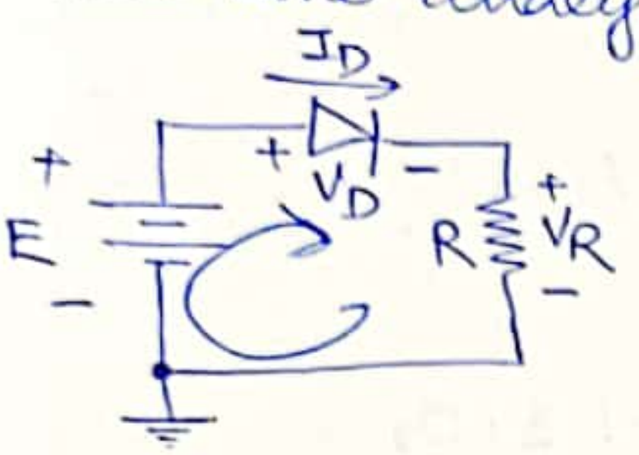
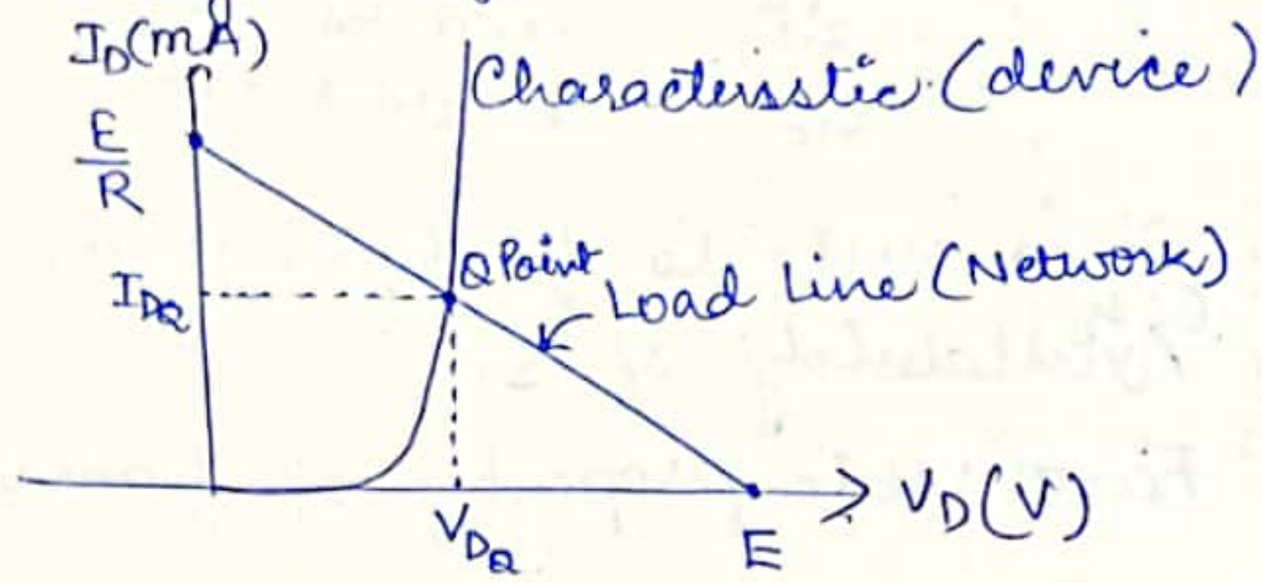
Diode Application:-

Load Line Analysis:-

A straight line is called as load line which intersect vertical axis at applied load R and Horizonal axis by applied voltage (E). The intersection of two curves will define the solution of N/w and will define current & voltage level of N/w. The analysis to follow this is called as Load-Line analysis.





$E - V_D - I_D R = 0$

$$\boxed{E = V_D + I_D R} \longrightarrow$$

At horizontal Axis, $I_D = 0$

$$\boxed{V_D = E \Big|_{I_D=0}}$$

At Vertical Axis, $V_D = 0$

$E = 0 + I_D R$

$$\boxed{I_D = \frac{E}{R}\Big|_{V_D=0}}$$

Quiescent Point :- Point of operation

⇒ The Load line is determined solely by the applied N/w, whereas the characteristics are defined by choosen device.

Question :- For the series diode configuration determine : a) V_{DQ} & I_{DQ} b) V_R.

Sol^n: $I_D = \frac{E}{R}\Big|_{V_D=0V}$

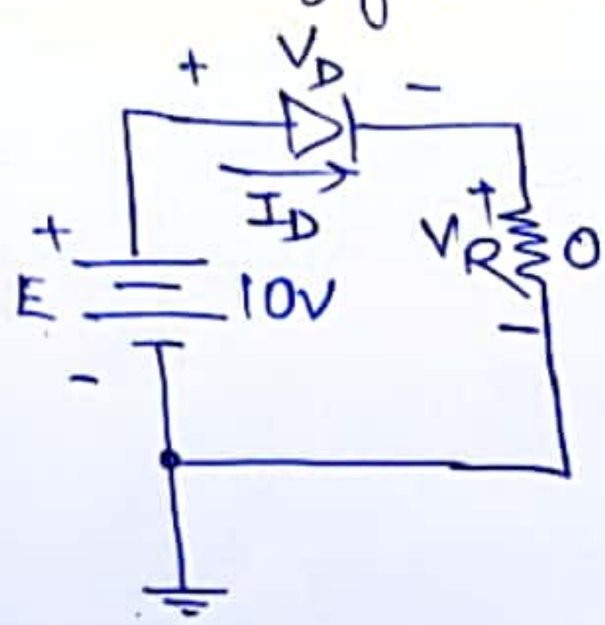
$I_D = \frac{10V}{0.5K\Omega} = 20mA$

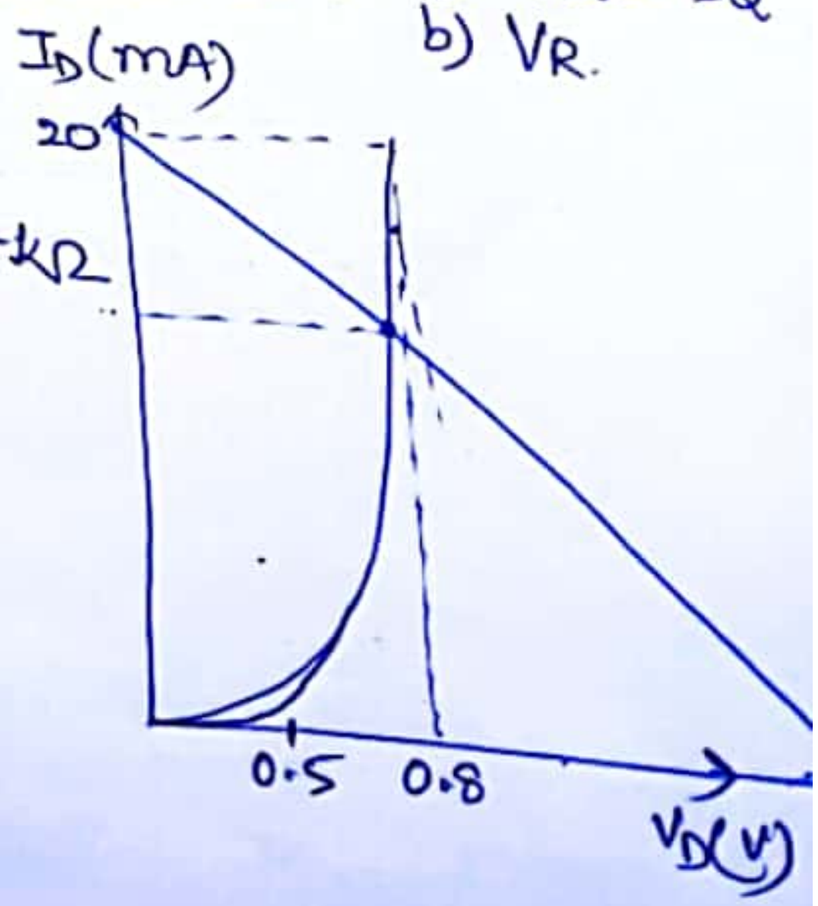
$V_D = 10V$

$V_{DQ} = 0.78V$.

$I_{DQ} = 18.5mA$

$R_D = \frac{V_{DQ}}{I_{DQ}} = \cancel{46}.42.16\Omega$





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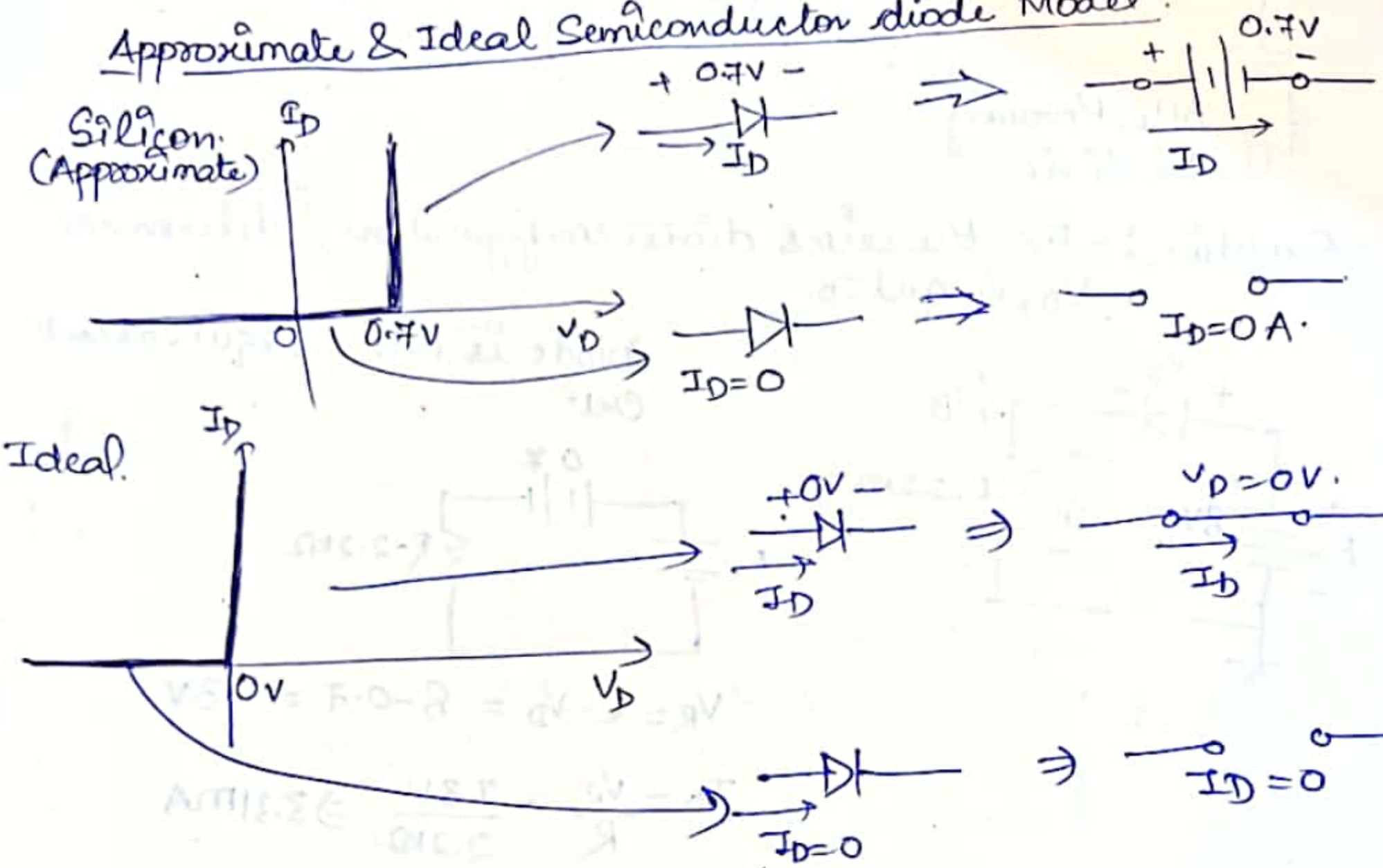
Series diode Configuration:-

The Forward resistance of diode is usually so small compared to other series elements of the N/w that it can be ignored.

Approximate & Ideal Semiconductor diode Model.



* When diode is in on-state if current established by applied current source such that its direction is matches with diode symbol and.

$V_D \geq 0.7V \longrightarrow$ for Si

$V_D \geq 0.3V \longrightarrow$ for Ge.

$V_D \geq 1.2V \longrightarrow$ for GaAs.

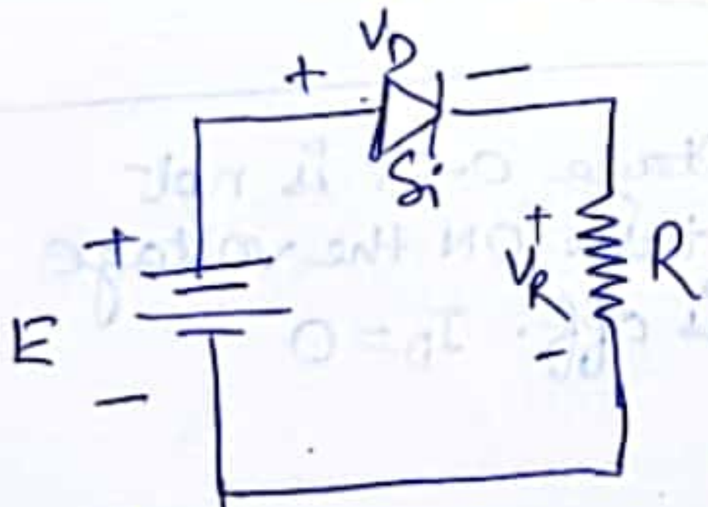
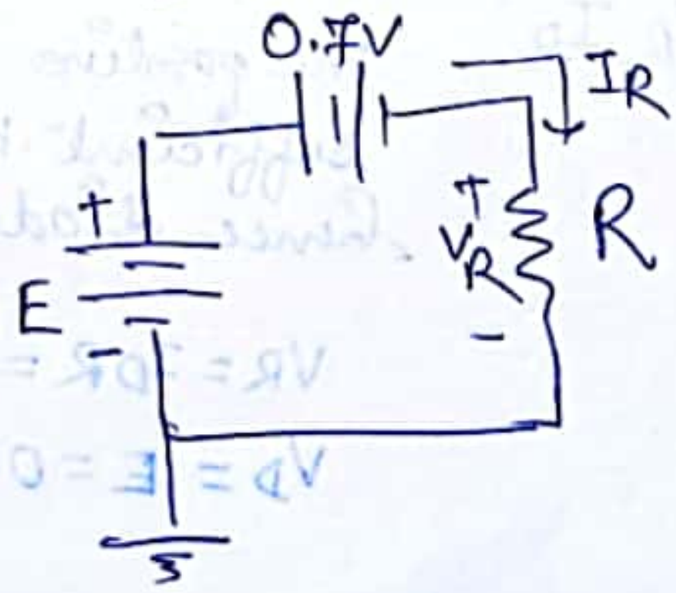


fig: Series Diode Configuration

Substitute the equivalent Model.



$$\boxed{V_R = E - 0.7}$$

$$\boxed{I_D = I_R = \frac{V_R}{R}}$$

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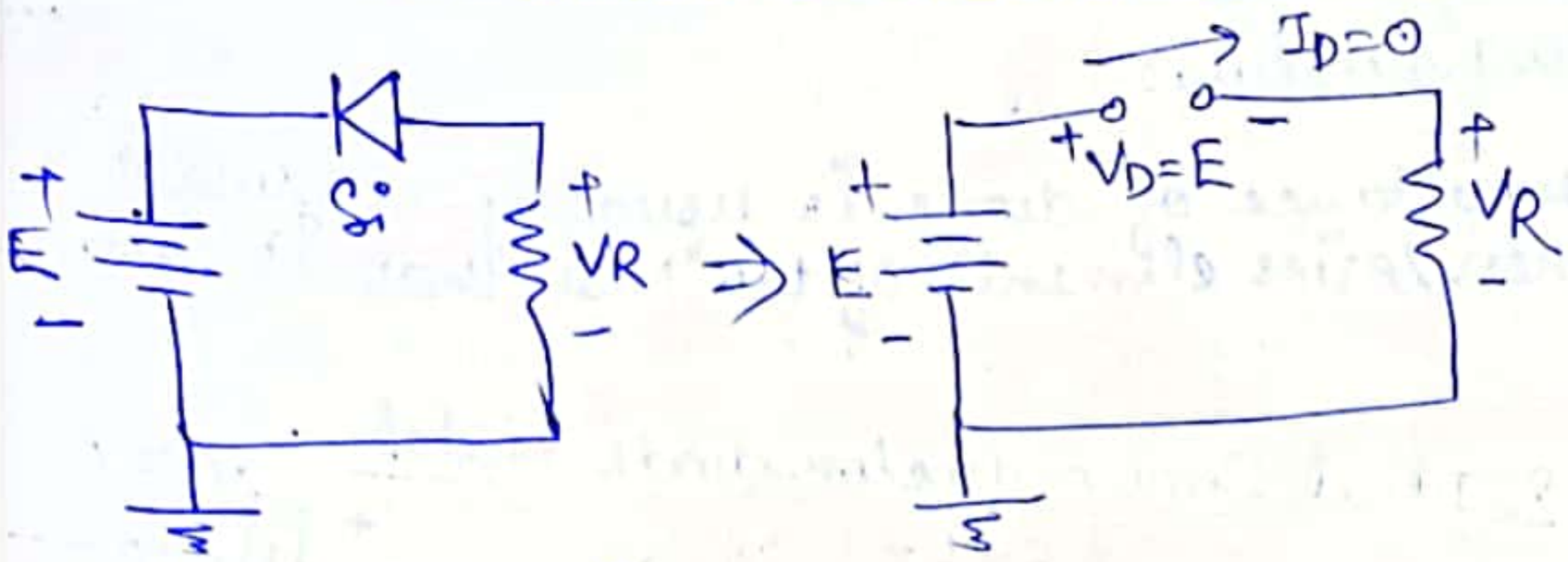
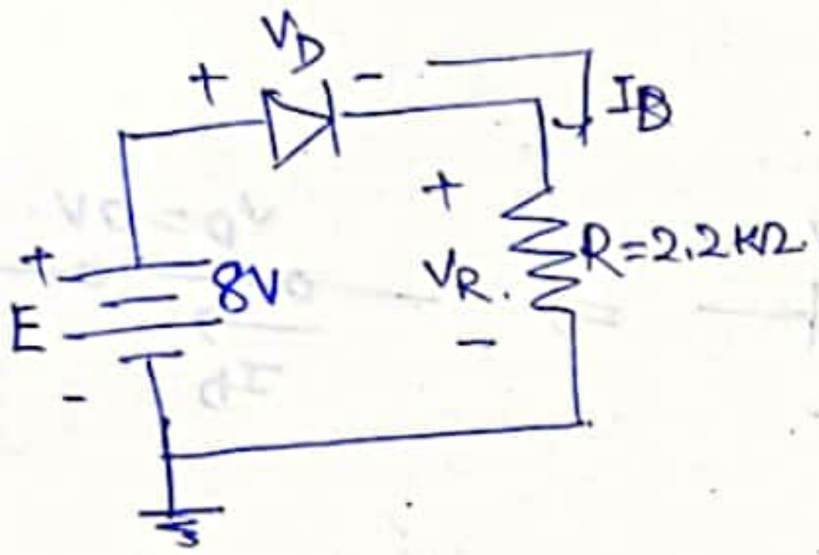
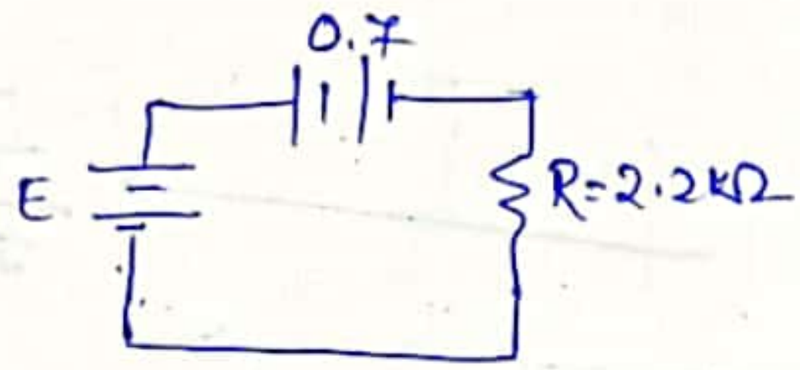


fig: After Reversing the diode.

<u>Question</u>:- For the series diode configuration, determine V_D, V_R and I_D.



Diode is F.B. ∴ equivalent ckt.

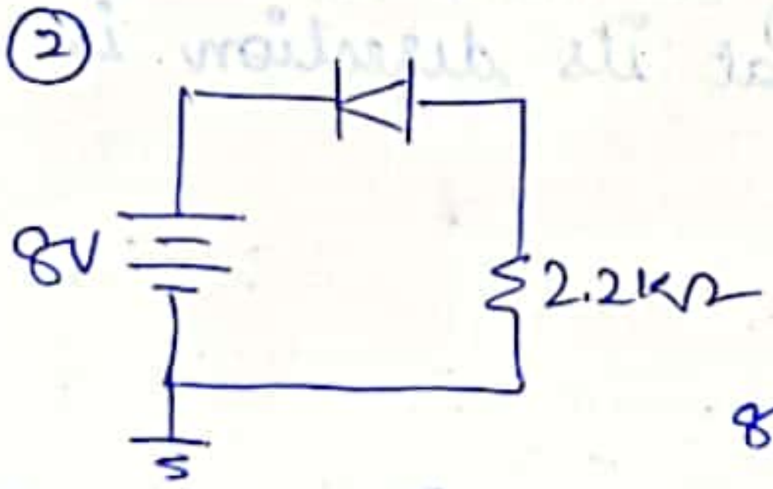


$V_R = E - V_D = 8 - 0.7 = 7.3V$

$I_D = \frac{V_R}{R} = \frac{7.3V}{2.2K\Omega} \Rightarrow 3.31mA$

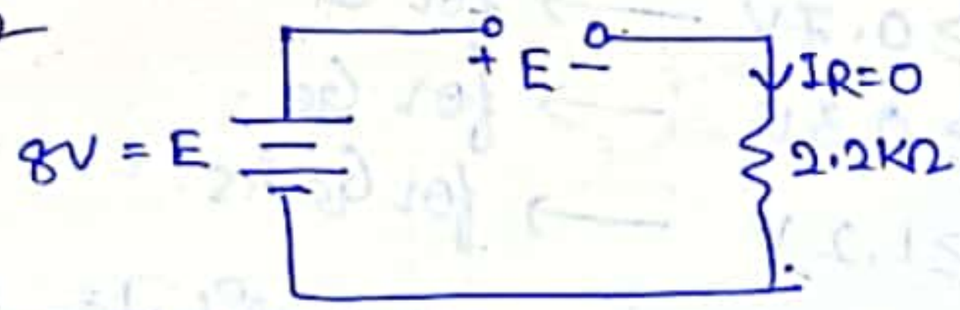
---

(2)



Diode is R.B.

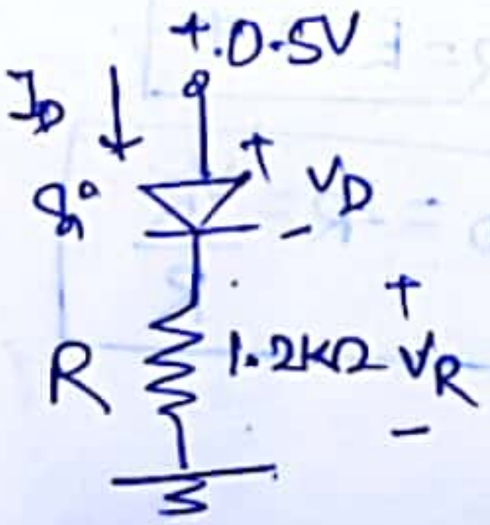
$V_R = V_D = E$ $\quad I_D = 0 \quad I_R = 0$



$V_D = 8V$.
$V_R = 0V$
$I_D = 0V$

---

(3) Determine V_D, V_R, I_D



The positive voltage 0.5V is not sufficient to turn ON the voltage hence diode is off. $I_D = 0$

$V_R = I_D R = 0$

$V_D = E = 0.5V$

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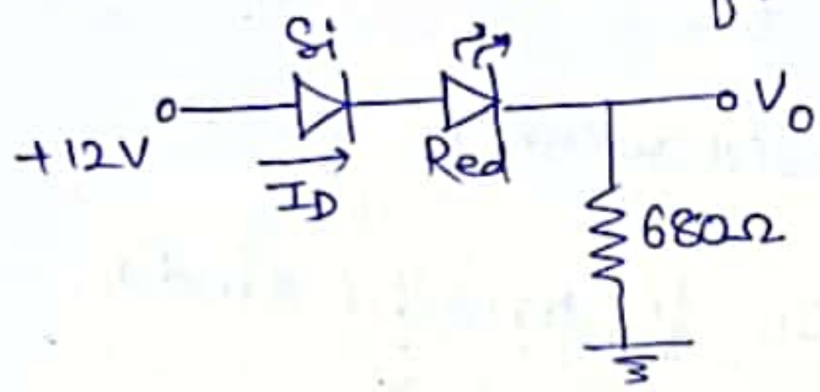
③ Determine V_0 & I_D for series circuit. V_T for Red LED = 1.8V.

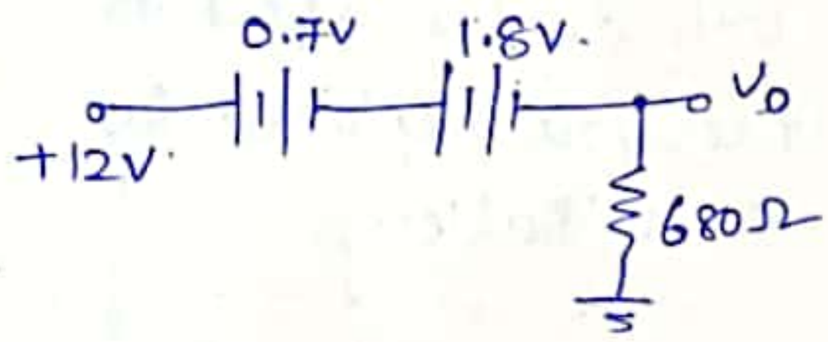


$\because V_{T_{Si}} = 0.7$

$V_{T_{RedLED}} = 1.8V$

$\because 12V < (0.7 + 1.8)$

$\therefore$ Diode is ON.



$V_0 = 12 - (0.7 + 1.8)$

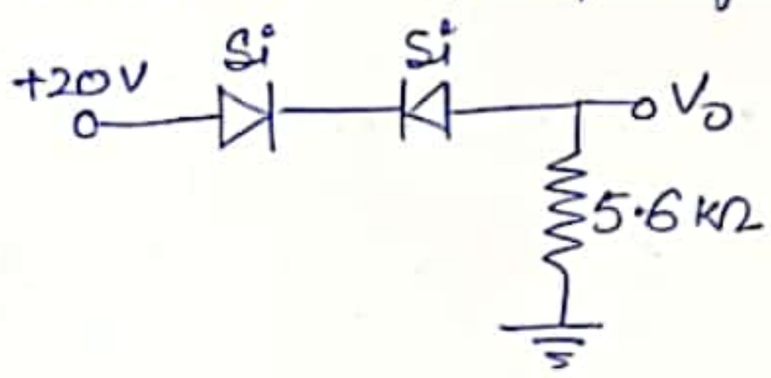
$= 12 - 2.5$

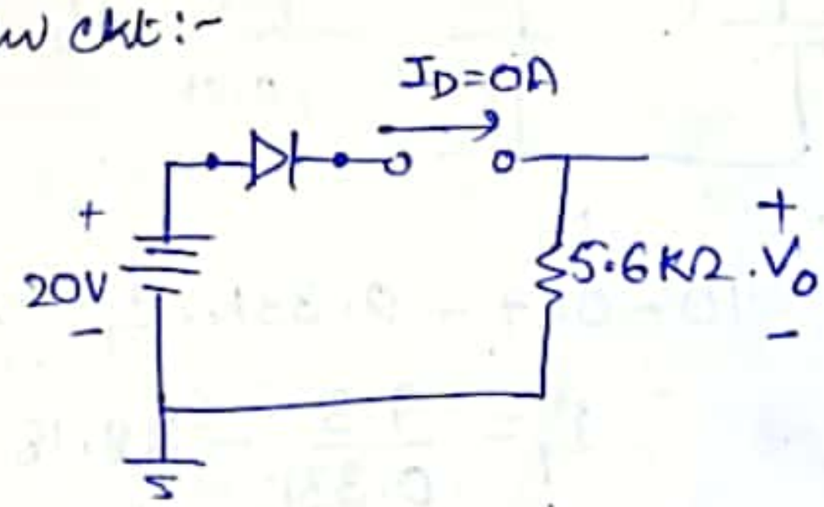
$\boxed{V_0 = 9.5V}$

$I_D = \frac{9.5}{680\Omega} = \underline{13.97mA}$

---

④ Determine I_D, V_{D_2}, V_0 for given ckt:-





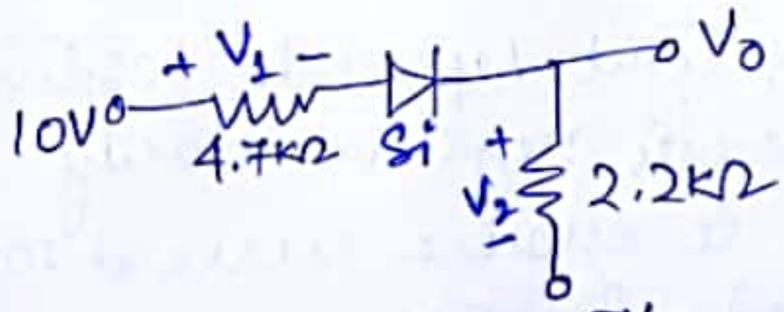
$I_D = 0A$ (because combination of s/ckt in series with o/ckt ~~cause~~ result open ckt).

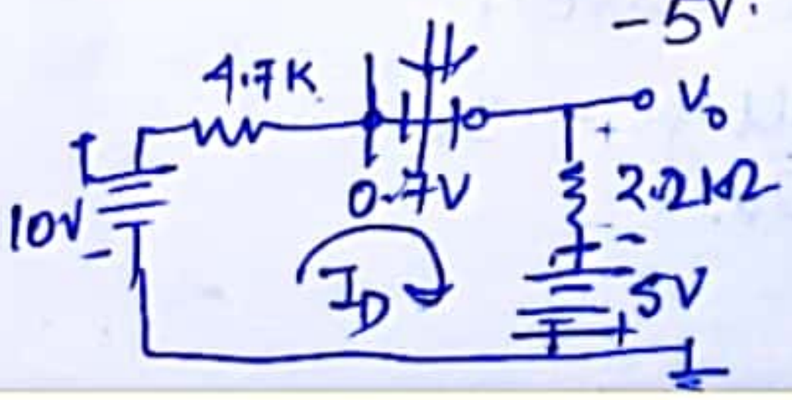
$V_{D_2} = E = 20V$

$V_0 = I_R \times 5.6K\Omega = 0V$.

---

⑤ Determine I, V_1, V_2 & V_0 for given series ckt.





$10 - 4.7KI_D - 0.7 - 2.2I_D + 5 = 0$

$14.3 = 6.9KI_D$

$I_D = \frac{14.3}{6.9} mA = \underline{2.072mA}$

$V_1 = I_D \times 4.7K = 2.072 \times 4.7K$
$= \underline{9.74V}$

$V_2 = I_D \times 2.2K = \underline{4.56V}$

$V_0 = 4.56 - 5 \Rightarrow \underline{-0.44V}$

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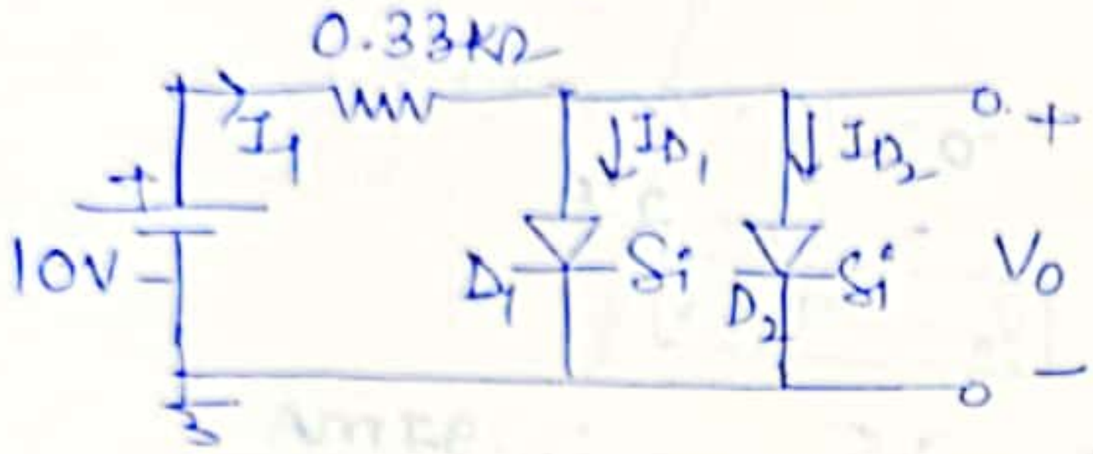
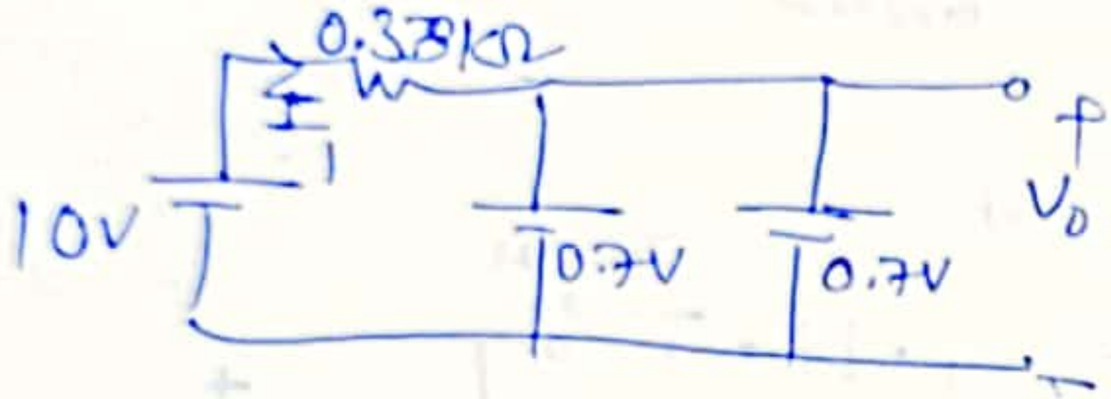
Parallel & Series-Parallel Configurations

Same method is applied as ~~were~~ were in series configuration.

Question: Determine V_o, I_1, I_{D_1} & I_{D_2} for parallel diode configuration:



both diodes are F.B therefore replaced by 0.7V Battery.



$$\boxed{V_o = 0.7V}$$

$$10 - 0.7 - 0.33k\Omega\, I_1 = 0$$

$$I_1 = \frac{9.3}{0.33K} = 28.18\ mA$$

$$I_1 = 28.18mA$$

∵ both diodes have similar Ch.

$$I_{D_1} = I_{D_2} = \frac{I_1}{2} = \frac{28.18}{2} = 14.09mA$$

$$\boxed{I_{D_1} = I_{D_2} = 14.09mA}$$

★ (Advance)

(2) In polarity detector, green light represents positive polarity and red light represents negative polarity. Find the result resistor R to ensure current 20mA through ON diode. both diode have

Reverse breakdown voltage = 3V.

Avg turn-on voltage = 2V.

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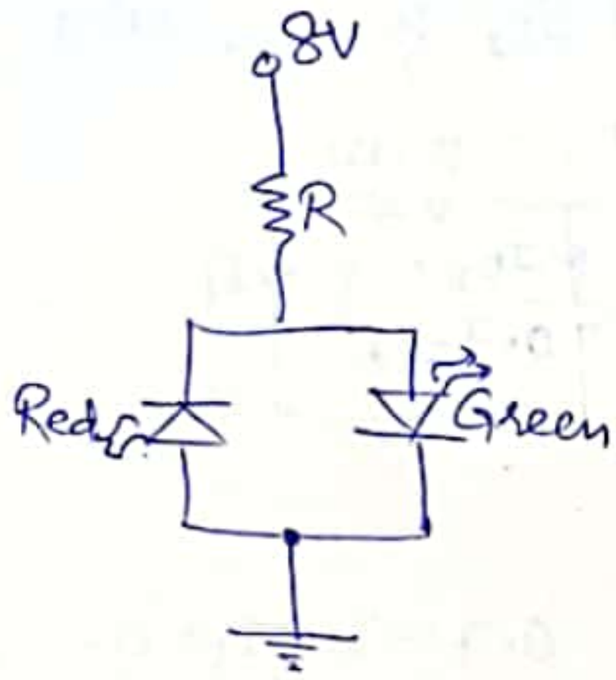
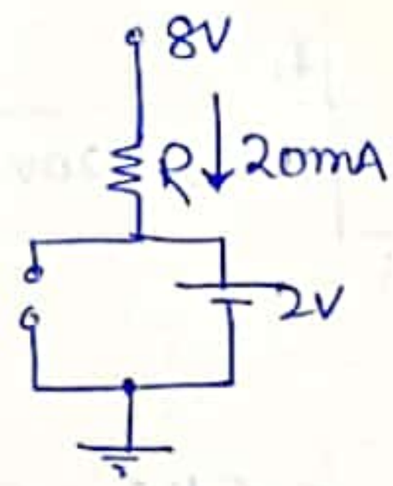


For positive polarity Green LED → ON
Red LED → OFF

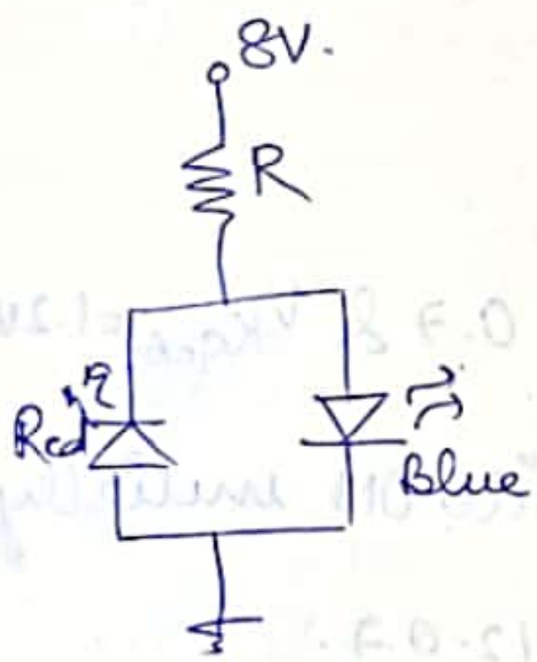


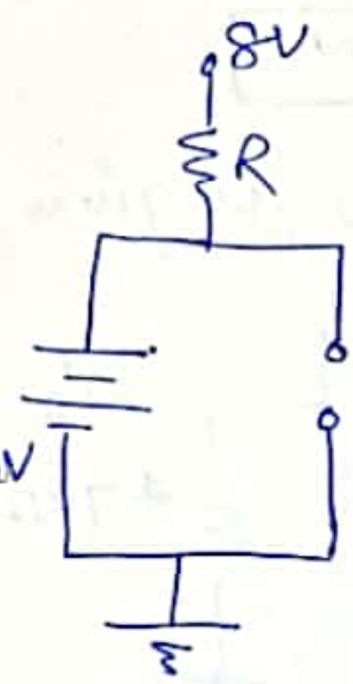
$R = \frac{8-2}{20mA}$

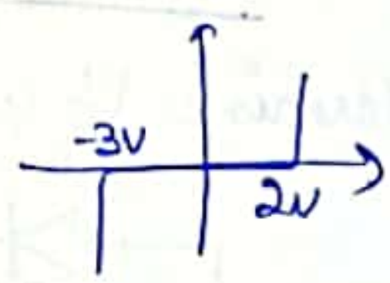
$= \frac{6}{20mA} \Rightarrow 300\Omega.$

$\boxed{R = 300\Omega}$

Ques3 :- In above problem if green diode is replaced by blue diode. Find ~~the~~ turn on voltage of blue diode is 5V.

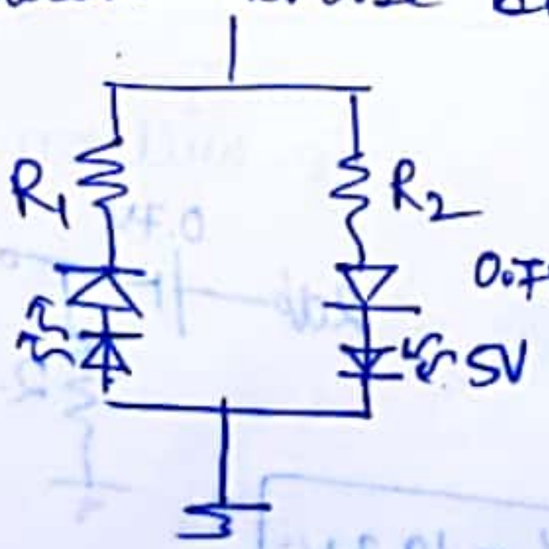






This cause damange of blue LED.

A simple solution to it to add appropriate resistance level to both diodes in series including other Si diode to represent reverse bias total breakdown voltage rating.



In this case when blue LED → ON
Red LED → off.

$= 5.7V$ Cause Total Voltage drop 5.7V. in series with blue LED.

Voltage accross $R_1 = 2.3V$.

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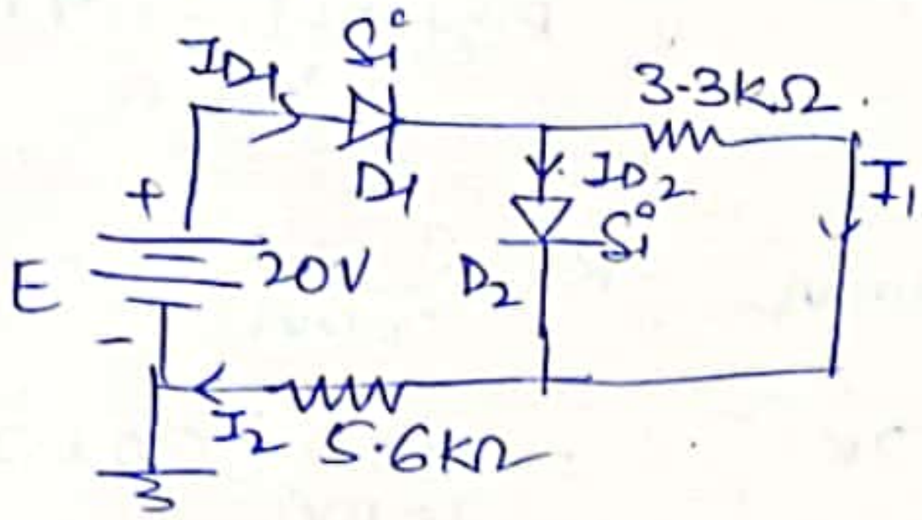
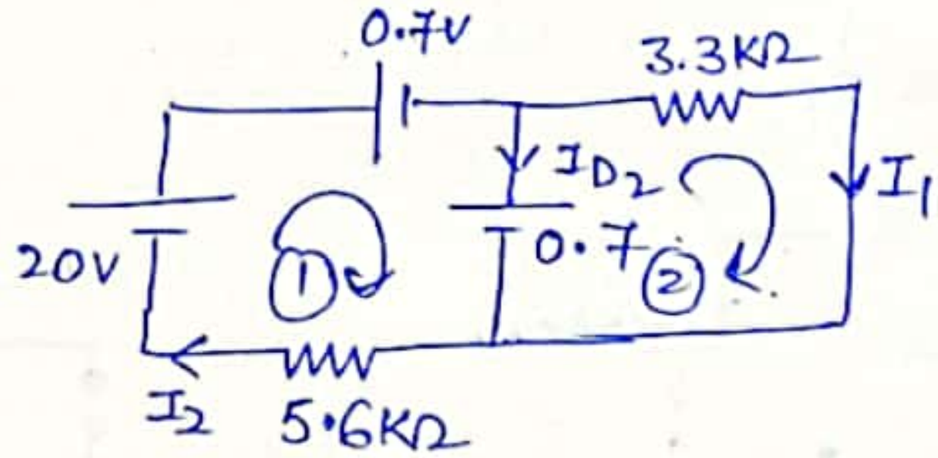
Question ④ Determine the currents I_1, I_2 and I_{D_2} for the N/w.





$$20 - 0.7 - 0.7 - 5.6K I_2 = 0$$

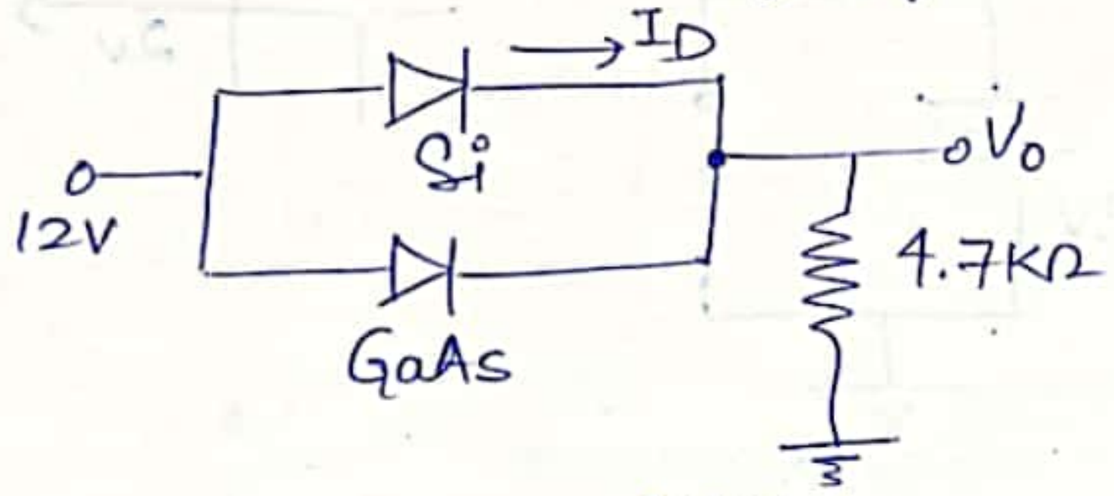
$$I_2 = \frac{18.6}{5.6} \Rightarrow 3.321 \text{ mA}$$

$$I_{D_2} = I_2 - I_1$$
$$= 3.321 - 0.212$$
$$\boxed{I_{D_2} = 3.11 \text{ mA}}$$

$$0.7 - 3.3 I_1 = 0$$
$$I_1 = \frac{0.7}{3.3} \text{ mA}$$
$$\boxed{I_1 = 0.212 \text{ mA}}$$

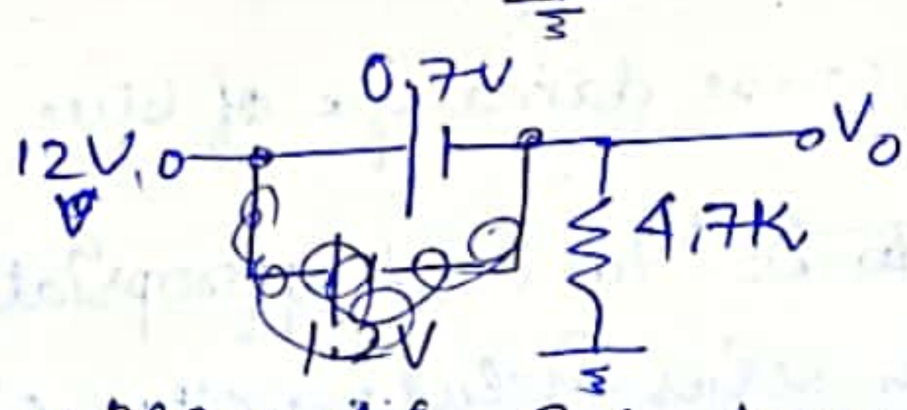
⑤ Determine V_o and I_D for given networks.

a)



$V_{K_{Si}} = 0.7$ & $V_{K_{GaAs}} = 1.2V$.

∴ Si will ON initially



$V_o = 12 - 0.7$

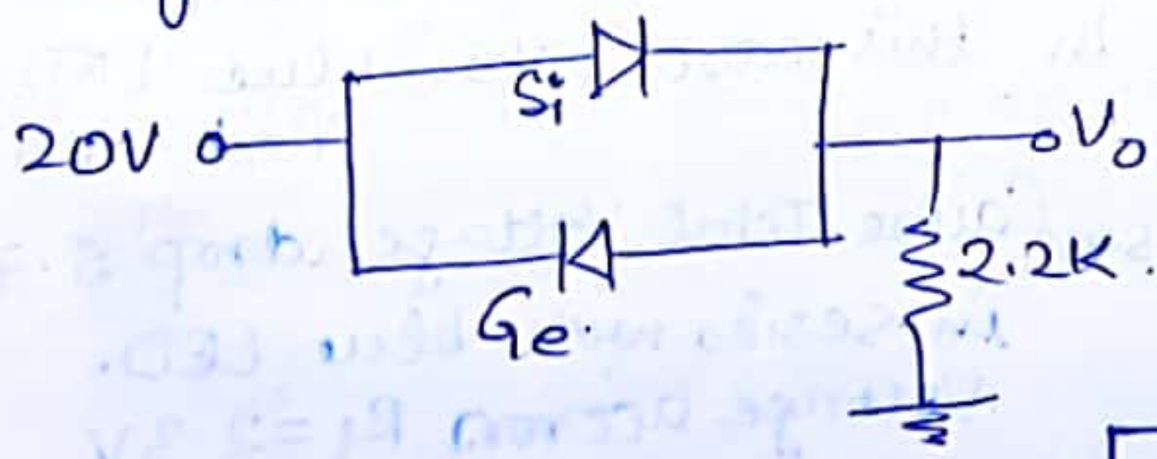
$\boxed{V_o = 11.3V}$

$$I_D = \frac{V_o}{4.7K} = \frac{11.3}{4.7} \text{ mA}$$

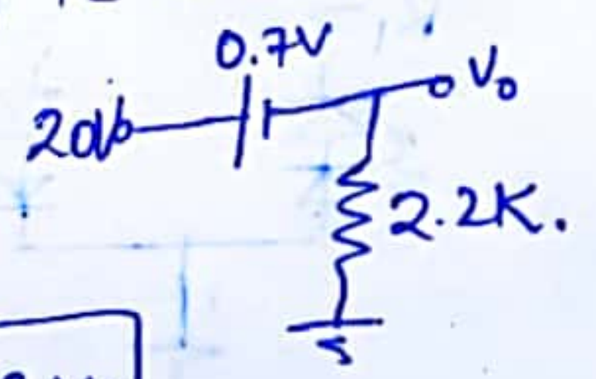
$\boxed{I_D = 2.40 \text{ mA}}$

⇒ Si diode on preventing GaAs from turning on.

b)



Ge will on first



$\boxed{V_o = 19.3V}$

$I_D = 2.2 \times 19.3$

$\boxed{I_D = 42.46 \text{ mA}}$

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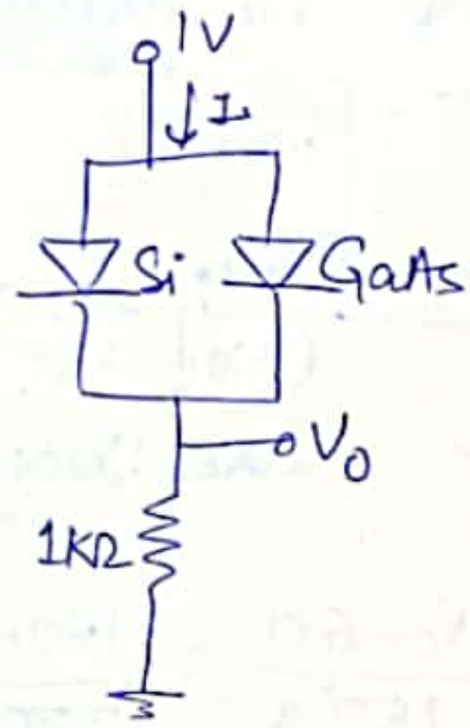
N/w.

(4) Determine V_0 and I for N/ws?

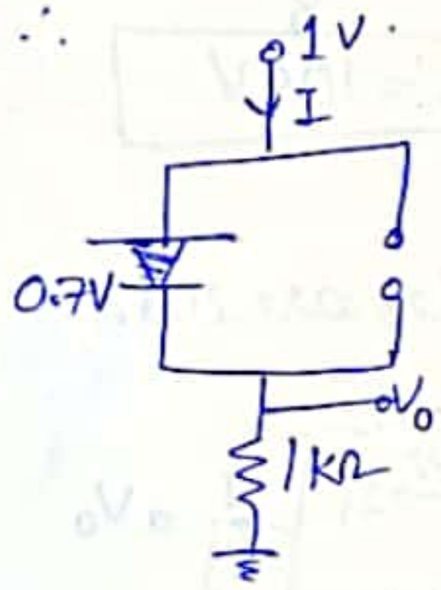
a)



Si Conc pass

V_K of Si is lower than V_K of GaAs.

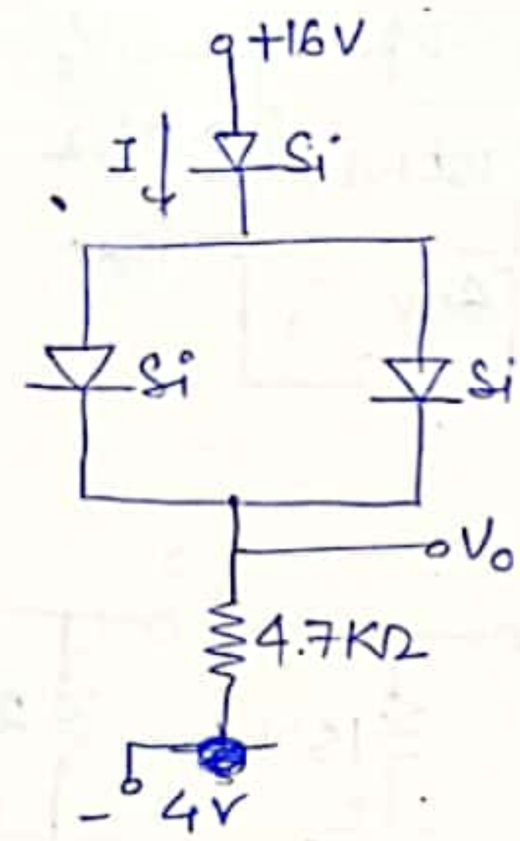
∴

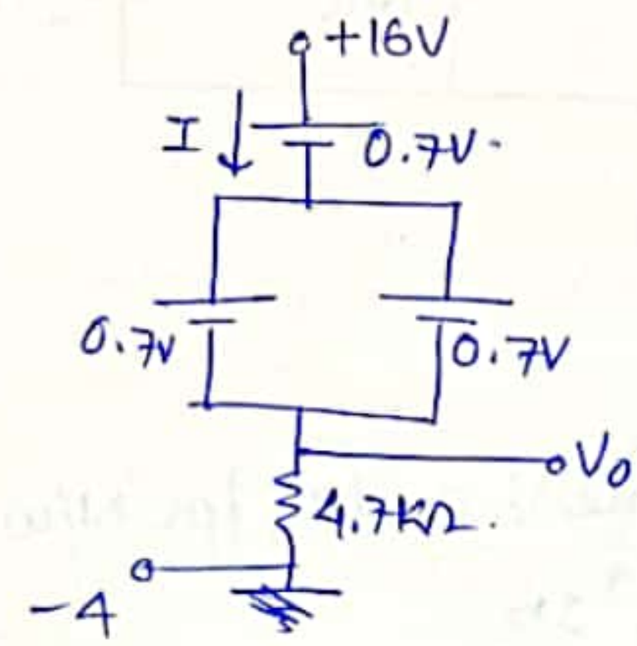


$I = \frac{0.3}{1K\Omega} \Rightarrow 0.3mA$

$\boxed{V_0 = 0.3V}$

b)





~~$V_0 = 16 - 1.4 = 14.6V$~~

~~$\boxed{V_0 = 14.6V}$~~

~~$I = \frac{14.6}{4.7K\Omega} = mA$~~

$16 - (0.7)^{\times 2} - V_0 = 0$

$\boxed{V_0 = 14.6V}$

$16 - 1.4 - 4.7I + 4 = 0$

$I = \frac{18.6}{4.7} = 3.96\ mA$

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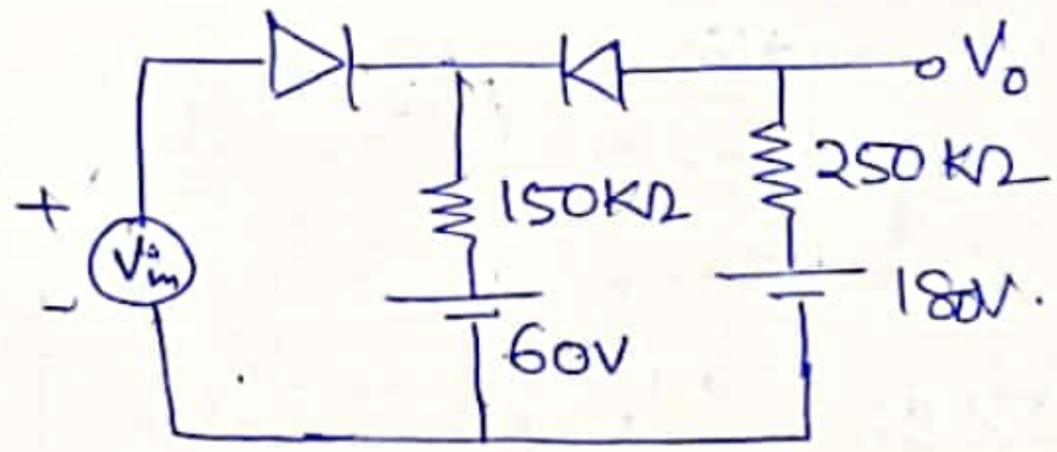
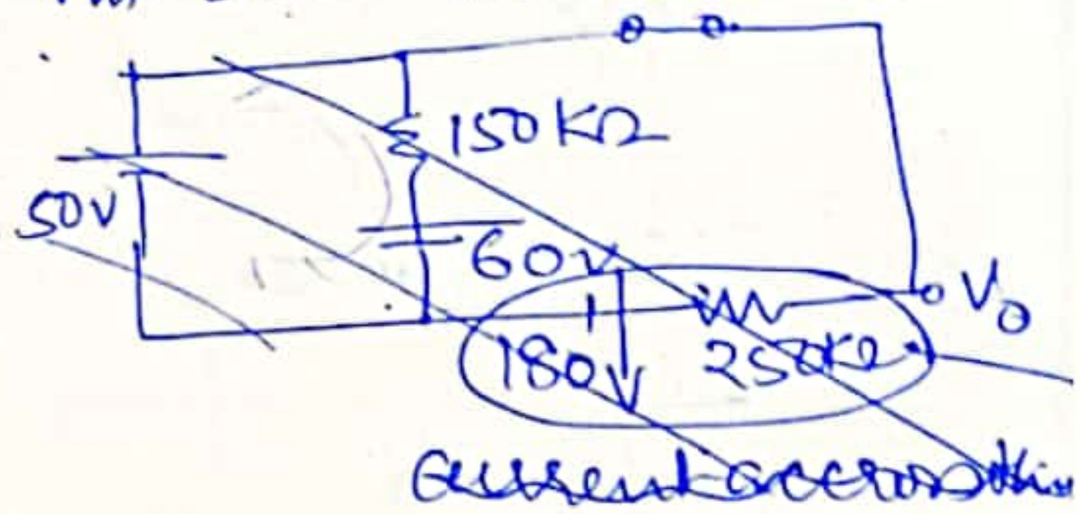
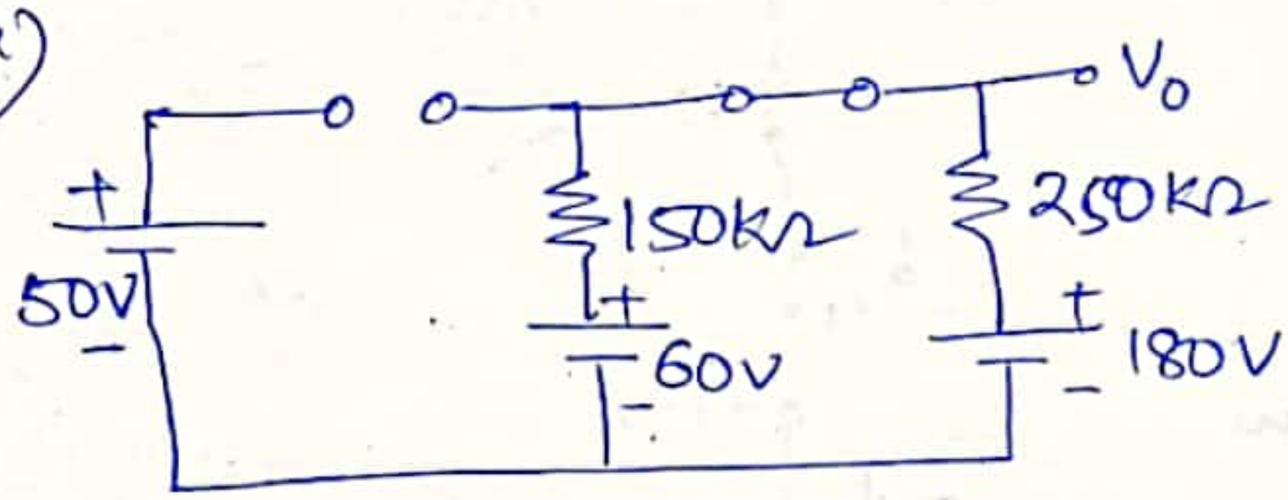
(7) Determine o/p voltage for $V_m = 50V$; $V_m = 80V$; $V_m = 180V$



(a) $V_m = 50V$. For Ideal diode



a)



$$\frac{V_o - 60}{\cancel{150}\ 3} = \frac{180 - V_o}{\cancel{250}\ 5}$$

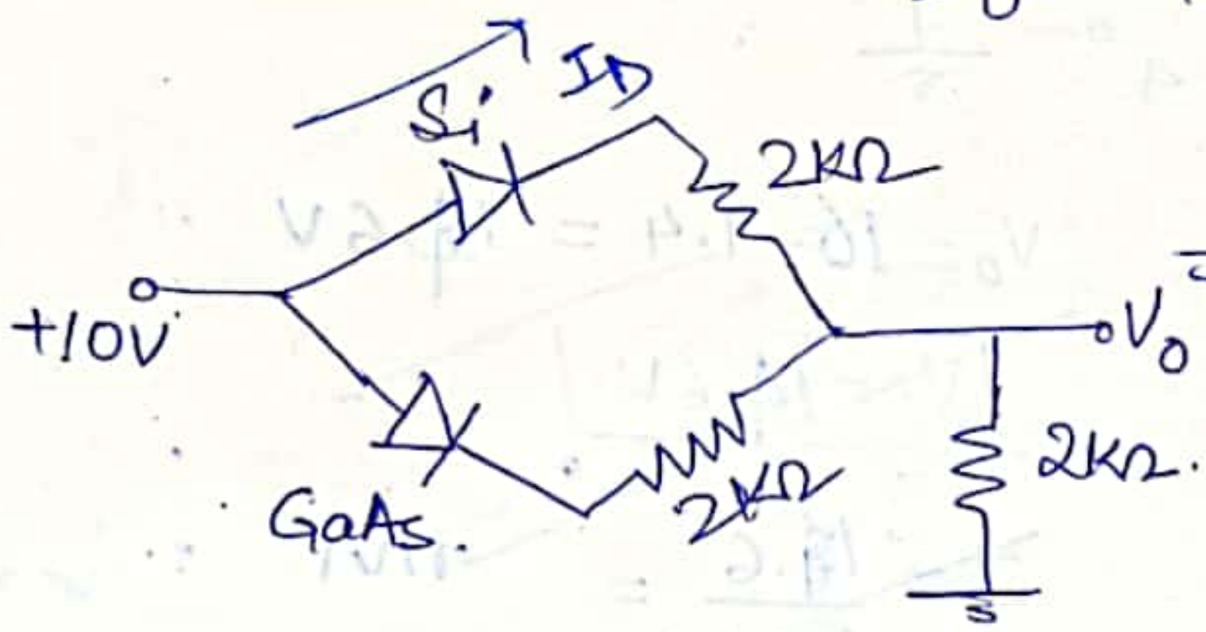
$$5V_o - 300 = 540 - 3V_o$$

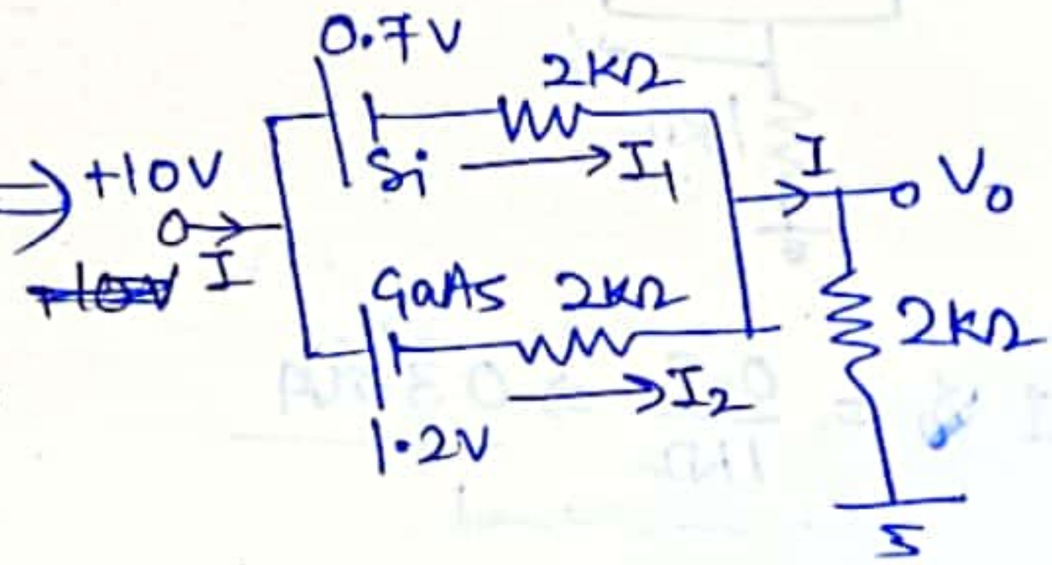
$$8V_o = 840$$

$$V_o = \frac{840}{8} = 105V.$$

$$\boxed{V_o = 105V}$$

(8) Determine V_o and I_D for N/w. both diodes are ON.





$$I_1 = \frac{10 - 0.7 - V_o}{2K} \qquad I_2 = \frac{10 - 1.2 - V_o}{2K}.$$

$$I = \frac{I_1 + I_2}{2} \qquad I = \frac{V_o}{2K}.$$

$$\frac{V_o}{2K} = \frac{10 - 0.7 - V_o}{2K} + \frac{10 - 1.2 - V_o}{2K}$$

$$V_o = 20 - 1.9 - 2V_o$$

$$3V_o = \frac{18.1}{1} \qquad V_o = \frac{18.1}{3} = 6.03V$$

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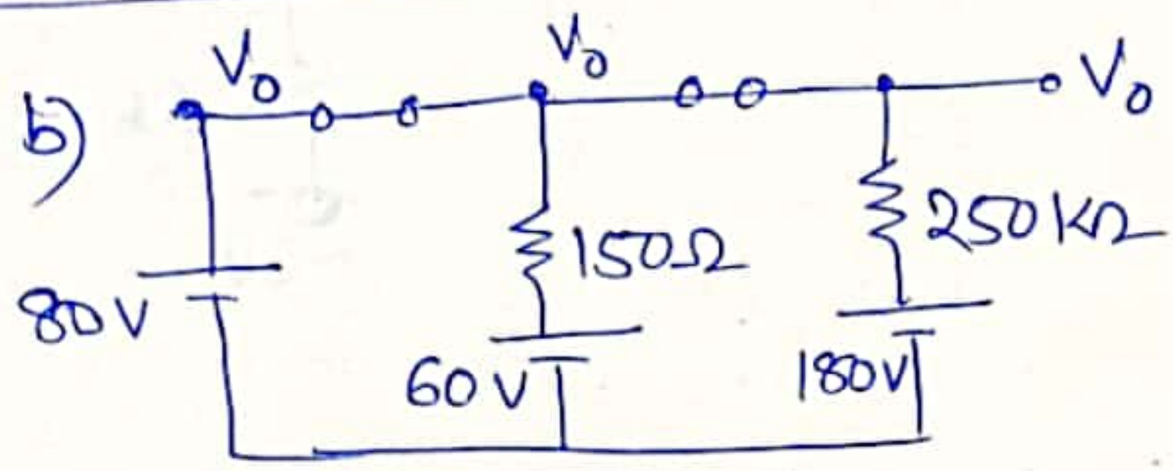
$\boxed{V_0 = 6.03V}$

$$I_D = I_1 = \frac{10 - 0.7 - 6.03}{2K} = \frac{10 - 6.73}{2K} = \frac{3.27}{2}$$

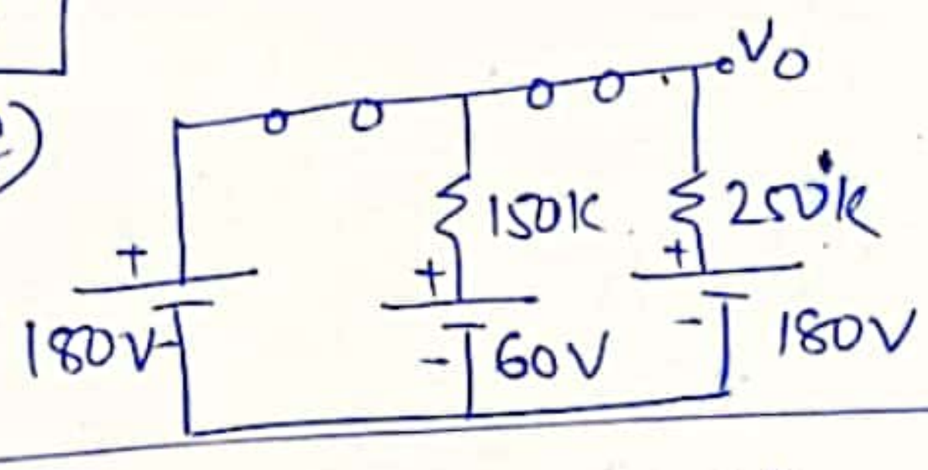
$\boxed{I_D = 1.635\,mA}$

b)



$\boxed{V_0 = 80V}$

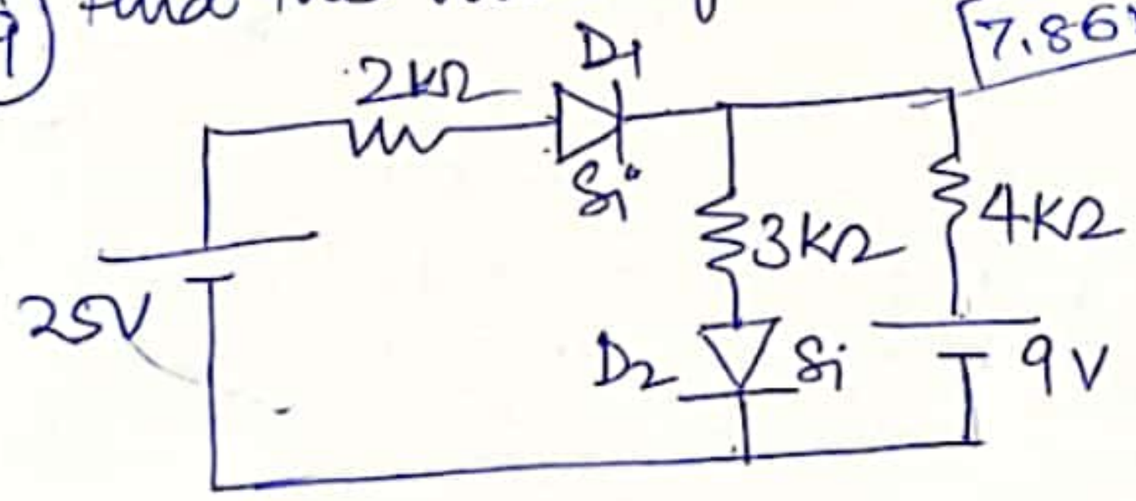
Similarly c)



$\boxed{V_0 = 180V}$

(9) Find the value of current through D_2:

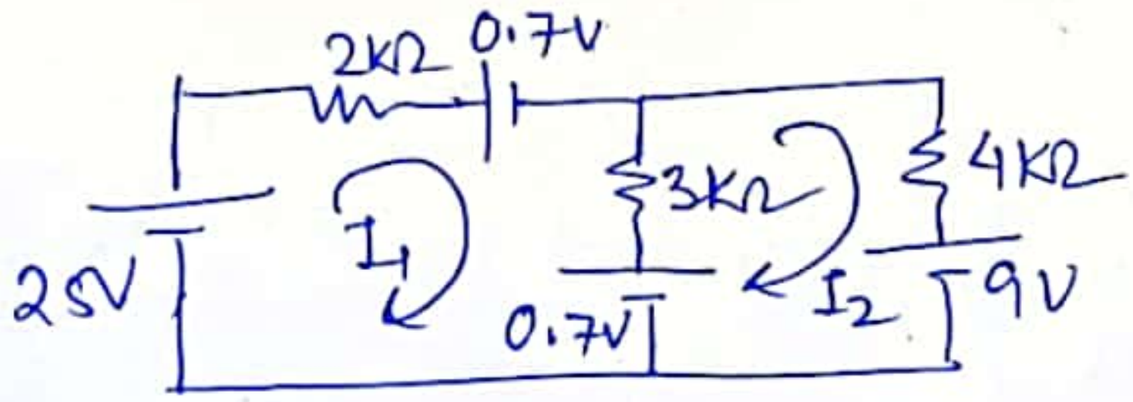
$\boxed{7.86\,mA \text{ Ans}}$



Loop (1)

$$25 - 2KI_1 - 0.7 - 3K(I_1 - I_2) - 0.7 = 0$$

$$5I_1 - 3I_2 = 23.6 \quad \text{—— (1)}$$



$$0.7 - 3(I_2 - I_1) - 4KI_2 - 9 = 0$$

$$-7KI_2 + 3KI_1 = 8.3 \quad \text{—— (2)}$$

apply Mesh analysis,

$$15I_1 - 9I_2 = 70.8$$

$$(-)\ 15I_1 \ (+)\ 35I_2 = 41.5$$

$$26I_2 = 29.3$$

$$I_2 = \frac{29.3}{26} = 1.126\,mA$$

sub I_1 in eqn (1)

$$5I_1 = 23.6 + 3I_2$$

$$I_1 = \frac{26.978}{5} = 5.3976 \approx 5.4\,mA$$

$$I = I_1 - I_2 = 5.4 - 1.126 \Rightarrow 4.27\,mA$$

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Rectifier :-

Diodes are used in rectifiers which are used in d.c power supply.

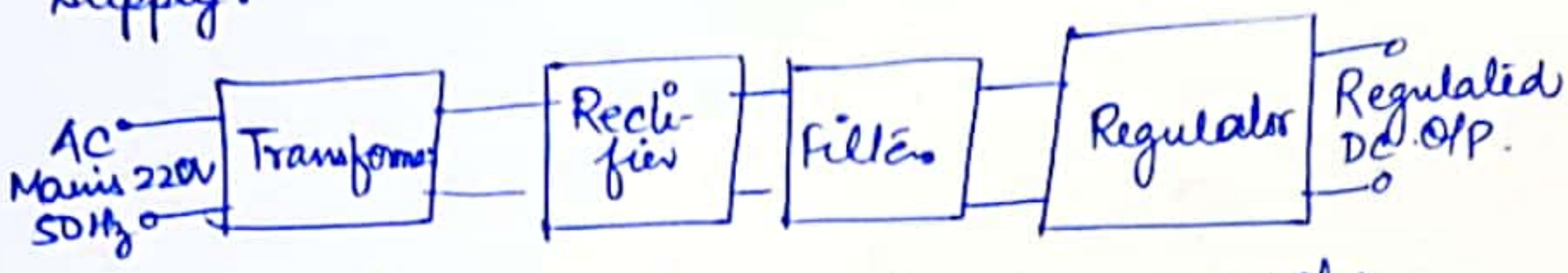


fig: Block diagram of a power supply.

Transformer :- It steps up or step down the ac mains voltage ~~into d.c voltage~~ according to requirement. It provides isolation.

Rectifier :- A rectifier converts ac voltage into d.c voltage.

Filter :- The O/P of rectifier May contain ripples. These ripples are removed with the help of filters.

Regulators :- It provide constant d.c voltage or regulated d.c irrespective of change in load or I/p Voltage.

Half Wave Rectifier :-

A rectifier circuit convert a.c. voltage into pulsating d.c. voltage. There are two type of Rectifiers.

1) Half Wave Rectifier
2) Full Wave Rectifier

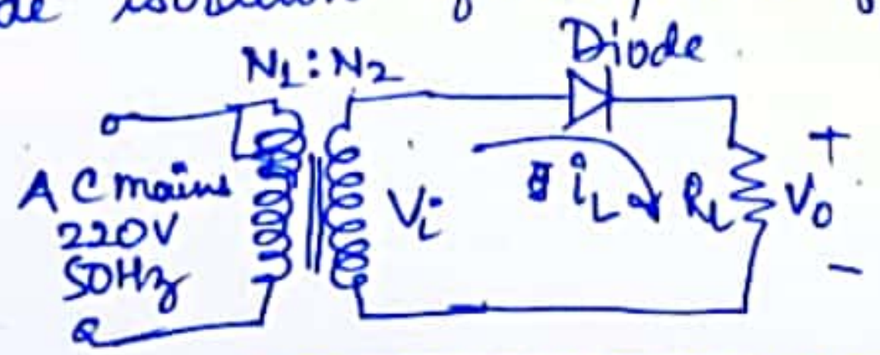
1) Half Wave Rectifier :-

It has transformer as an input to rectifier circuit.

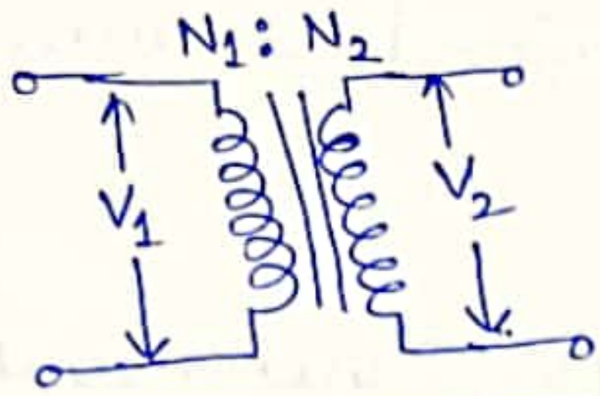
Transformer has two F^n s:

→ It allows to step the source up and down.

→ It provide isolation of a.c power from rectifier circuit



$V_i = V_m \sin \omega t$

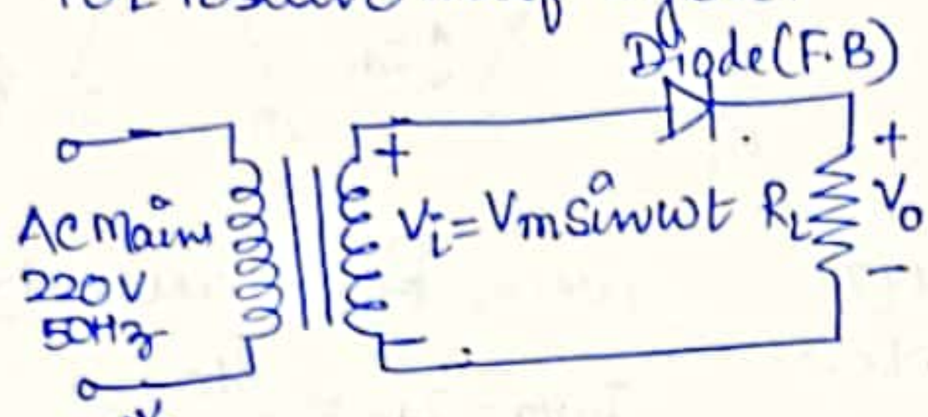


The primary and secondary voltage of transfor. are:

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

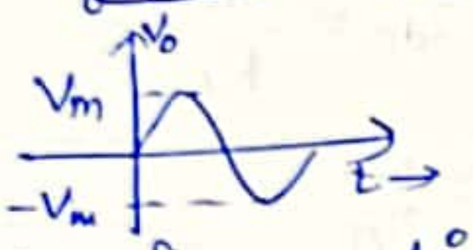
$$\boxed{V_i = V_m \sin \omega t}$$

For Positive half cycle :-

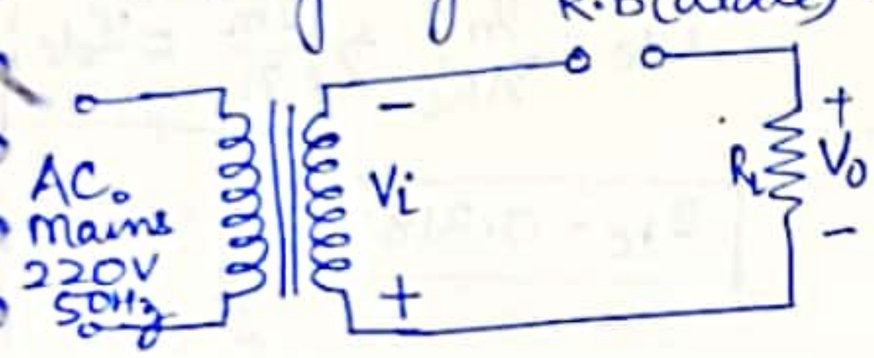


1) Diode is F.B and current i_L flows into it through load R_L to produce o/p Voltage V_o.

2) The Forward Voltage of diode is very small ∴ $\boxed{V_o \simeq V_i}$

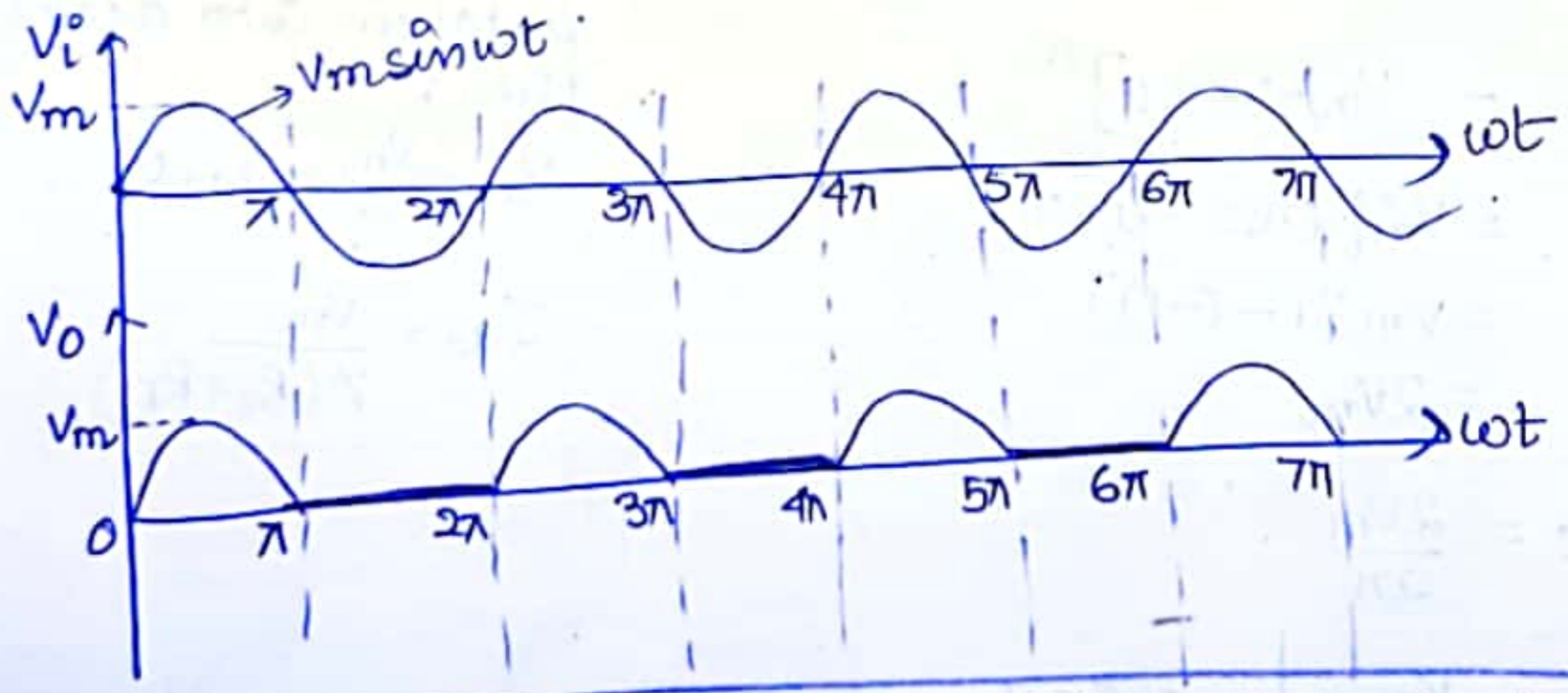


During negative half cycle :-



1) Diode is R.B hence it does not conduct and $i_L = 0$ & $V_o = 0$.

Input & O/P Waveform for half Wave Rectifier.



Note :- A HWR delivers power to the load during only half cycle of the ac power supply ∴ It is half wave rectifier.

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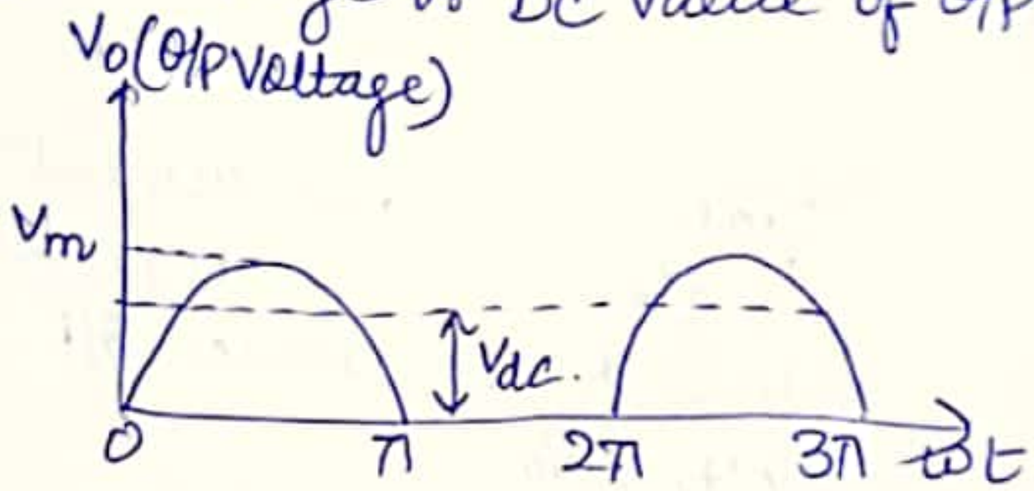
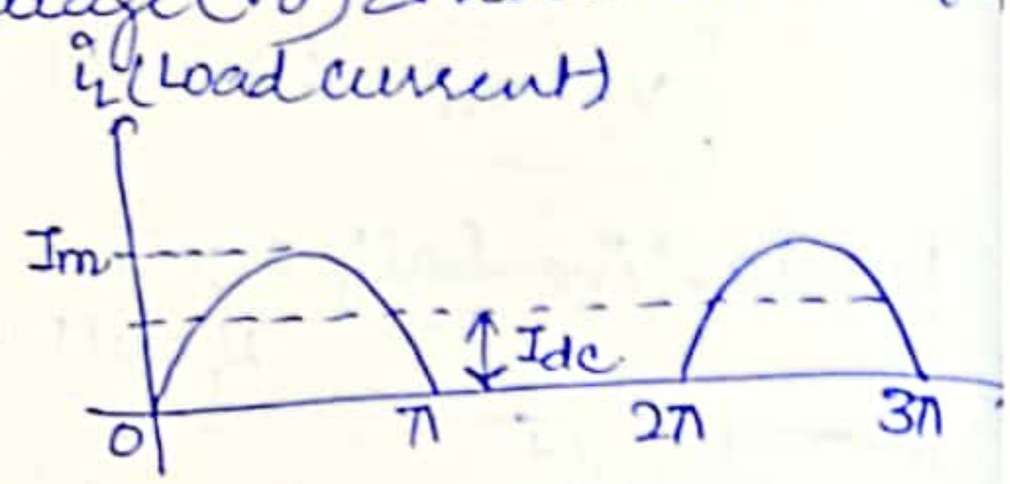
Average or DC ~~Vol~~ Values of O/P Voltage & Load current for HWR

Parameters of HWR:-

1) Average or DC value of O/P Voltage (V_o) & load current (i_L)





$$V_o = \begin{cases} V_m \sin\omega t & \text{for } 0 \le \omega t \le \pi \\ 0 & \text{for } \pi \le \omega t \le 2\pi \end{cases}$$

$$V_{avg} = V_{dc} = \frac{\text{Area under the curve over full cycle}}{\text{Base}}$$

$$\text{Area} = \int_0^{2\pi} V_o \, d(\omega t) = \int_0^{\pi} V_o \, d(\omega t) + \int_{\pi}^{2\pi} V_o \, d(\omega t)$$

$$= \int_0^{\pi} V_m \sin\omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 \, d(\omega t)$$

$$= V_m[-\cos\omega t]_0^{\pi}$$

$$= V_m[\cos 0 - \cos\pi]$$

$$= V_m[1-(-1)]$$

$$= 2V_m$$

$$V_{dc} = \frac{2V_m}{2\pi}$$

$$\boxed{V_{dc} = \frac{V_m}{\pi}} = 0.318 V_m$$

dc O/P voltage is 31.8% of max ac I/P voltage.

average or dc current

$$I_{avg} = I_{dc} = \frac{V_{dc}}{R_L}$$

$$V_{dc} = \frac{V_m}{\pi}$$

$$I_{dc} = \frac{V_m}{\pi R_L} \Rightarrow \boxed{\frac{I_m}{\pi} = I}$$

$$\boxed{I_{dc} = 0.318 I_m}$$

If Fwd resistance R_f is taken into account then:

$$\boxed{V_{dc} = \frac{V_m}{\pi} - I_{dc} R_f}$$

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

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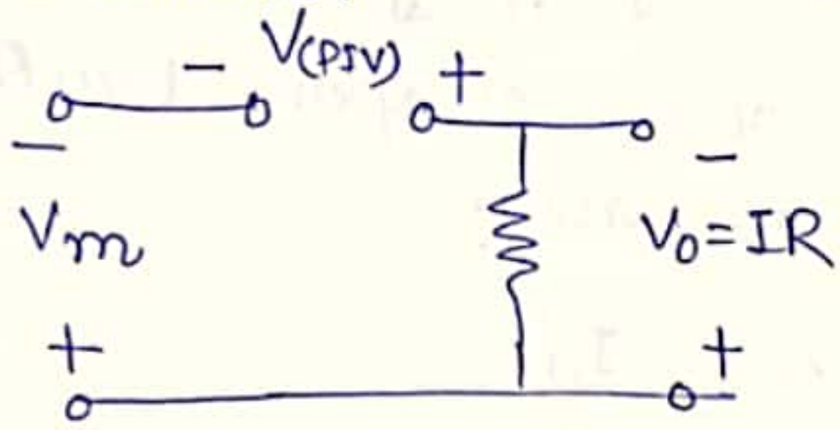
PIV (Peak Inverse Voltage):-

The max value of ~~the~~ voltage occurs at the peak of negative cycle of I/P voltage.

or.

The max value of voltage at which a diode in R.B must with stand.



Diode is R.B therefor O/ckt and $I=0$

$V_0 = 0$

$$\boxed{V_{(PIV)} = V_m}$$

$$\boxed{\text{PIV Rating} \geq V_m}$$ → half Wave Rectifier

→ PIV Rating of diode must equal or exceed the peak value of applied Voltage.

Ripple Factor:-

The O/P Voltage or load current of Rectifier contains two components { ac component, dc component.

AC component present at O/P is called as ripple. This ripple accounts for pulsation at the O/P of Rectifier which is undesirable.

⇒ Small the ripple, more effective the rectifier O/P.

⇒ Ripple Factor is measure of purity of the O/P of a rectifier

Ripple Factor (r) is a ratio of r.m.s value ~~of O/P~~ to average of dc value.

$$r = \frac{\text{r.m.s value of a.c component (due to ripple) (O/P)}}{\text{d.c component}}$$

$$\boxed{r = \frac{V_{ac}(rms)}{V_{dc}} = \frac{I_{ac}(rms)}{I_{dc}}}$$

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Ripple Factor calculation

$$r = \frac{I_{r(rms)}}{I_{dc}}$$

rms value of rectified o/p $I_{rms} = \sqrt{I_{r(rms)}^2 + I_{dc}^2}$

where $I_{ac} \rightarrow$ R.M.S value of a.c component at o/p

$I_{dc} \rightarrow$ d.c or average value.

$$I_{rms}^2 = I_{r(rms)}^2 + I_{dc}^2$$

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

For HWR:-

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

$I_{rms} \rightarrow$ rms value of load current.

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2 \, d(\omega t)}$$

$$i_L = \begin{cases} I_m \sin\omega t & \text{for } 0 \le \omega t \le \pi \\ 0 & \text{for } \pi \le \omega t \le 2\pi \end{cases}$$

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} (I_m \sin\omega t)^2 d(\omega t)} \Rightarrow \sqrt{\frac{1}{2\pi} I_m^2 \int_0^{2\pi} \left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)}$$

$$= \sqrt{\frac{I_m^2}{2\pi \times 2}\left[\omega t - \frac{\sin 2\omega t}{2}\right]_0^{\pi}} \Rightarrow \sqrt{\frac{I_m^2}{2\times 2\pi}\left[\pi - 0\right]}$$

$$= \sqrt{\frac{I_m^2}{2\pi} \times \frac{\pi}{2}} \Rightarrow \Rightarrow \frac{I_m}{2}$$

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

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

put value of I_{dc} & I_{rms} in given eqn:-

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

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

$$\boxed{r = 1.21}$$

⇒ ripple factor of HWR is very high which is undesirable

TUF (Transformer Utilization Factor):—

TUF is defined as a ratio of d.c power delivered to the a.c rating of transformer secondary.

$$\boxed{TUF = \frac{V_{dc} \cdot I_{dc}}{V_{rated} I_{rms}}}$$

For HWR:— assuming $R_L >> R_f$

$$V_{dc} = \frac{V_m}{\pi}, \quad I_{dc} = \frac{I_m}{\pi}$$

$$V_{rated} = \frac{V_m}{\sqrt{2}} \qquad I_{rms} = \frac{I_m}{2}.$$

Note:- Rated Value:- Maximum value of I or V or any other parameter beyond which machine will not be operating according to its desired operation.

$$TUF = \frac{[V_m/\pi][I_m/\pi]}{[V_m/\sqrt{2}][I_m/2]}$$

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

$$\boxed{TUF = 28.7\%}$$

$r_s \rightarrow$ resistance of secondary winding

$$\%\text{Regulation} = \frac{(V_{dc})_{no\,load} - (V_{dc})_{load}}{(V_{dc})_{load}} \times 100$$

Voltage Regulation:—

The variation of d.c o/p voltage as a function of d.c load current is called as voltage regulation.

$$\boxed{\%\text{Voltage Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100}\ \%$$

It is a max voltage that the rectifying diode has to withstand during R.B period.

When no load, zero current accross load resistor.

Full load Represents → Normal load indicated by dle-

$$V_{dc(load)} = I_{dc} R_L = \frac{I_m R_L}{\pi}$$

$$\because V_m = I_m (R_L + R_f + R_s)$$

$$V_{dc(load)} = \frac{V_m (R_L)}{(R_L + R_f + R_s)}$$

$$V_{dc(NL)} = V_{dc(load)} \big|_{R_L = 0}$$

$$V_{dc(NL)} = \frac{V_m}{\pi}$$

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Efficiency of a rectifier :-

It is defined as ratio of d.c power delivered to the load to a.c I/p power.

$$\boxed{\eta = \frac{\text{D.C power delivered to the load}}{\text{A.C input power}}}$$

$$\eta = \frac{P_{d.c}}{P_{a.c}}$$

$$P_{d.c} = I_{d.c}^2 R_L$$

$$P_{ac} = I_{rms}^2 (R_L + R_f + R_s)$$

R_s → Resistance of secondary winding

R_f → Forward Resistance.

R_L → Load Resistance

$$\eta = \frac{I_{dc}^2 \times R_L}{I_{ac}^2 (R_f + R_L + R_s)}$$

efficiency of HWR :-

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

$$\eta = \frac{\left(\frac{I_m}{\pi}\right)^2 R_L}{\left(\frac{I_m}{2}\right)^2 (R_f + R_L + R_s)} = \frac{4}{\pi^2} \times \frac{R_L}{(R_L + R_f + R_s)} = \frac{0.406}{(1 + R_f/R_L + R_s/R_L)}$$

$$\boxed{\eta = \frac{0.406}{1 + R_f/R_L + R_s/R_L}}$$

$R_L >> (R_f + R_s)$ ∴ $\boxed{\eta_{max} = 0.406 = 40.6\%}$

Parameters of HWR :-

1. $I_{dc} = \frac{I_m}{\pi}$ (Avg Value) $\qquad V_{dc} = \frac{V_m}{\pi} \qquad V_{rated} = \frac{V_m}{\sqrt{2}}$
2. $V_{rms} = \frac{V_m}{2}$ (r.m.s Value) $\qquad I_{rms} = \frac{I_m}{2}$
3. $r = 1.21$
4. $TUF = 28.7\%$
5. $\eta = 40.6\%$
6. $PIV = V_m$

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Drawbacks of HWR.

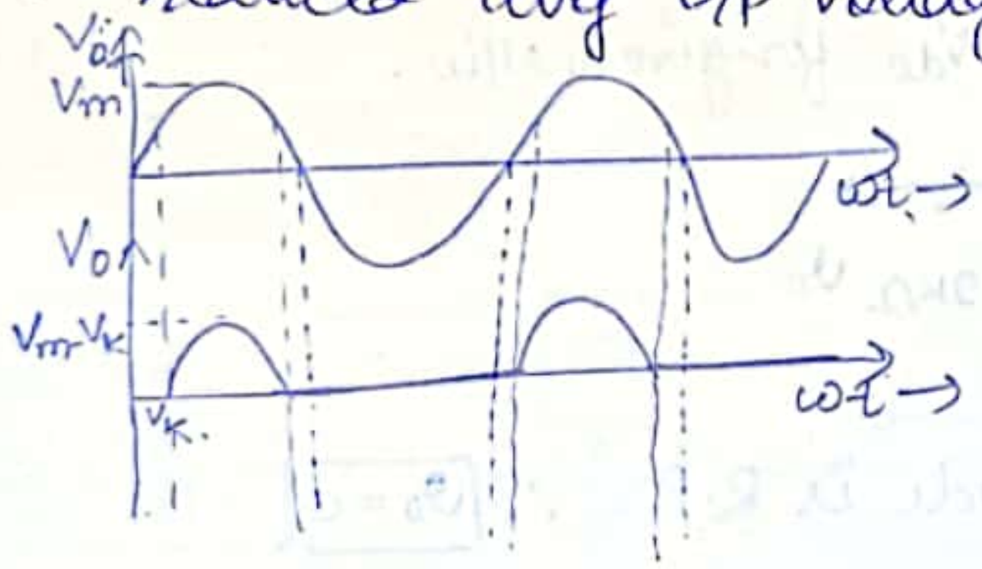
1. ripple factor is high. ∴ O/P contains lot of varying components.
2. Efficiency is very less.
3. Low TUF. (Transformer is less utilized).
4.

Effect of Cut-in Voltage or knee Voltage on O/P of HWR

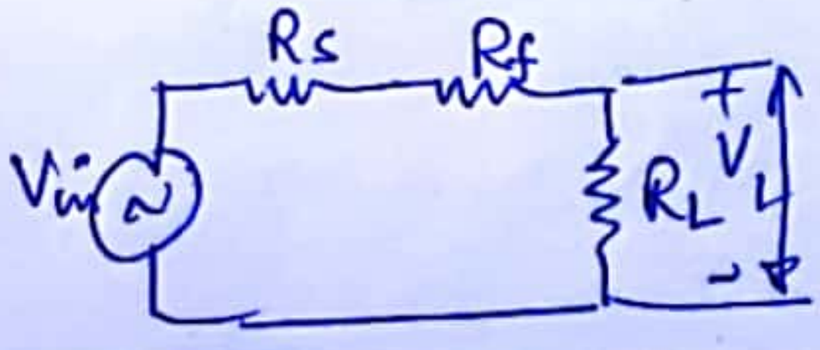
Si Diode in HWR will not be turned on until $V_i > V_K$.
For the time $V_i < V_K \rightarrow \boxed{V_o = 0}$.

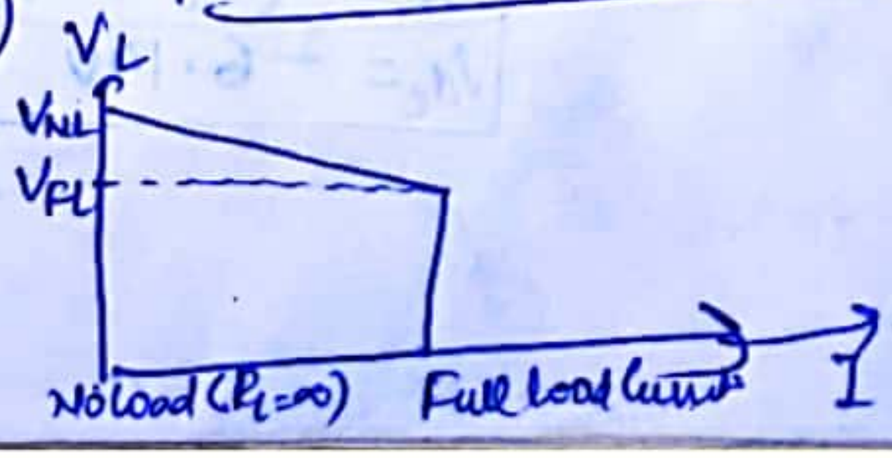
Similarly amplitude of O/P Voltage $V_o = V_i - V_K$.

∴ Peak of O/P Voltage is $\boxed{V_o = V_m - V_K}$. Hence area above the zero level for O/P voltage is reduced resulting in reduced avg O/P voltage.



(*) $\% \text{Regulation} = \dfrac{\frac{V_m}{\pi} - \frac{V_m}{\pi}\left(\frac{R_L}{R_L+R_f+R_s}\right)}{\frac{V_m}{\pi}\left(\frac{R_L}{R_L+R_f+R_s}\right)} \Rightarrow \boxed{\% \text{Regulation} = \frac{R_f+R_s}{R_L} \times 100\%}$





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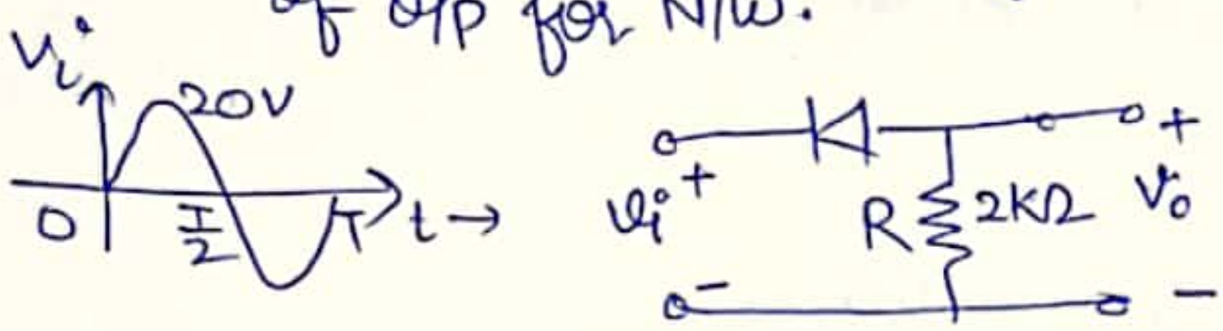
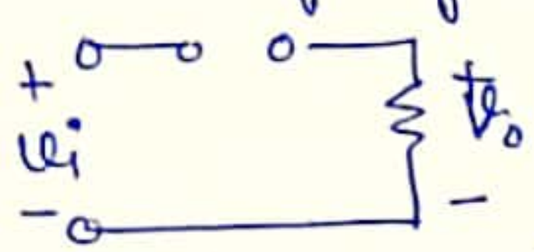
Ques: 2 Sketch the o/p voltage V_o and determine dc level of o/p for N/w.

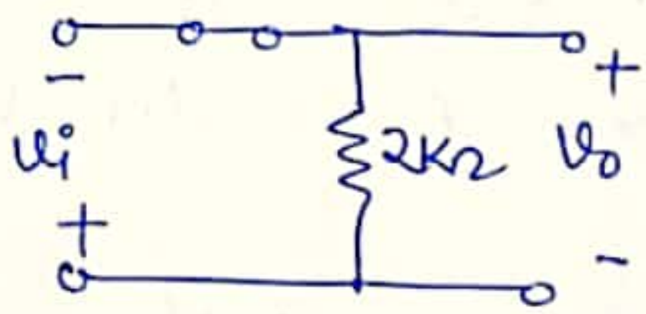


For +ve half cycle diode is R.B. ∴ Ckt is

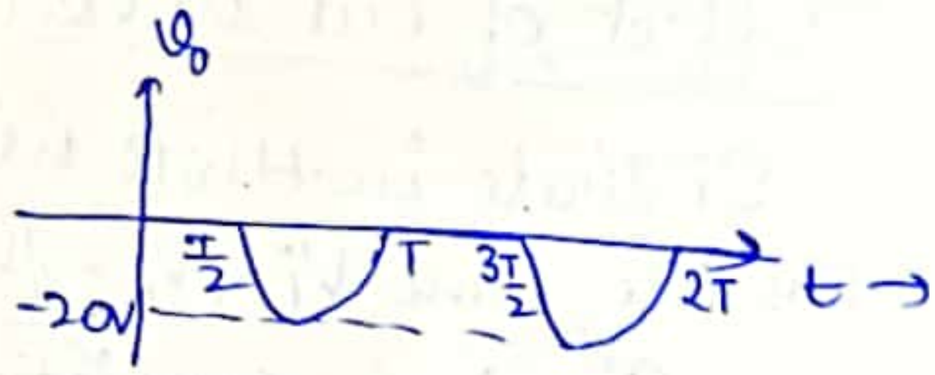


$\therefore \boxed{v_o = 0}$

For -ve half cycle diode is F.B. ∴



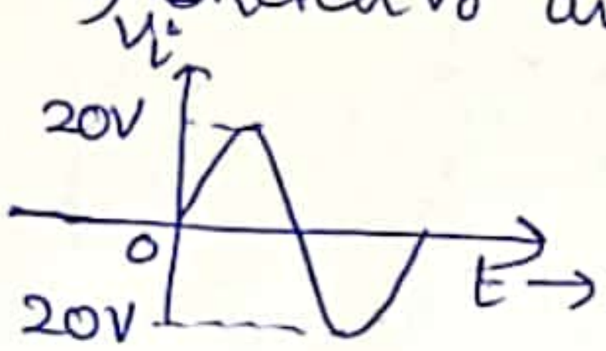
$\boxed{v_o = -v_i}$

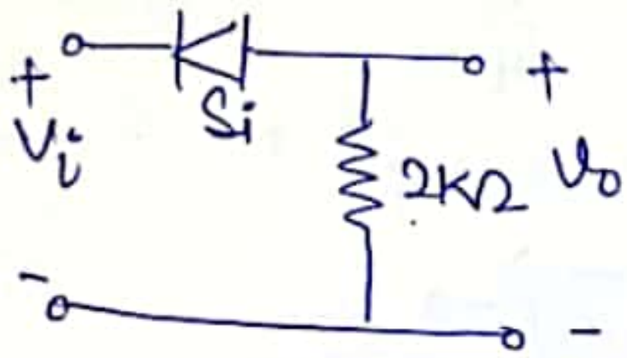


∴ Average value of o/p = $-0.318\,V_m = -0.318 \times 20V$

$$\boxed{V_{dc} = -6.360\,V}$$

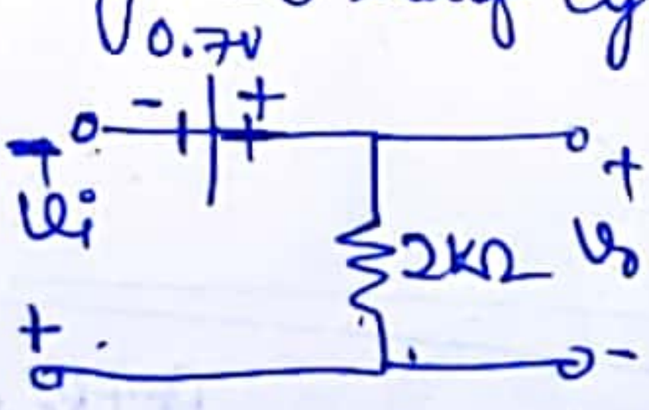
b) Sketch V_o and determine V_{dc} for given N/w.





For Positive half cycle, Diode is R.B. ∴ $\boxed{v_o = 0}$

For negative half cycle, Diode is F.B.



$v_o = -(v_i - 0.7)$

$V_{dc} = -(V_m - 0.7) \times 0.318$

$$\boxed{V_{dc} = -6.14V}$$

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Full Wave Rectifier :-

This type of rectifier utilizes both half cycles of a.c I/P voltage. In FWR an unidirectional current flows through the load during entire cycle of I/P voltage.

There are two type of FWR :-

i) Centre-tap FWR.

ii) Full-wave Bridge Rectifier.

Center Centre-tap Rectifier :-

This rectifier circuit makes use of two diodes D_1 & D_2 which are connected to centre-tap secondary winding of transformer. The secondary is taken as zero voltage reference point.

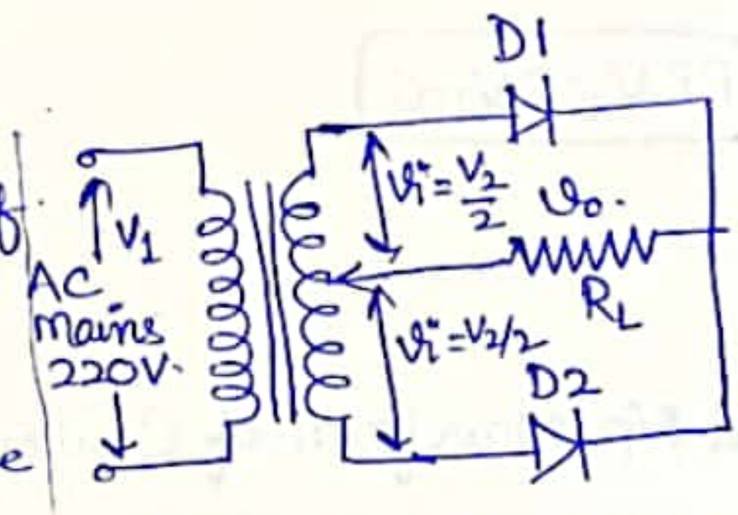
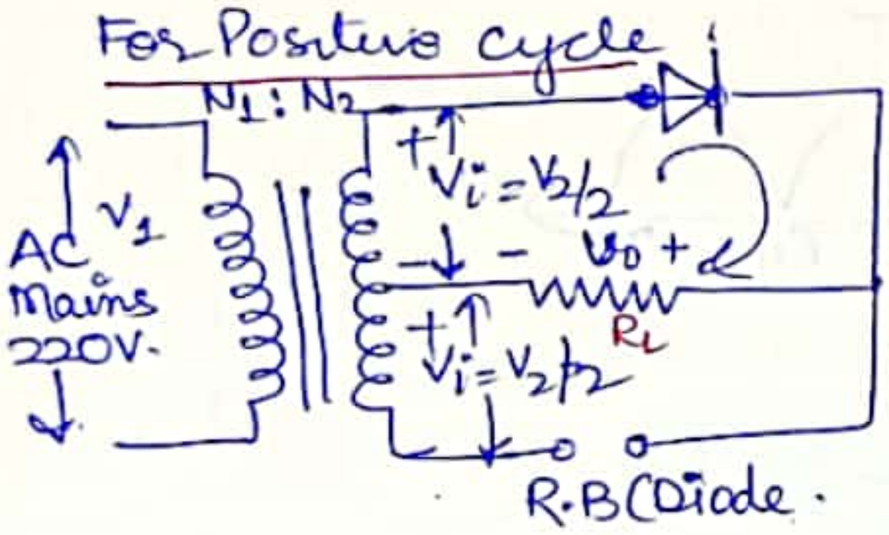


fig: Centre tap Full Wave Rectifier

The half of secondary voltage is taken as the instantaneous input voltage v_i.

Let $v_i = V_m \sin \omega t$

For Positive cycle



$D_1 \rightarrow$ conducts

$D_2 \rightarrow$ cut-off.

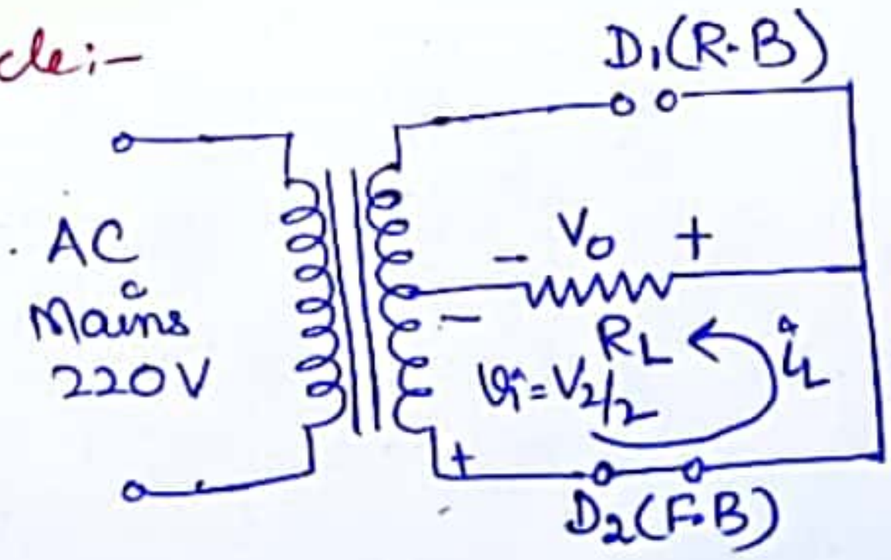
i_L flows through resistor R_L.

During negative half cycle :-

$D_1 \rightarrow$ R.B (cut-off).

$D_2 \rightarrow$ F.B (conducts)

$i_L \rightarrow$ flows through R_L.



Note :- For Positive half cycle one diode conducts and for negative half cycle another therefore current flows unidirectionally continuously

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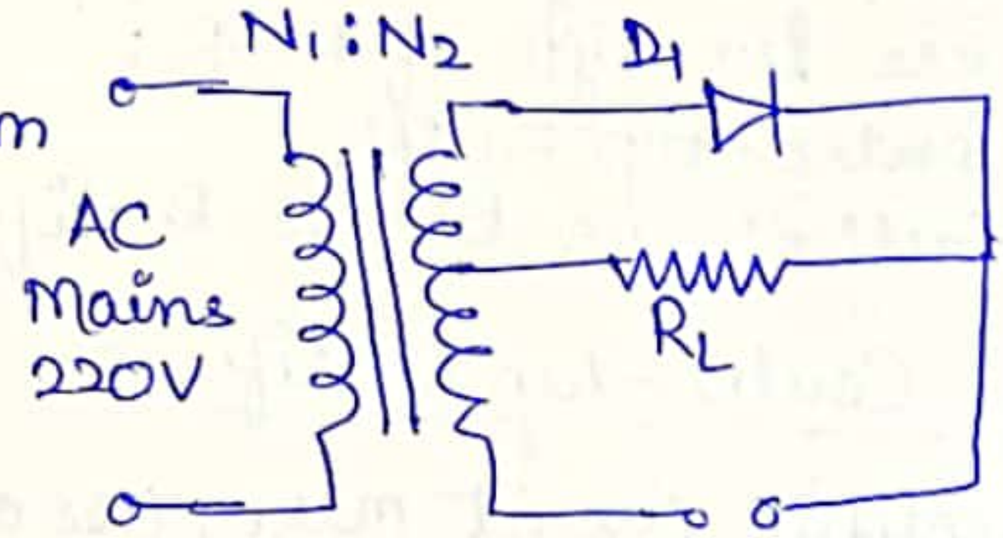
Peak Inverse Voltage of Centre-tap Rectifier:-

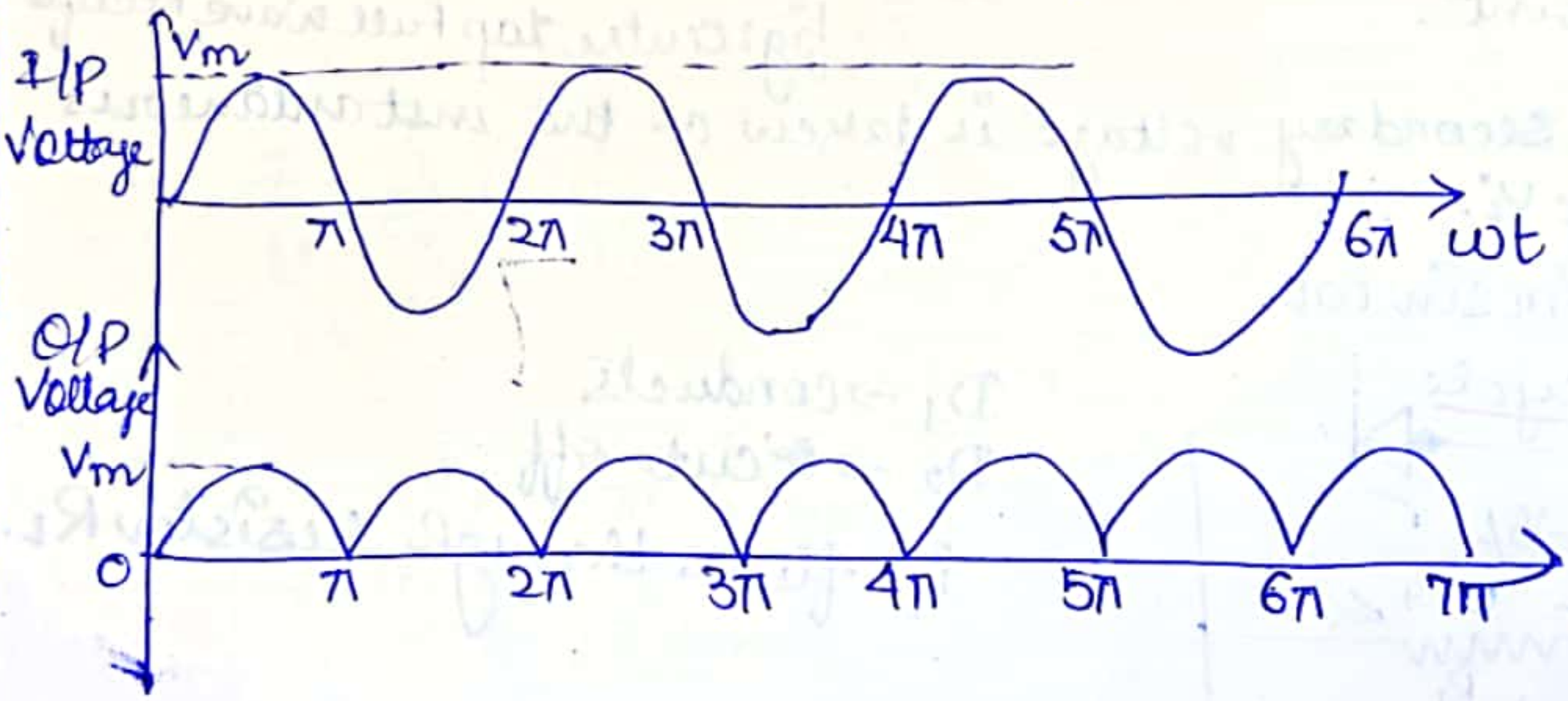
Since D_2 is off ~~before~~ therefore total voltage ~~tot~~ is V_m. reflect accross 100

Peak Inverse Volt $= V_m + V_m$
$= 2V_m$

$\boxed{PIV = 2V_m}$



I/P and O/P Waveform of Center-tap Full Wave Rectifier:-



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Full Wave Bridge Rectifier :-

In this, ~~brig~~ bridge configuration of Diode is connected accross secondary of transformer. This circuit avoid the need of a center-tap-transformer.

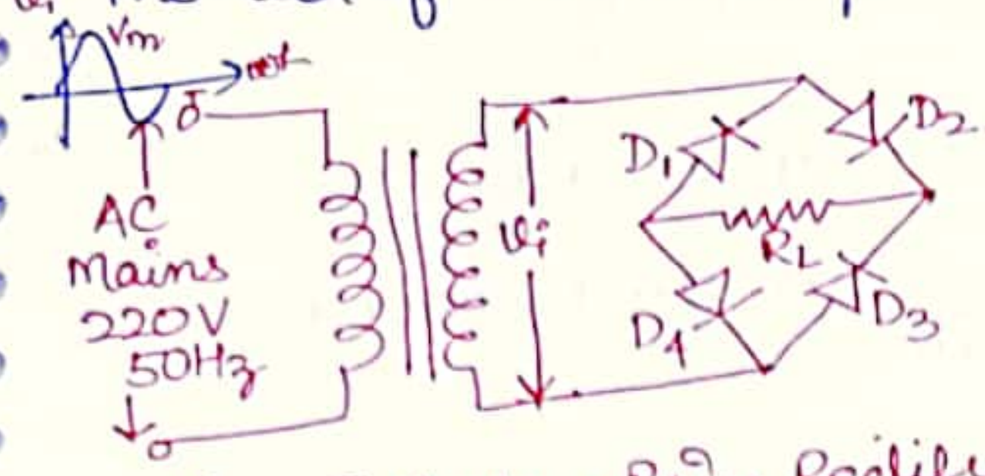
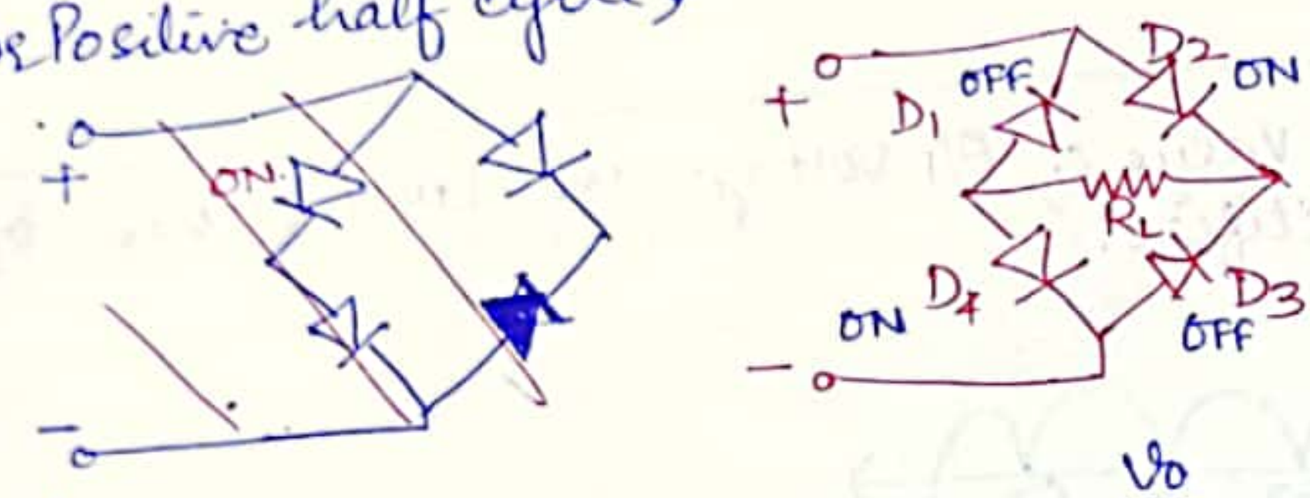
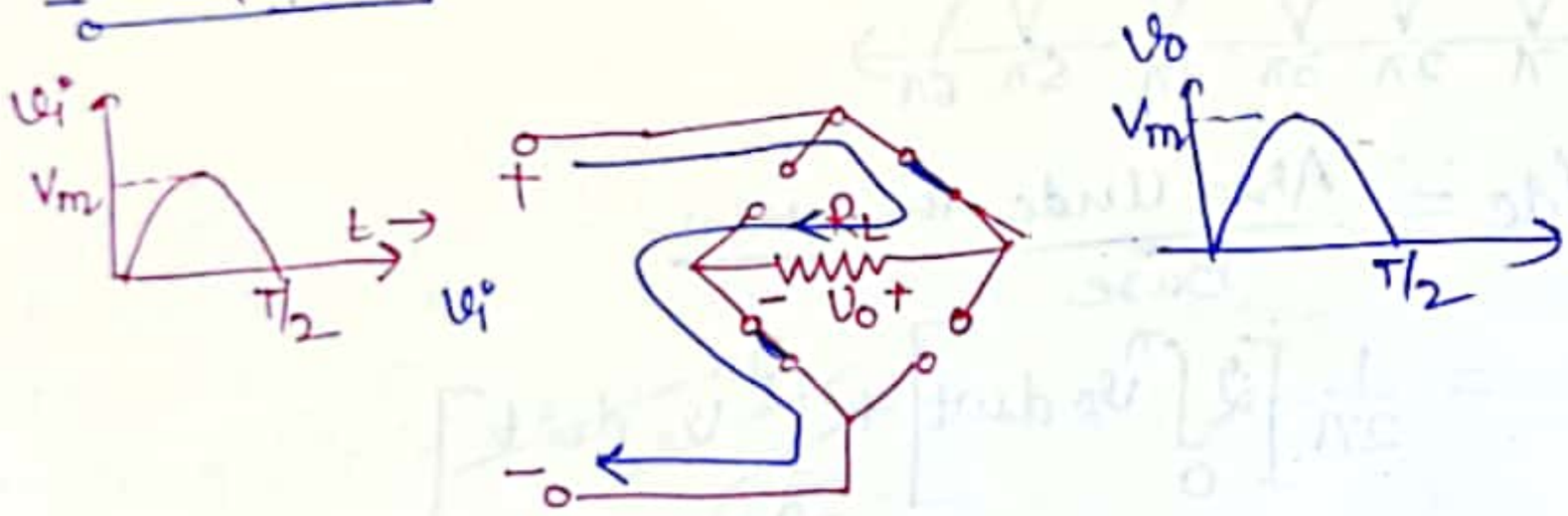


fig:- Full Wave Brige Rectifier

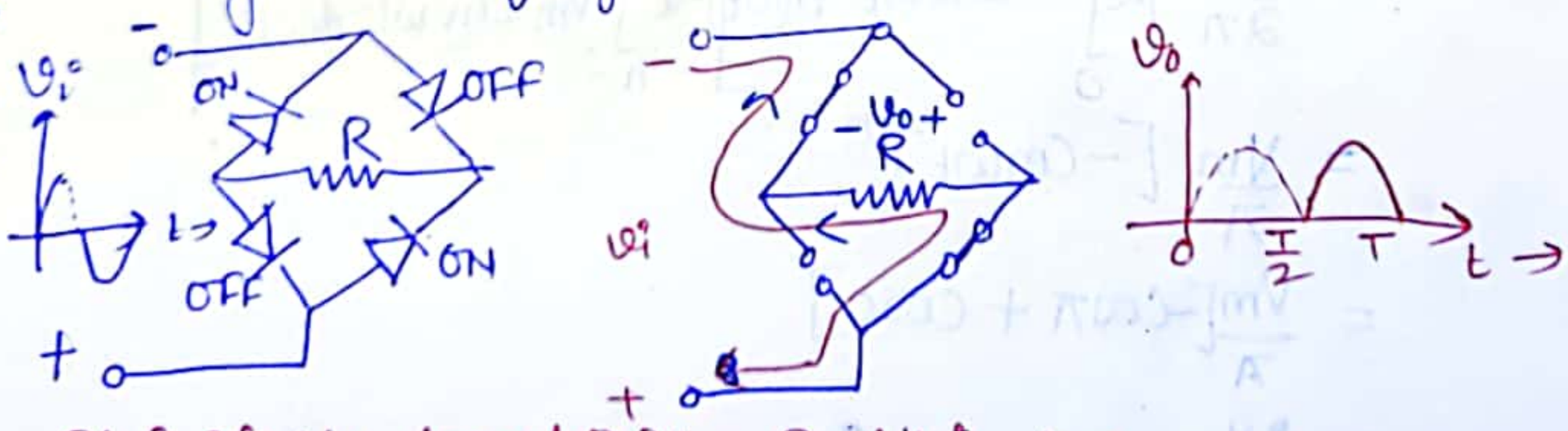
$D_1, D_3 \rightarrow OFF$
$D_2, D_4 \rightarrow ON$

For Positive half cycle,

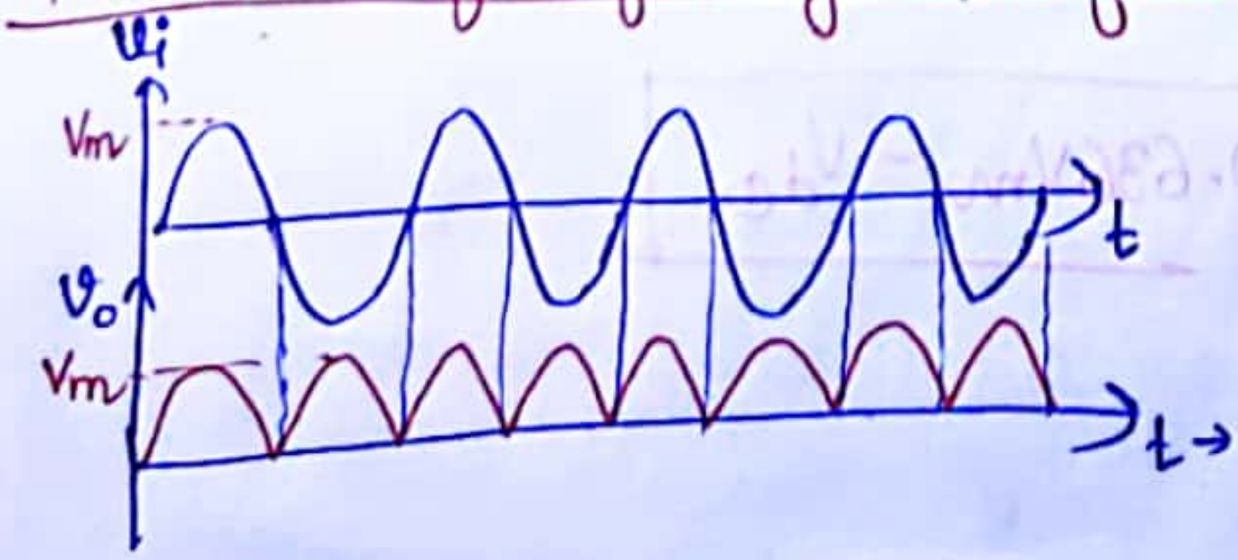




For negative half cycle :-



I/p & O/p Waveform of Bridge Rectifier :-



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PIV of Full-Wave Bridge Rectifier:—

$$\boxed{PIV = V_m}$$

Advantage & Disadvantage of Full Wave Bridge Rectifier:—

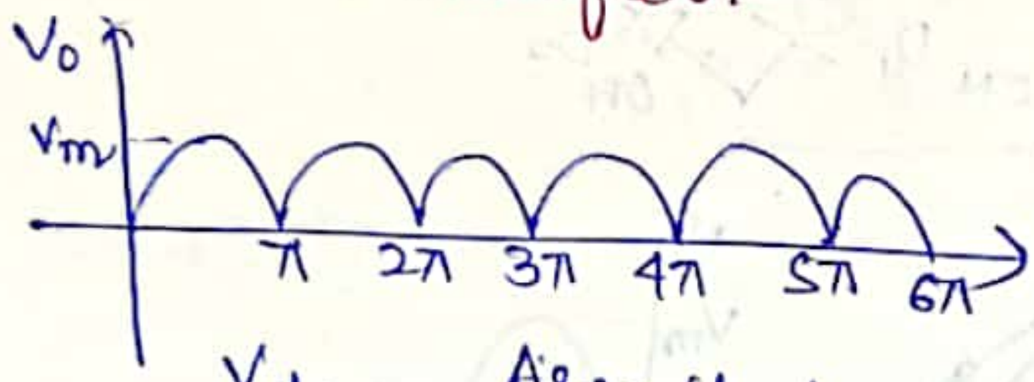
Advantages:—

1. It does not require center-tap winding hence transformer is less expensive.
2. PIV Rating is V_m only hence diode used in center-tap are costlier.

Disadvantage:—

1) Need of Extra diodes.

Average of D.C Value of O/P Voltage and Load current of Full Wave rectifier:—



$$V_{dc} = \frac{\text{Area Under the curve}}{\text{Base}}$$

$$= \frac{1}{2\pi}\left[2\int_0^{\pi} v_o \, d\omega t\right] + \cancel{\int_{\pi}^{2\pi} v_o \, d\omega t}\Big]$$

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

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

$$= \frac{V_m}{\pi}\left[-\cos\pi + \cos 0\right]$$

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

$$\boxed{V_{dc} = \frac{2V_m}{\pi}} = \boxed{0.636 V_m = V_{dc}}$$

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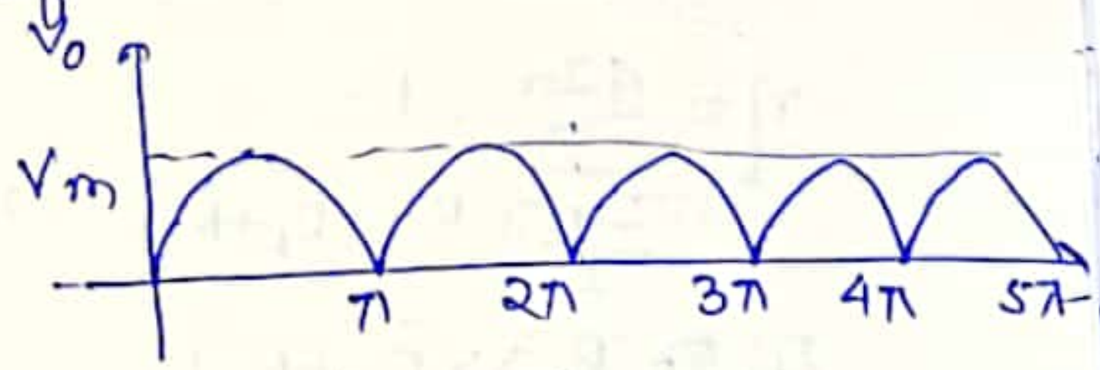
Similarly;

$$\boxed{I_{dc} = 0.636 I_m}$$

Ripple Factor of Full Wave Rectifier :-



$$r = \frac{V_{rms}}{V_{avg} \text{ or } V_{dc}}$$

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

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

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

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

$$= \frac{V_m}{\sqrt{2}\sqrt{\pi}}\sqrt{\left[(\omega t) - \frac{\sin 2\omega t}{2}\right]_0^{\pi}}$$

$$= \frac{V_m}{\sqrt{2}\sqrt{\pi}}\sqrt{\left[\pi - 0\right]} \Rightarrow \frac{V_m\sqrt{\pi}}{\sqrt{2}\sqrt{\pi}}$$

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

$$\cancel{r = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{2V_m/\pi}{V_m/\sqrt{2}}\right)^2 - 1} \Rightarrow \sqrt{(2\sqrt{2}/\pi)^2 - 1}}$$

$$\cancel{r =}$$

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

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

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

$$\boxed{r = 0.482}$$

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Efficiency of Full-Wave-Rectifier :-

$$\eta = \frac{I_{dc}^2 * R_L}{I_{rms}^2 (R_L + R_F + R_s)} \qquad I_{dc} = \frac{2I_m}{\pi} \qquad I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$\eta = \frac{\frac{4I_m^2}{\pi^2} \times R_L}{\frac{I_m^2}{2}(R_L + R_F + R_s)} = \frac{8}{\pi^2}\left(\frac{1}{1+(R_F+R_s)/R_L}\right) = \frac{0.812}{1+R_F/R_L}$$

If $R_L >> (R_F + R_s)$

$$\eta = 0.812 \qquad \boxed{\eta = 81.2\%}$$

Transformer Utilization Factor :-

For FWR :-

$$\text{TUF of secondary} = \frac{I_{dc} \times V_{dc}}{I_{rms} \times V_{rms}} = \frac{(2I_m/\pi)(2V_m/\pi)}{(I_m/\sqrt{2})(V_m/\sqrt{2})}$$

Rate Value = R.M.S Value

$$\text{TUF of secondary} = \frac{4 \times 2}{\pi^2} = \frac{4}{\pi^2} \times 2 = \frac{8}{\pi^2} = 81.2\%$$

$$\boxed{TUF = 81.2\%}$$

As we know that, a FWR, consists of two HWRs, working independently and feeding a common Load.

TUF of primary winding = 2 × TUF of HWR.
= 2 × 0.287.

$$\boxed{TUF_{(primary)} = 0.574.}$$

$$\text{avg TUF} = TUF_{primary} + TUF_{secondary}$$

$$= \frac{0.574 + 0.812}{2} = 0.693 = 69.3\%$$

Voltage Regulation efficiency :-

It is same as derived for HWR. The O/P d.c voltage & at no load and No load doubles for FWR. i.e Regulation is same.

$$\boxed{\% \text{ Regulation} = \frac{R_f}{R_L} \times 100}$$

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Comparision of FWR & HWR :-

Parameter	HWR.	FWR.	
		Center-tap	Bridge.
1) Number of diodes	1	2	4.
2) PIV.	V_m	$2V_m$	V_m.
3) D.C or avg current	I_m/π	$2I_m/\pi$	$2I_m/\pi$
4) R.M.S current	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
5) Ripple Factor	1.21.	0.482	0.482.
6) Reclification efficiency	40.6%	81.2%	81.2%.
7) TUF	28.7%		

Advantage of FWR :-

1. The amount of dc current & Voltage is double than that of HWR so efficiency is double.
2. Ripple Factor is less.
3. Ripple frequency is double. (∴ Small components used for smoothen the o/p)
4. In secondary winding, current flows for both the voltage cycles, so core saturation does not occur in transformer.

Disadvantage :-

1. The PIV rating of diodes is higher so costlier diode are required.
2. The cost of center-tapped transformer is higher.

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Numerical Based Rectifier :-

① Forward Resistance $R_F = 20\Omega$.
Applied input voltage $V = 60\sin\omega t$
Load Resistance $R_L = 800\Omega$.
It is used in HWR. Determine:

(i) I_m, I_{dc}, I_{rms}
(ii) A.C power I/p & D.C power O/p.
(iii) O/p d.c. voltage.
(iv) Rectification Efficiency

Sol^n (i) $I_m = \frac{V_m}{R_F + R_L}$

$$I_m = \frac{60}{800+20} = \frac{60}{820}$$

$$\boxed{I_m = \frac{6}{82} = 0.073\,A}$$

$$I_{dc} = \frac{I_m}{\pi} = \frac{0.073}{3.14}$$

$$\boxed{I_{dc} = 0.023\,A}$$

$$I_{rms} = \frac{I_m}{2} = \frac{0.073}{2}$$

$$\boxed{I_{rms} = 0.0365}$$

(ii) A.C power I/P $= (I_{rms})^2 \times (R_F + R_L)$

$$= (0.0365)^2 \times (820)$$

$$= \cancel{109.24\,W}$$

$$\boxed{P_{ac} = 1.095\,W}$$

D.C power O/P $= V_{dc} I_{dc}$

$$= \frac{0.073 \times 60}{\pi^2}$$

$$\boxed{P_{dc} = 0.443\,W.}$$

(iii) O/P dc voltage

$$V_{dc} = \frac{V_m}{\pi} = \frac{60}{\pi}$$

$$\boxed{V_{dc} = 19.09\,V}$$

(iv) $\eta = \frac{P_{dc}}{P_{ac}} \times 100$

$$= \frac{0.443}{1.095} \times 100$$

$$\boxed{\eta = 40.45\%}$$

FWR

② A center-tap full wave rectifier has load resistance $R_L = 1000\Omega$. Forward resistance R_F of each diode is 20Ω. The voltage accross half of secondary winding is given by the equation $V = 200\sin 314t$. Determine:

(i) Peak value of current
(ii) Average or D.C value of current
(iii) The rms value of current.
(iv) Ripple Factor
(v) Rectification efficiency

Sol^n $R_L = 1000\Omega$.
$R_F = 20\Omega$
$V_i = 200\sin 314t$
$V_m = 200$

(i) $I_m = \frac{200}{1000+20} = \frac{200}{1020}$

$$\boxed{I_m = 0.196\,A}$$

(ii) $I_{dc} = \frac{2I_m}{\pi} = \frac{2 \times 0.196}{\pi} = 0.124$

$$\boxed{I_{dc} = 0.124\,A}$$

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(iii) $I_{rms} = \frac{I_m}{\sqrt{2}}$

$= \frac{0.196}{1.41} = \underline{0.14A}$

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

$= \sqrt{\left(\frac{0.14}{0.124}\right)^2 - 1}$

$= 0.507$

$\boxed{r = 50.7\%}$

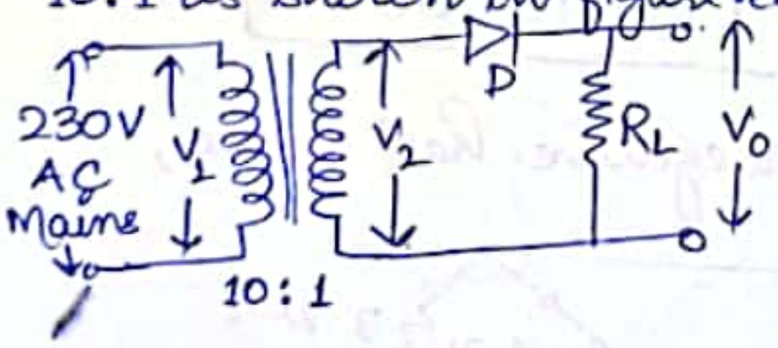
(v) $\eta = \frac{I_{dc}^2 R_L}{I_{rms}^2 (R_L + R_F)}$

$= \frac{(0.124)^2 \times 1000}{(0.14)^2 \times (1020)}$

$\boxed{\eta = 0.77}$

calculate DC voltage

③ An a.c supply of 230V is connected to a HWR through transformer having turn Ratio 10:1 as shown in figure. Calculate the value of V_{dc} & PIV?



$\frac{N_1}{N_2} = 10$

$V_1 = 230V$

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

$\therefore V_2 = \frac{N_2}{N_1} \times V_1 \Rightarrow \frac{230}{10}$

$\boxed{V_2 \Rightarrow 23V}$

$V_m = \sqrt{2} V_2 = \sqrt{2} \times 23 = \cancel{32.5}$

$\boxed{V_m = 32.52}$

(i) $V_{dc} = \frac{V_m}{\pi}$

$\boxed{V_{dc} = 10.35V}$

(ii) PIV = V_m

$\boxed{PIV = 32.52V}$

Ques④:- Ckt shown in figure have HWR with transformer coupled I/P. Determine the value of D.C Load current.

b) determine the max & avg values of power delivered to the load.

$\frac{V_1}{V_2} = \frac{N_1}{N_2} = 2$

$V_2 = \frac{1}{2} \times 230 = 115V$

$\boxed{V_2 = 115V}$

$V_m = \sqrt{2} V_2$

$= \underline{162.63V}$

$V_{dc} = \frac{V_m}{\pi} = \underline{51.76V}$

$I_{dc} = \frac{V_{dc}}{R_L} = \underline{0.258A}$

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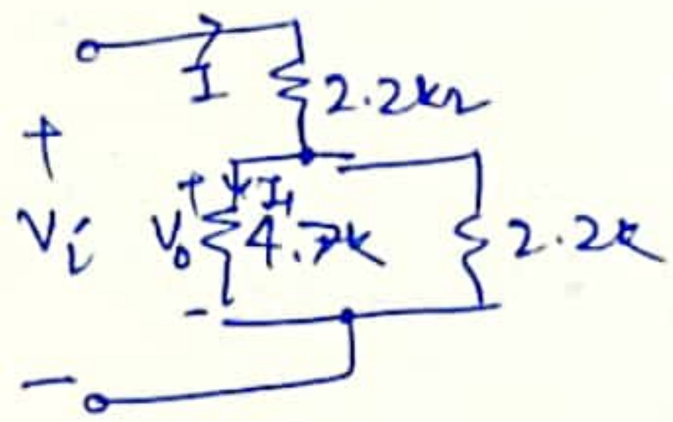
$P_{dc} = I_{dc}^2 \times R_L$

$= (0.258)^2 \times 200$

~~$= 3.34 \times 10^{-4}$ W.~~

~~$P_{dc} = 0.334$ mW.~~

$P_{dc} = 13.52W$



$I = \frac{200}{(4.7 \| 200) + 2.2}$

$= 54.05$ mA

$I_1 = \frac{2.2 \times 54.05}{6.9}$

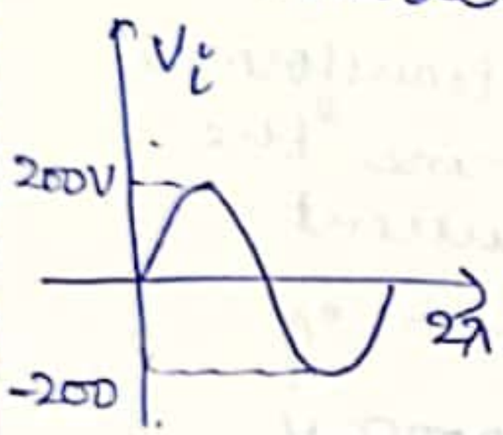
$I_1 = 17.23$ mA

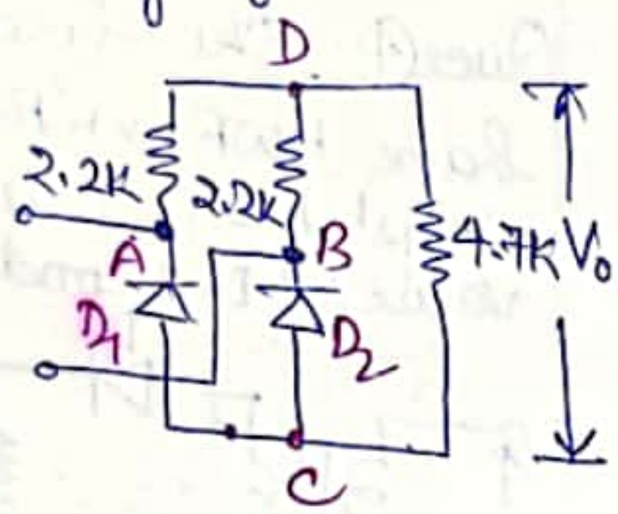
$V_o = 4.7 \times 17.23$

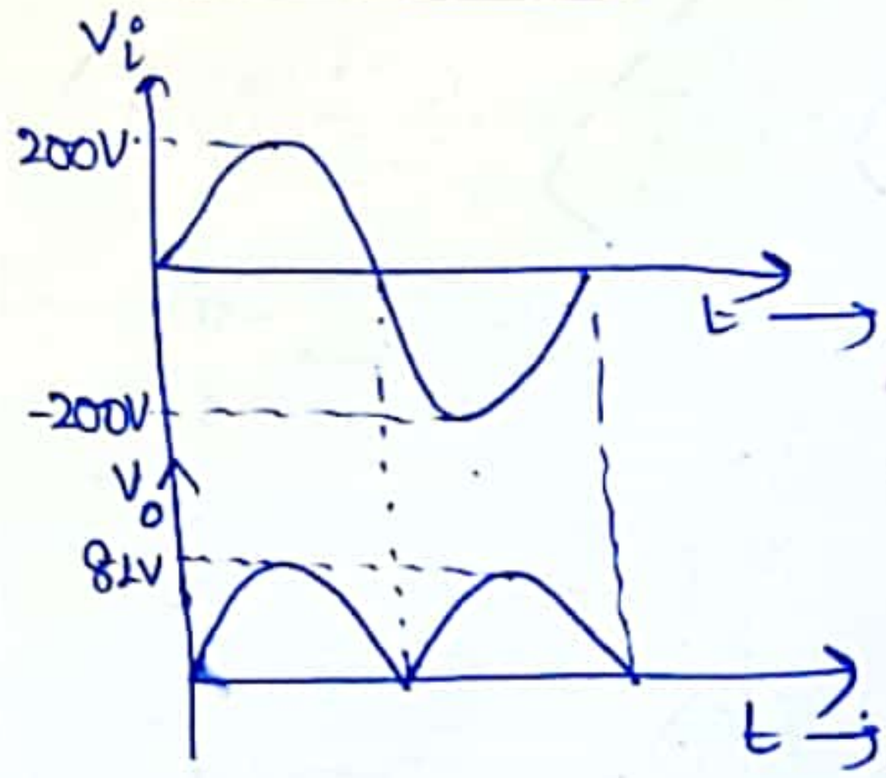
$V_o = 80.98$ V

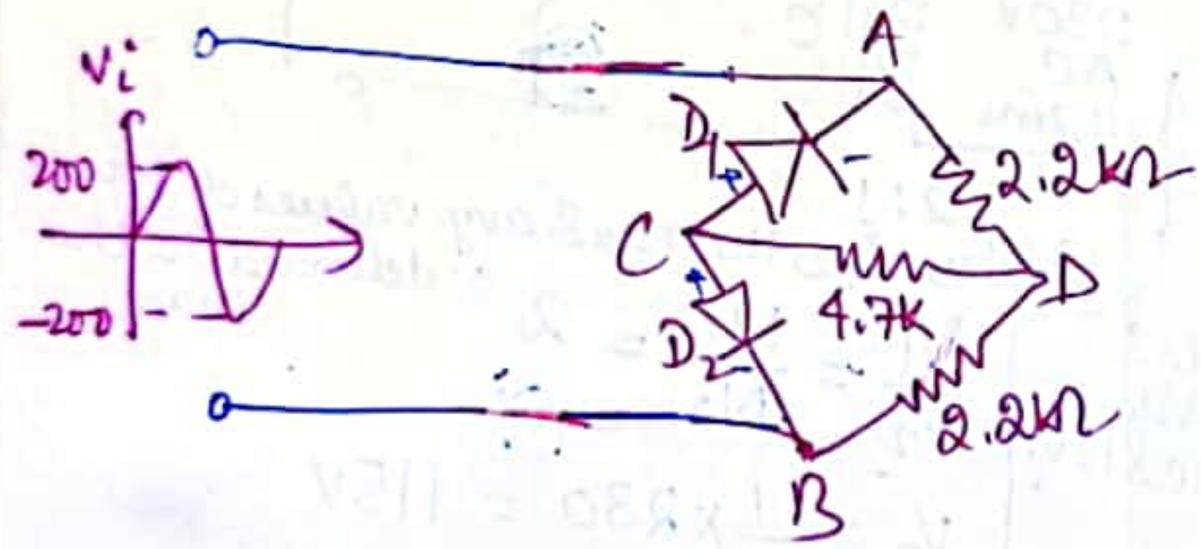
FWR

4 (7) For the ckt. Sketch V_o. Required PIV Rating of each diode?



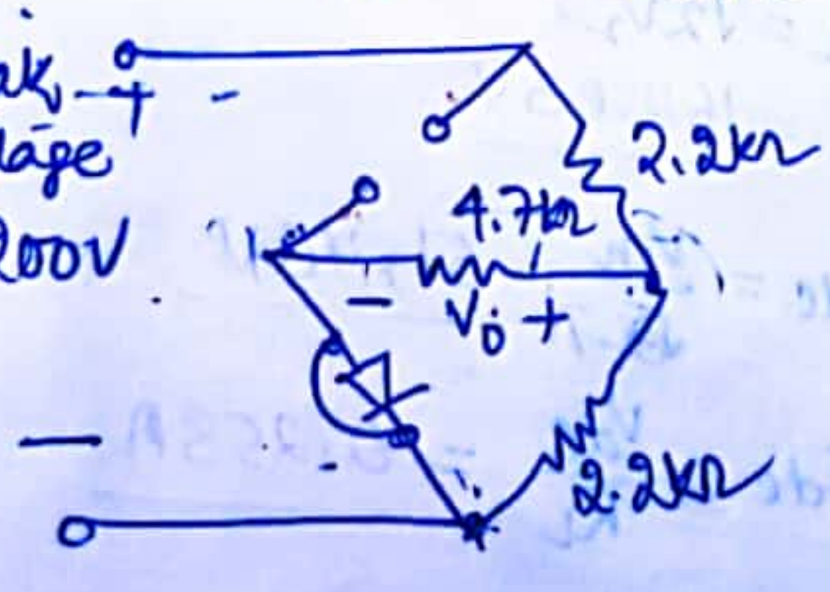






For Positive half cycle D_1 is off & D_2 ON.

Peak Voltage $V_m = 200V$



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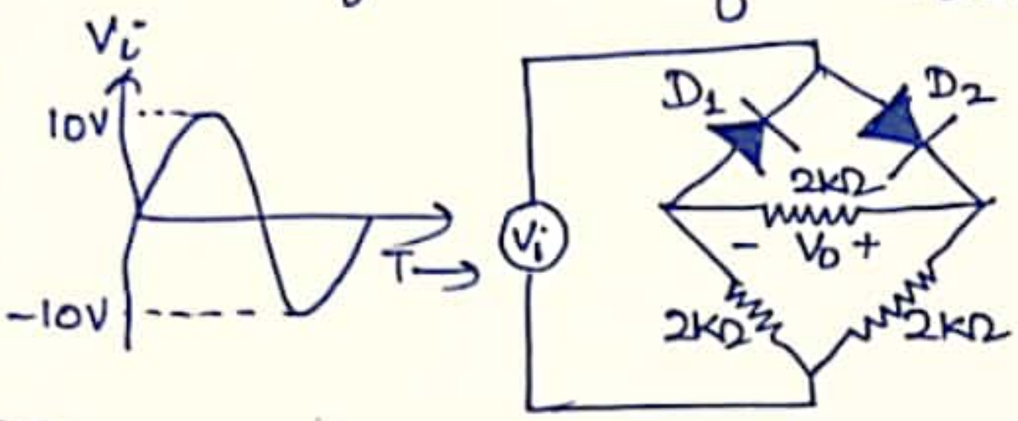
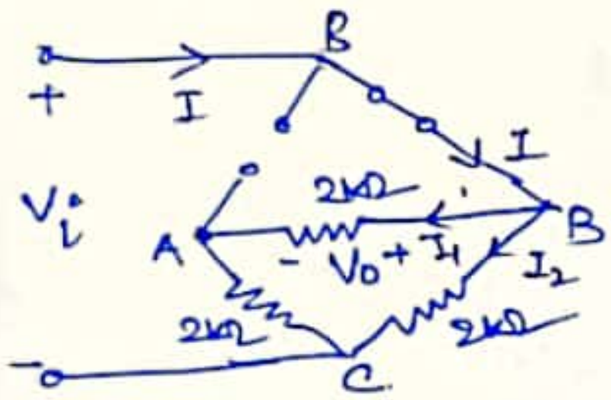
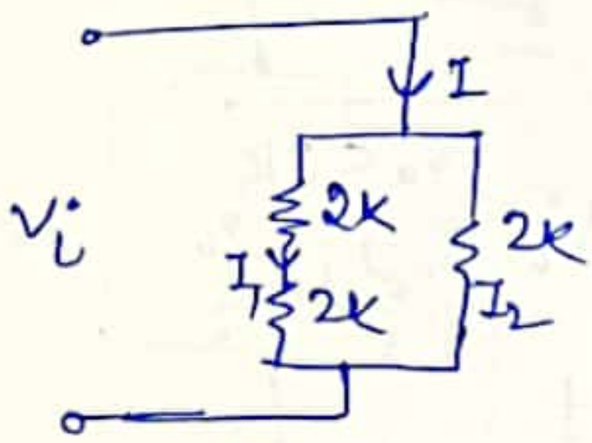
(8) Determine the O/P Waveform for the N/W shown in fig. and calculate O/P dc level. and Required PIV of each diode.



For Positive half cycle,





$$I_1 = \frac{2K}{4K+2K} \times I$$

$$R_{eq} = \cancel{2K \parallel} \; 4K \parallel 2K$$

$$= \frac{4 \times 2}{6_3}$$

$$= \frac{4}{3} k\Omega$$

$$I = \frac{V}{R} = \frac{10 \times 3}{4_2} \Rightarrow \frac{15}{2}$$

$$\boxed{V_o = \frac{V_i}{2}}$$

$$\boxed{I = 7.5 \text{ mA}}$$

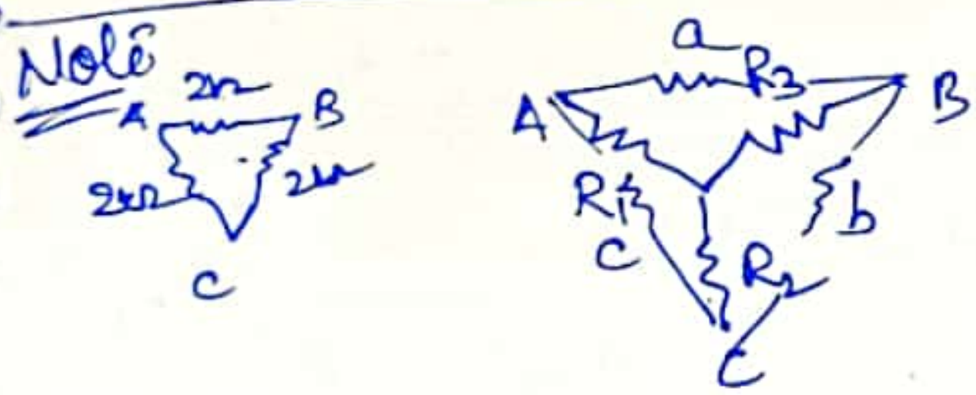
$$I_1 = \frac{2}{6_3} \times \frac{15}{2} = \frac{5}{3} = 1.67 \text{ mA}$$

$$\boxed{I_1 = 1.67 \text{ mA}}$$

$$V_o = 2k\Omega \times 1.67 \text{ mA}$$

$$\boxed{V_o = 3.33 \text{ V}}$$

Note



$$R_1 = \frac{ac}{a+b+c} = \frac{2 \times 2}{2+2+2} \Rightarrow \frac{4}{6} \Rightarrow \frac{2}{3}$$

$$R_2 = \frac{bc}{a+b+c}$$

$$R_3 = \frac{ab}{a+b+c}.$$

For negative half cycle.

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HWR based Numericals.

(1) A.C Voltage of 200V applied to a HWR through transformer turns Ratio 4:1. Load Resistance value 300Ω. Assuming Diode is ideal one determine following:-

1) d.c O/P Voltage
2) PIV.
3) Max Value of Power delivered to load.
4) Average value of power delivered to load.

Sol^n

$$\frac{N_1}{N_2} = \frac{4}{1} = \frac{V_1}{V_2}$$

$$\boxed{V_1 = 4V_2}$$

Secondary rms voltage $V_2 = \frac{1}{4}V_1 = \frac{1}{4} \times 200 = 50V$.

$$\boxed{V_2 = 50V}$$

$$V_m = V_2\sqrt{2}$$
$$= 50\sqrt{2}$$
$$\boxed{V_m = 70.7V}$$

$$V_{dc} = \frac{V_m}{\pi}$$

$$\boxed{V_{dc} = 22.50V.}$$

(ii) $PIV = V_m$.

$$\boxed{PIV = 70.7V}$$

(iii) $V_{dc} = \frac{V_m}{\pi} = 22.50V$.

$$I_m = \frac{V_m}{R_L} = \frac{70.7V}{300}$$
$$= 0.236A$$

$$P_m = I_m^2 \times R_L$$
$$\boxed{P_m = 16.67W}$$

(iv) $P_{dc} = I_{dc} V_{dc}$

$$= \frac{V_{dc}^2}{R_L} = \frac{(22.5)^2}{300}$$

$$\boxed{P_{dc} = 1.68W}$$

(2) A HWR is utilized to supply 20V d.c to a resistive load 400Ω. The diode in HWR has $R_f = 40\Omega$. Determine the max value of a.c voltage required at the I/P.

Sol^n:- $V_{dc} = 20V$
$R_L = 400\Omega$
$R_f = 40\Omega$

(i) Load Current $I_{avg} = I_{dc} = \frac{I_m}{\pi}$

$$I_{dc} = \frac{20}{400} = \frac{1}{20}$$

$$\boxed{I_{dc} = 0.05A}$$

(ii) $I_m = I_{dc} \times \pi$
$= 0.05 \times \pi$
$$\boxed{I_m = 157.07mA}$$

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Clippers

Diodes can be used to change the appearance of an applied waveform.

Clippers are networks that employ diodes to 'clip' away a portion of an I/P signal without distorting the remaining part of the applied waveform.

HWR is a simplest form of diode clipper – One resistor & a diode. Depending on the orientation of diode, the positive and negative region of applied signal is clipped off.

~~There are two type of clippers~~
~~1) Series 2) Parallel.~~

~~Series Clipper:–~~

~~In series clipper configuration the diode is in series with Load.~~

~~Step① Take careful note of where o/p voltage is defined.~~

~~Step② Try to develop an overall sense of response by Checking each power supply and conventional current direction through it.~~

~~Step③ Determine the region of applied voltage when the diode is on and when it is off.~~

Clippers find extensive use in RADAR, digital & other electronic systems.

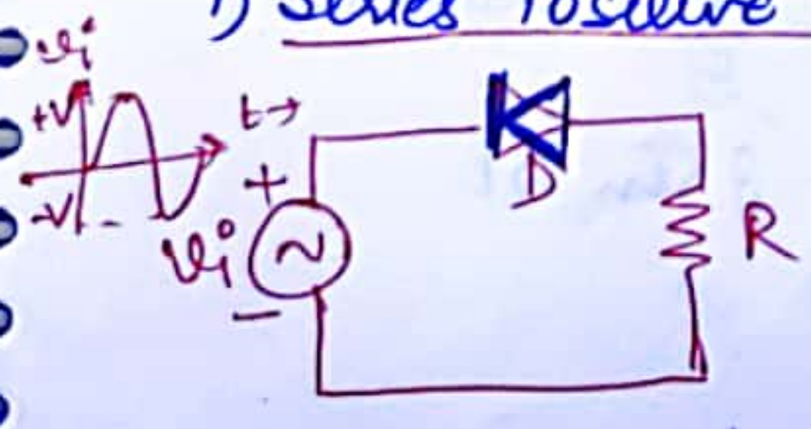
Clipper circuit can be classified as,

1) Positive Clipper
2) Negative Clipper
3) Biased Clipper
4) Combination Clipper

1) Positive Clipper:–

It remove positive half cycle of I/p waveform. It is further classified into following two ways.

i) Series Positive Clipper.



→ In ~~+ve~~ -ve half cycle,
Diode → F.B or S/ckt, I_D flows.

→ In ~~Negative~~ +ve half cycle.
Diode → R.B or O/ckt, $I_D = 0$

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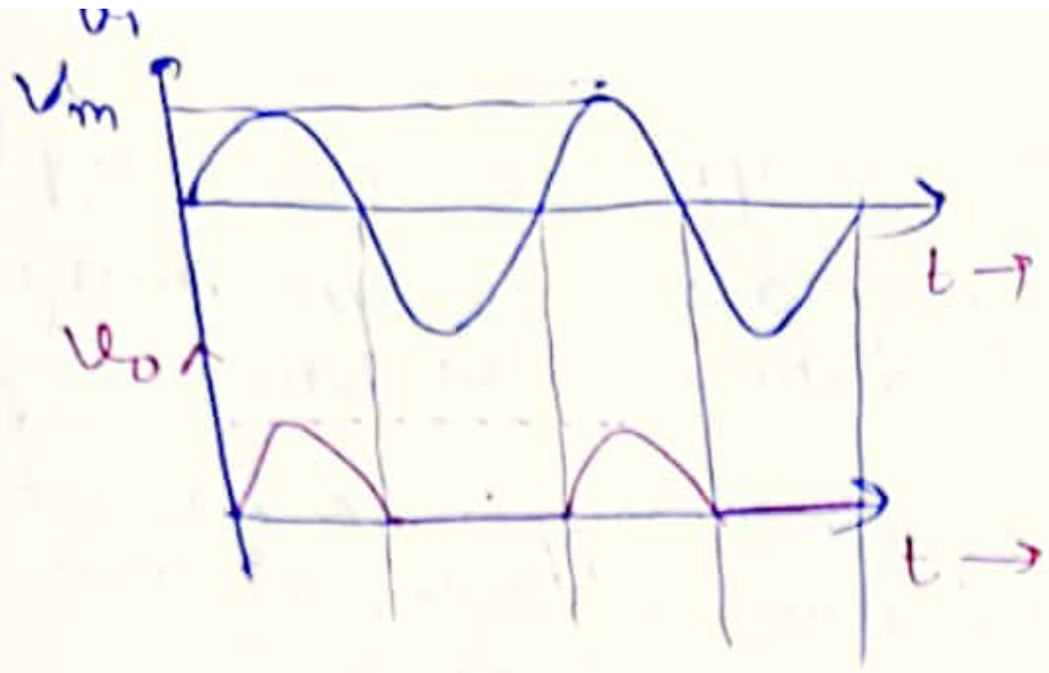
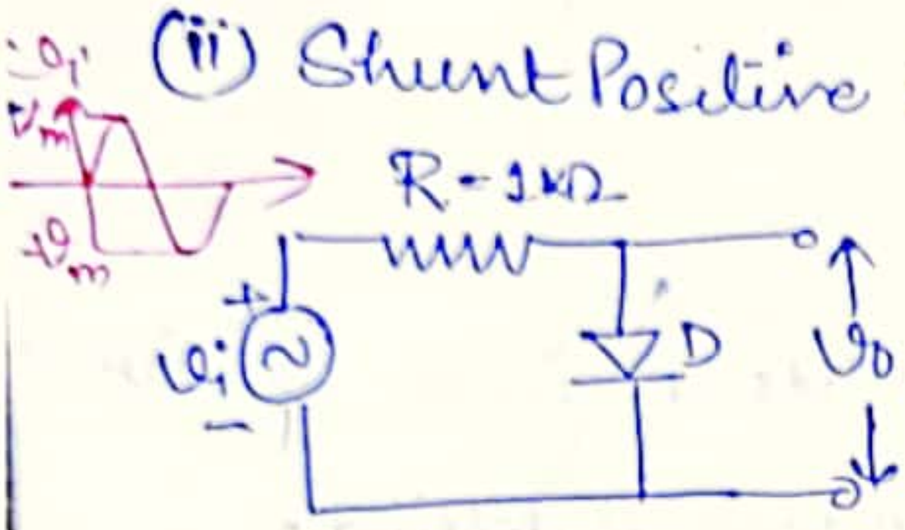
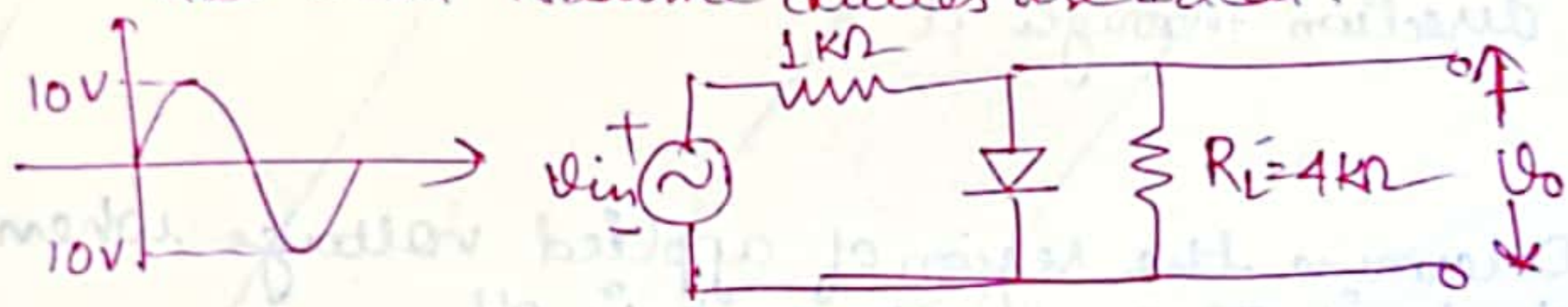


(ii) Shunt Positive Clipper :-

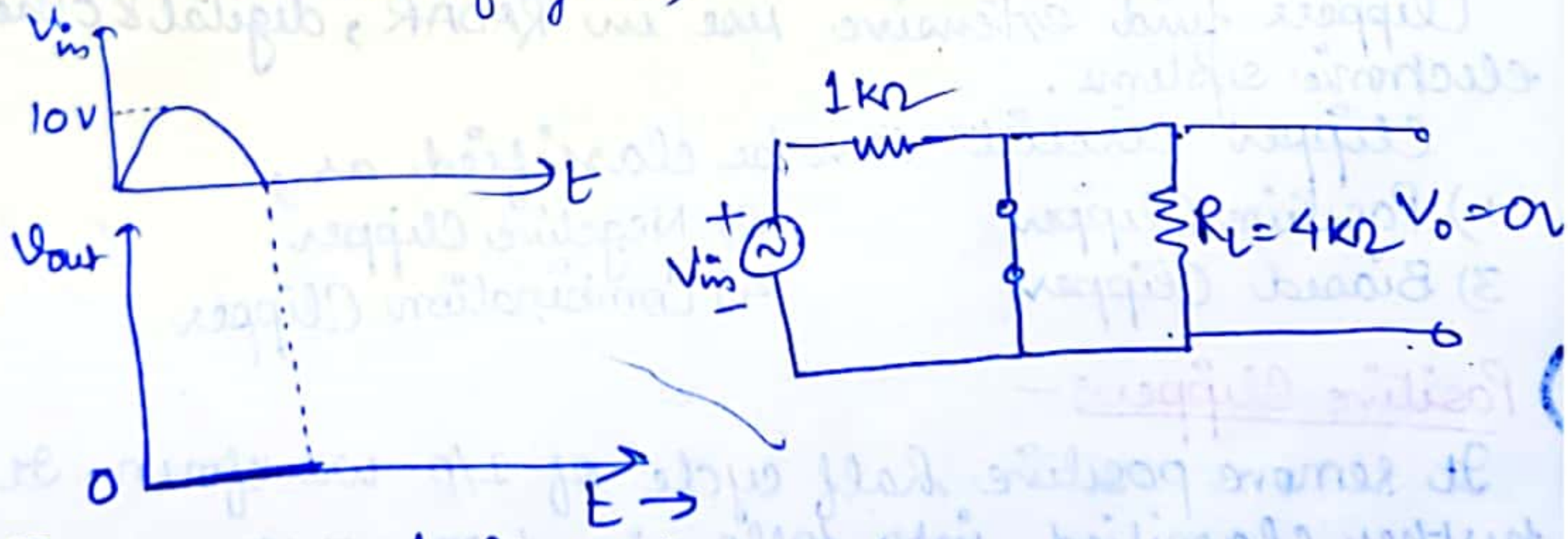


For Positive half cycle.
Diode → F.B
I_D flows.
For Negative half cycle.
Diode → R.B.
$I_D = 0$.

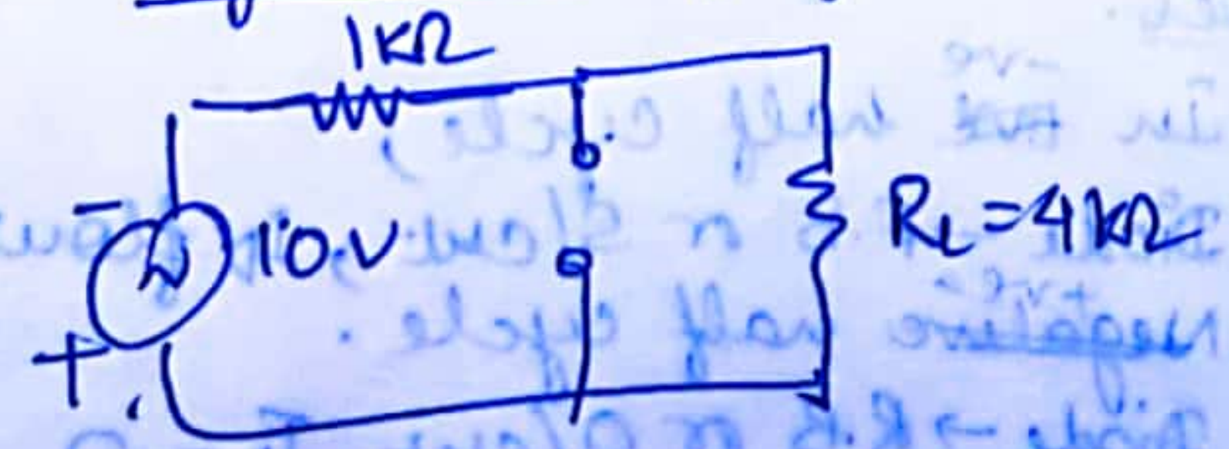
Question :- Determine the output waveform of given ckt.
~~Ass~~ ~~Ideal~~ Assume diodes are Ideal.



For Positive half cycle,



For negative half cycle



$$v_o = \frac{4}{\cancel{5}} \times (\overset{2}{\cancel{10}} \sin \omega t)$$
$$= 8 \sin \omega t.$$

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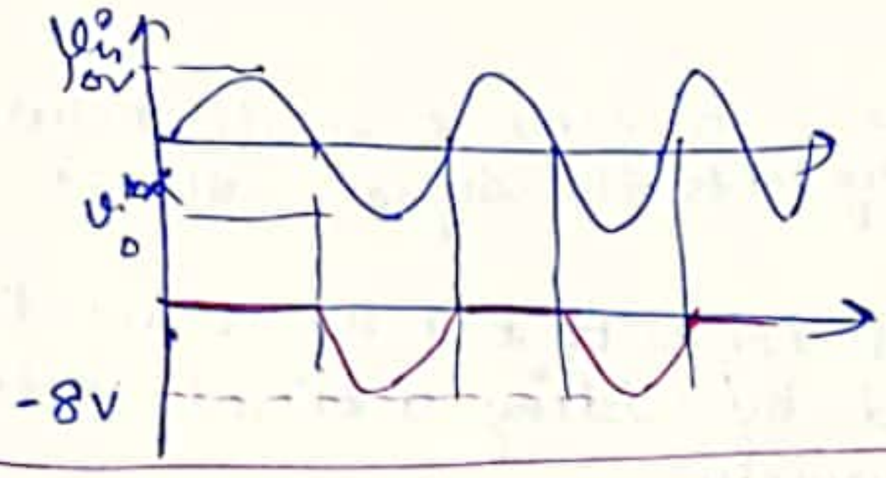
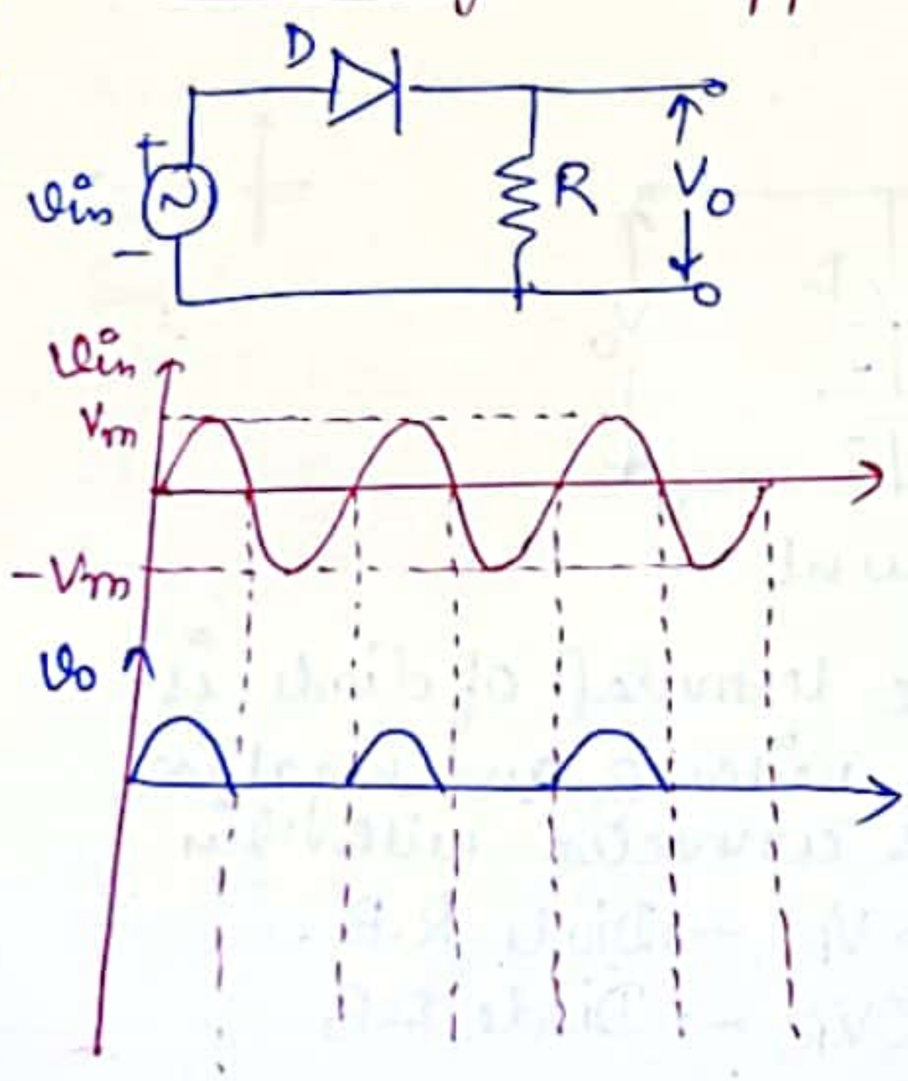


2) Negative Clipper

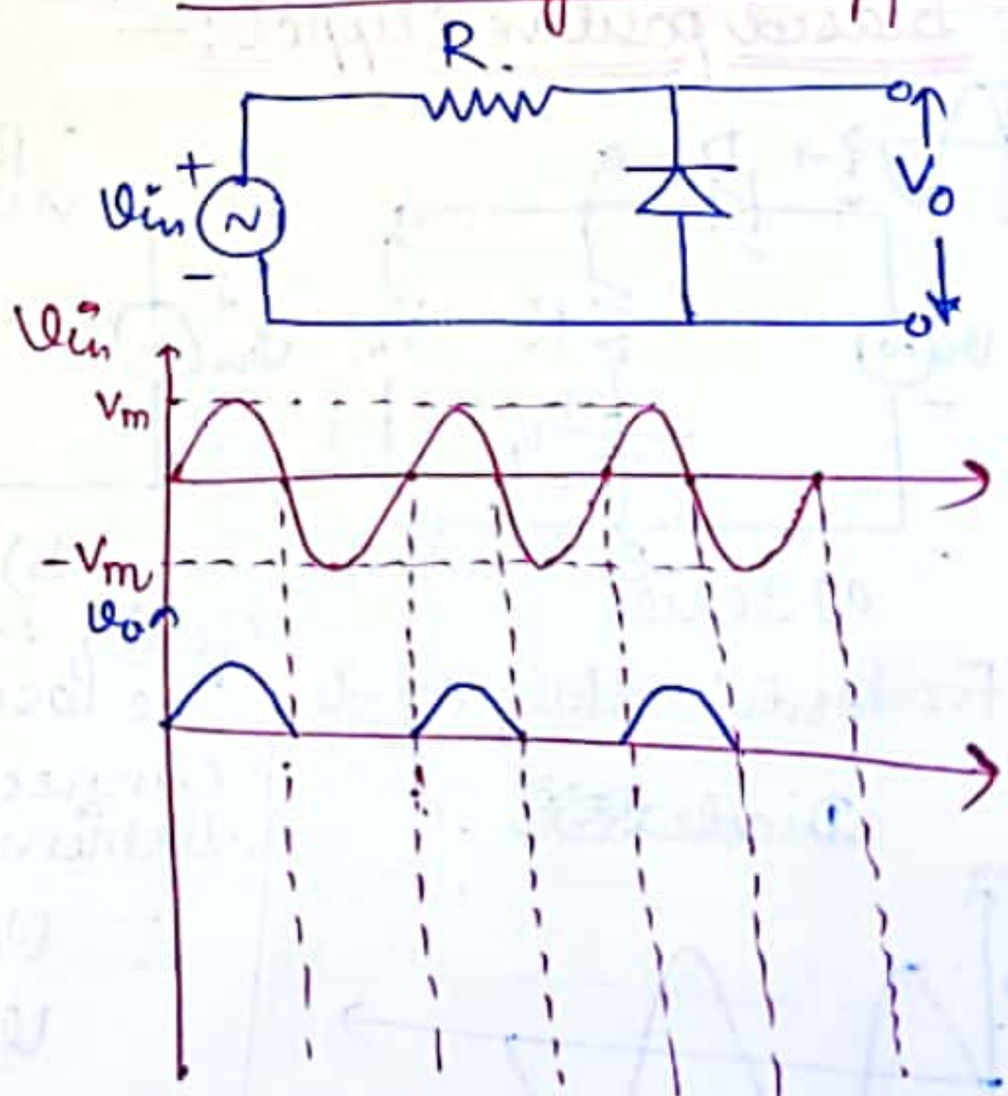
This remove negative half cycle of I/P voltage waveform. There are two type of negative clipper.

a) Series Negative clipper
b) Shunt Negative Clipper.

a) Series Negative Clipper



b) Shunt Negative Clipper



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3) Biased Clipper :-

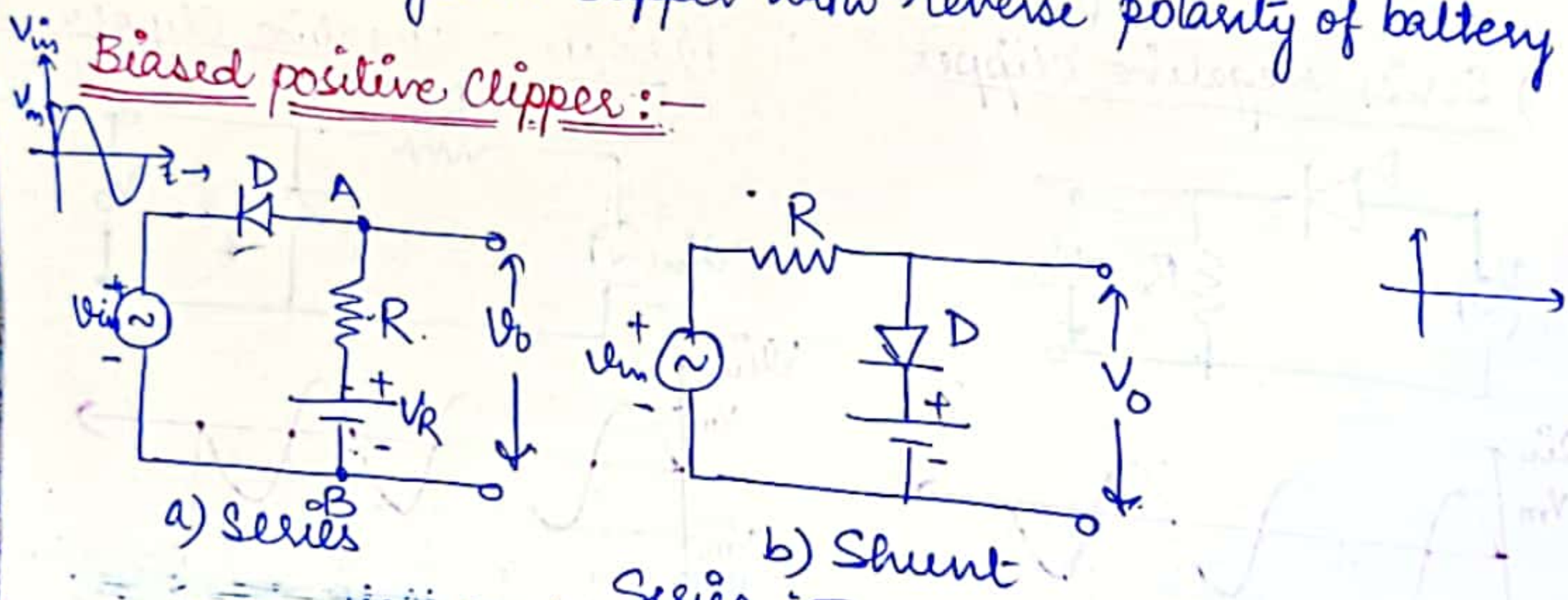
When there is a requirement to remove small portion of negative or positive half cycle of the signal voltage then biased clipper is used.

The name biased mean that refers to the adjustment of clipping level is achieved by adding a biased voltage in series with diode or resistor.

Biased clipper may be of two types:

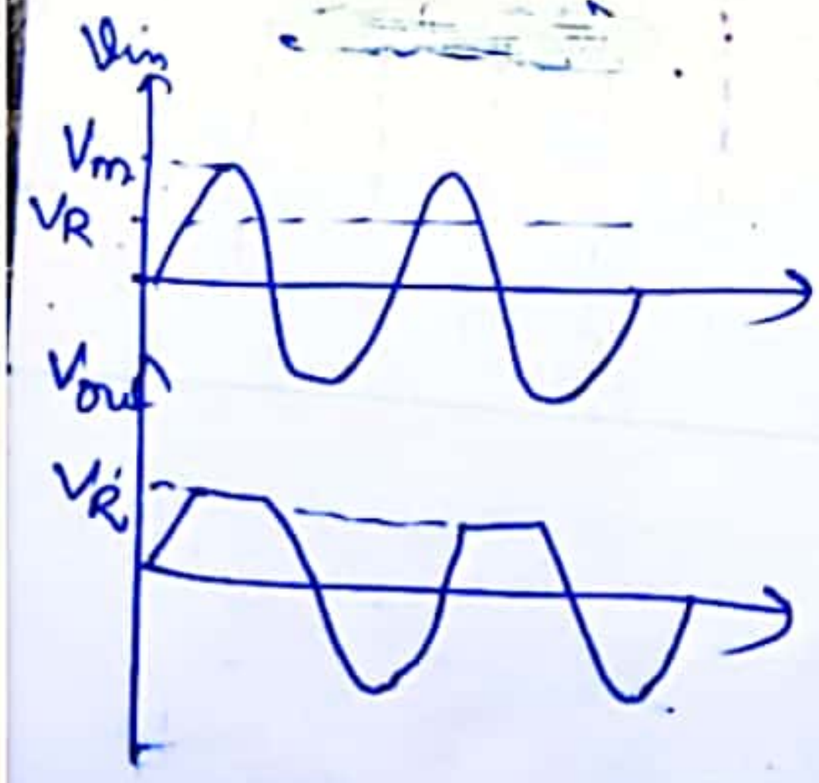
1) Biased positive clipper
2) Biased positive clipper with reverse polarity of battery
3) Biased negative clipper
4) Biased negative clipper with reverse polarity of battery

Biased positive clipper :-



a) Series

b) Shunt



Series :-

The Positive terminal of diode is connected with VR and negative terminal is connected with Vin

$\therefore$ $V_{in} > V_R \rightarrow$ Diode R.B.

$V_{in} < V_R \rightarrow$ Diode F.B

When diode is F.B.

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

and Diode R.B. V_0 is voltage accross branch ~~A-B~~ AB.

$$\boxed{V_0 = V_R}$$

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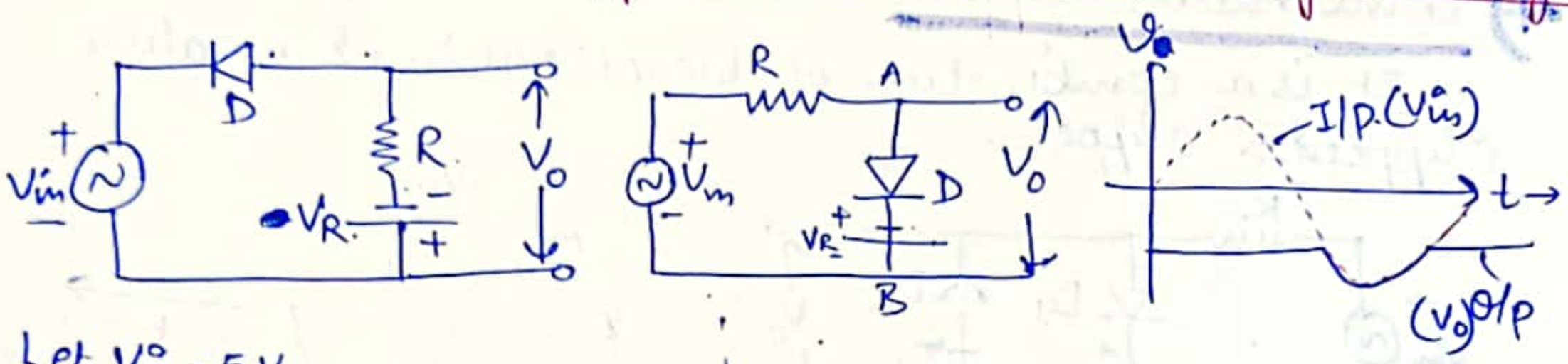
When Di: +ve terminal of diode is connected with V_{in}
−ve " " " " " V_R.

$V_{in} > V_R \rightarrow$ Diode F.B ON. $\rightarrow V_0 = V_R$.

$V_{in} < V_R \rightarrow$ " R.B OFF $\rightarrow V_{AB}$ Open ckt.
No current accross R.

$\therefore \boxed{V_0 = V_{in}}$

b) Biased Positive clipper with Reverse polarity of battery



Let $V_{in} = 5V$
$V_R = 3V$.

Diode is R.B all the time expect when $V_{in} < (-V_R)$

Ex:- when $V_{in} = -4V$.
$V_R = -3V$.

$\because V_{in} < V_R$

$\therefore$ Diode F.B. S/ckted.

hence $\boxed{V_0 = V_{in}}$

otherwise $\boxed{V_0 = -V_R}$

Diode is FB all time hence Branch AB is's Resulting Voltage

$\boxed{V_{AB} = V_0 = -V_R}$

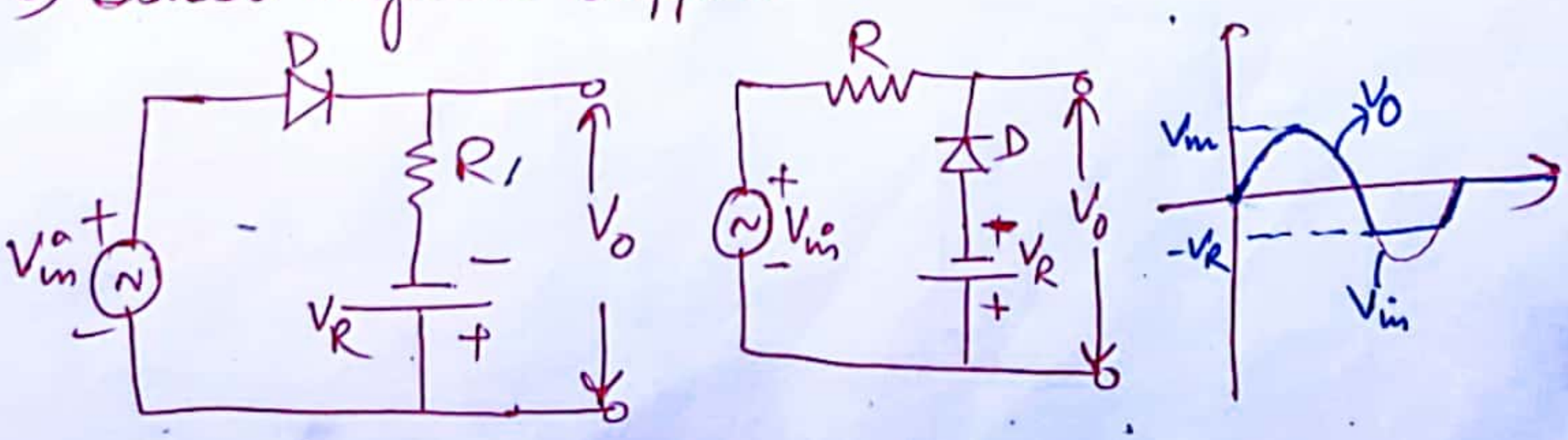
But when $(-V_R) < V_{in}$

Then Diode R.B.

hence Open circuited

$\therefore \boxed{V_0 = V_{in}}$

c) Biased Negative clipper



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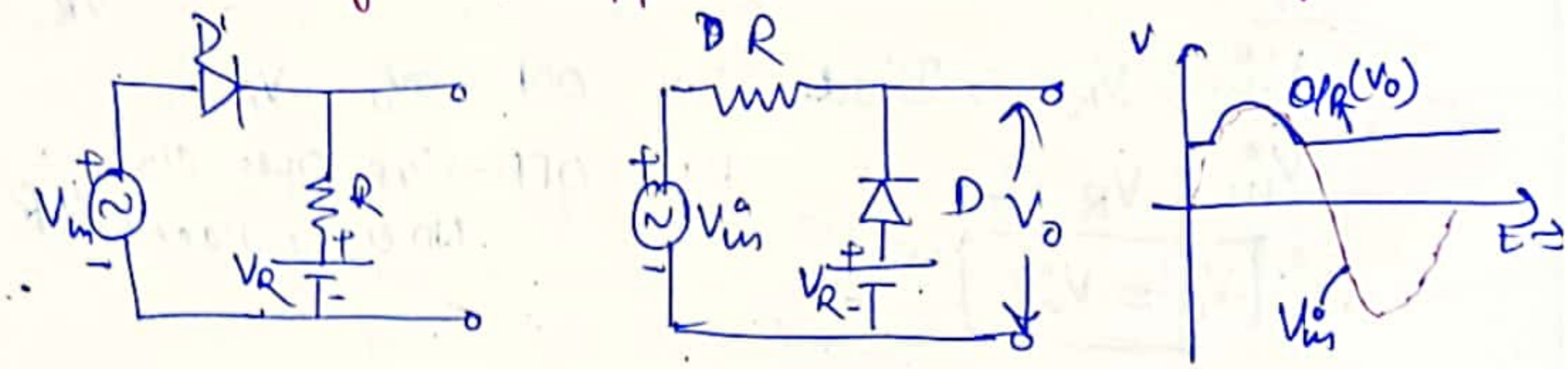
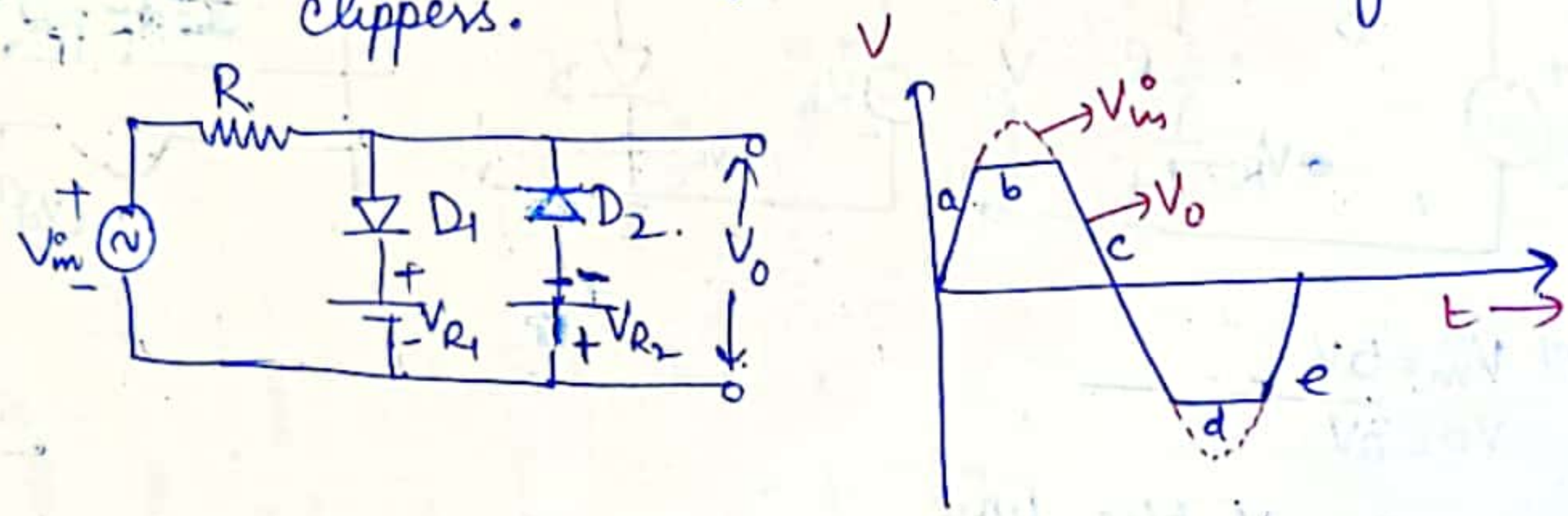
(d) Biased Negative clipper with reverse polarity



4) Combination Clipper:-

It is a combination of biased positive & negative clippers.



$V_m \geq V_{R_1}$ $D_1 \rightarrow$ F.B(ON)
$D_2 \rightarrow$ RB (OFF)

$\therefore \boxed{V_o = V_{R_1}}$ (It is shown by branch b in curve.

$V_m < V_{R_1}$ $D_1 \rightarrow$ R.B(OFF)

$\therefore \boxed{V_o = V_m}$ (until $V_m > -V_{R_2}$)

when $V_m > -V_{R_2} \longrightarrow \boxed{V_o = -V_{R_2}}$ (Represented by branch b).

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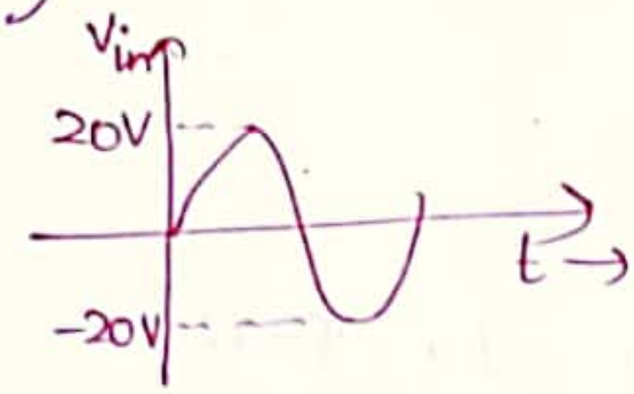
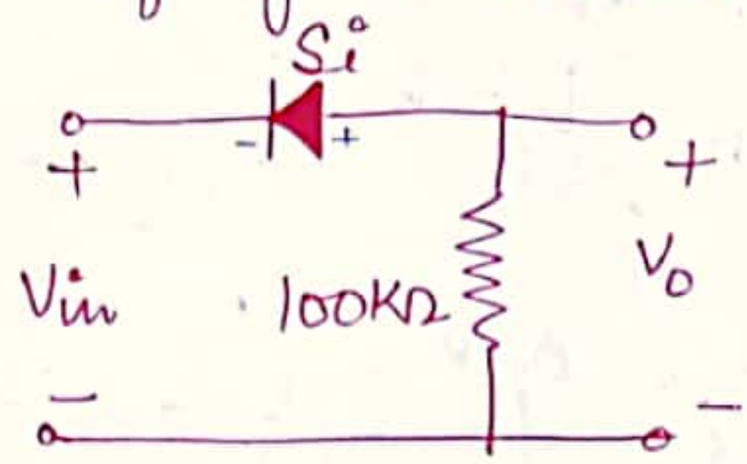
Question :- Determine V_0 for given network.

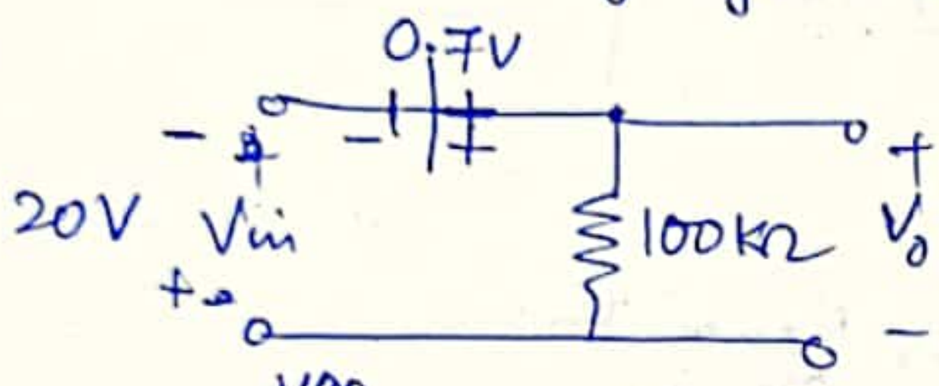
a)





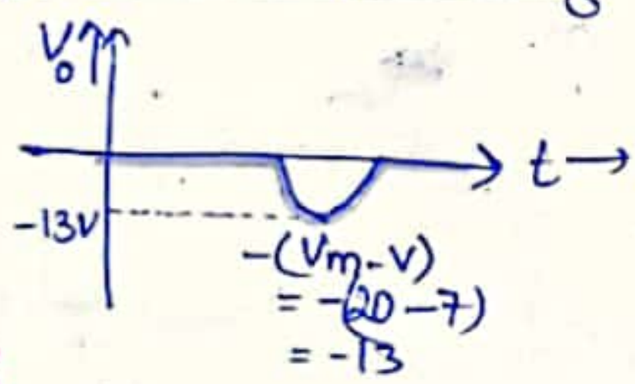
In +ve half cycle Diode R.B. $\therefore \boxed{V_0 = 0}$

In -ve half cycle Diode is F.B.

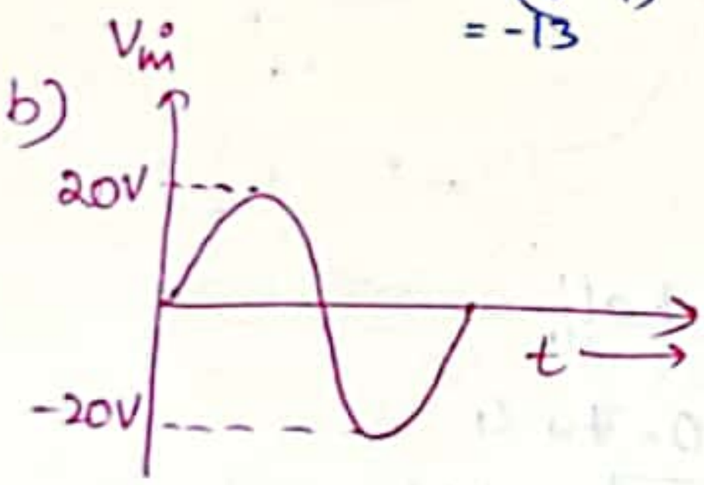


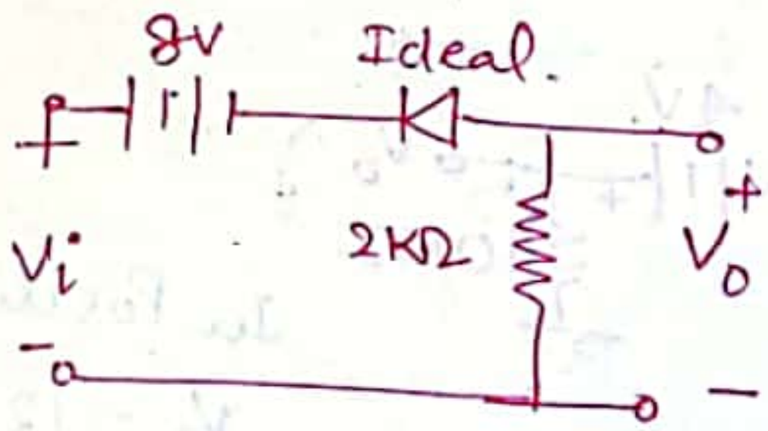
$\boxed{V_0 = V_m - 0.7V}$

Diode will turn of after 0.7V



b)

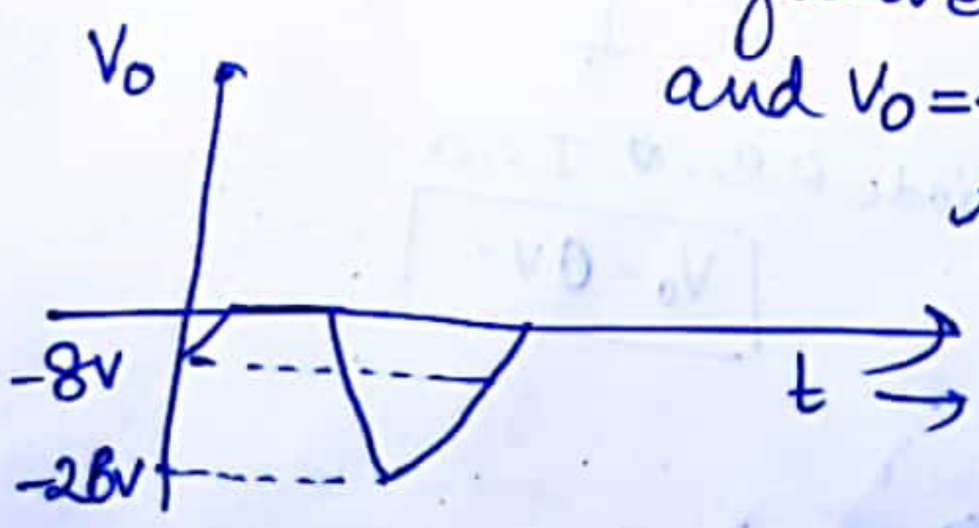




In positive half cycle, when $V_{in} < 8V$, Diode is F.B. hence $V_0 = -8V$ at ~~begin~~ begining.

In negative ~~$V_0 =$~~ after $V_{in} > 8V$. Diode is R.B & $\boxed{V_0 = 0}$

~~When~~ In negative half cycle, diode is F.B and $V_0 = -(V_{in} + 8V)$ at every instant of time.



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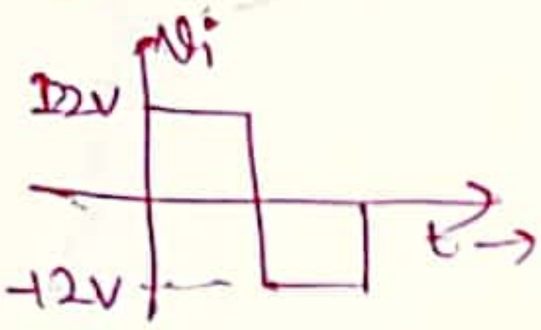
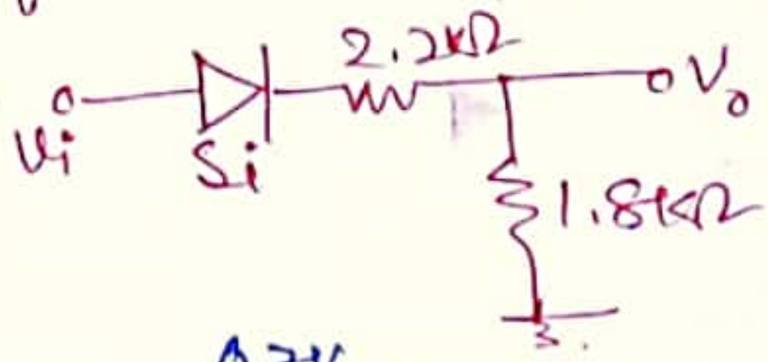
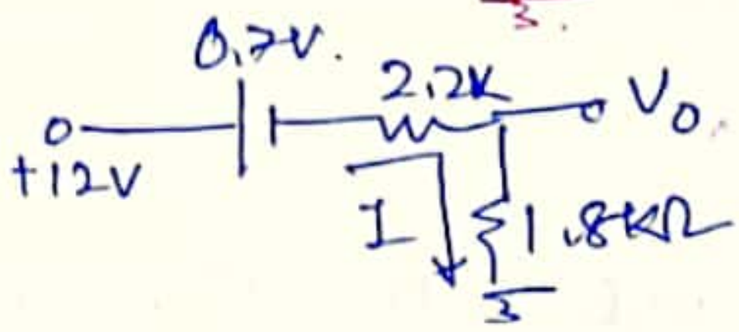
② Determine V_o for each N/W.





For $V_i = +12V$.



$V_o = I \times 1.8K\Omega$.

$12 - 10.7 - 2.2I - 1.8I = 0$

$I = \frac{11.3}{4} = \underline{2.8mA}$

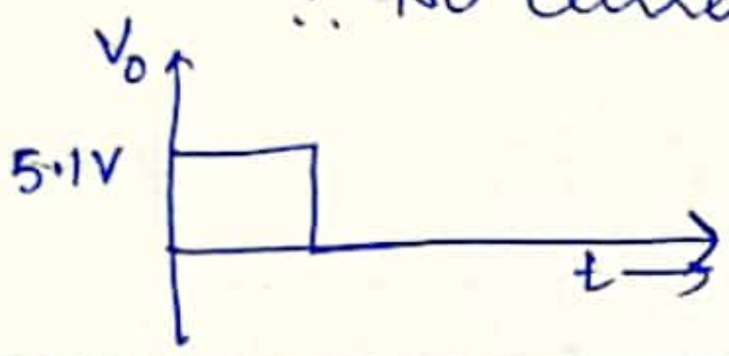
$V_o = 2.8m \times 1.8K$

$\boxed{V_o = 5.1V}$

For $V_i = -12V$

Diode is R.B..

∴ No current flows hence $V_o = 0$



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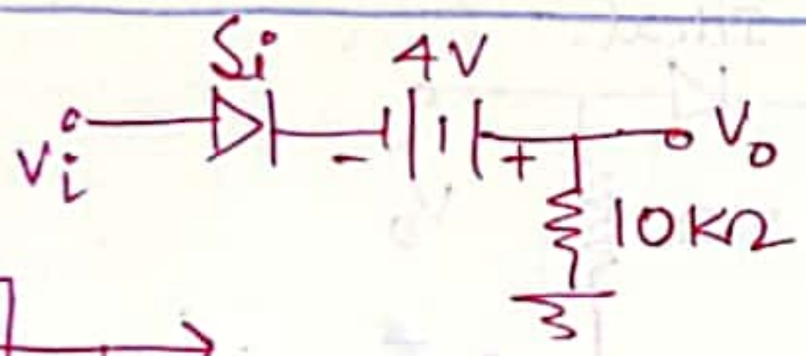
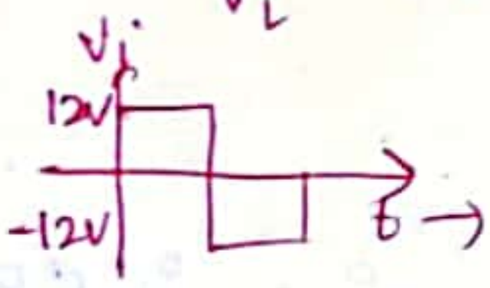
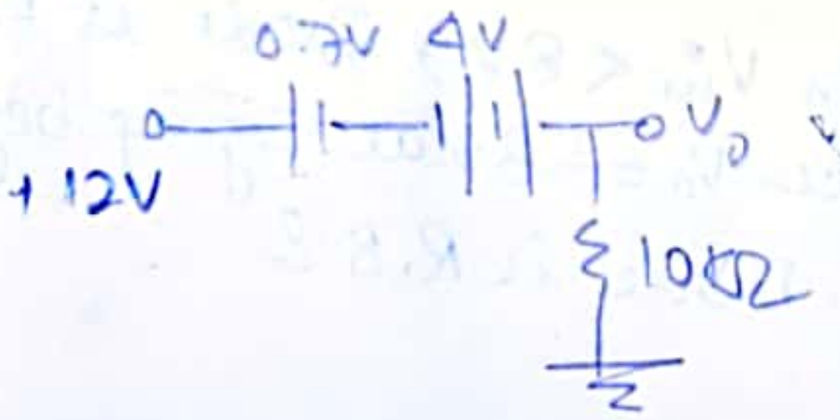




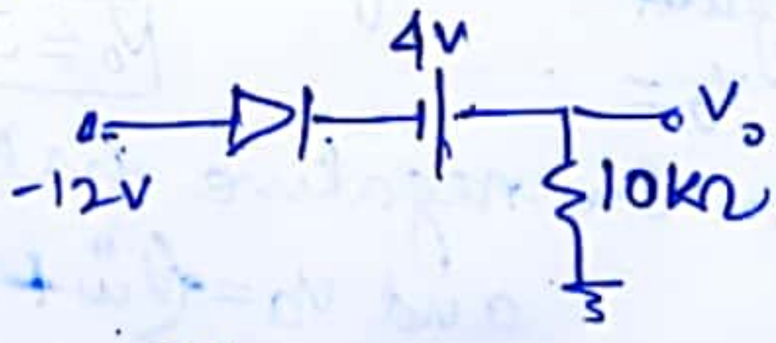
In Positive half..

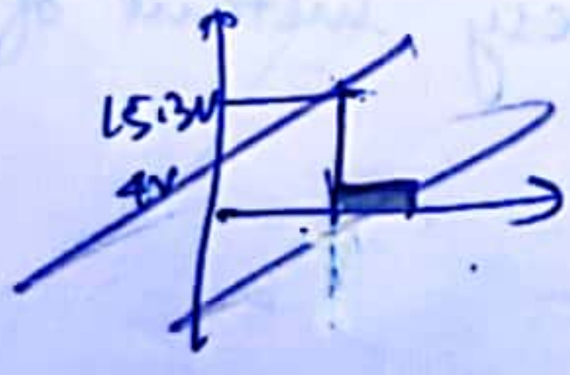
$V_o = 12 - 0.7 + 4$

$\boxed{V_o = 15.3V}$



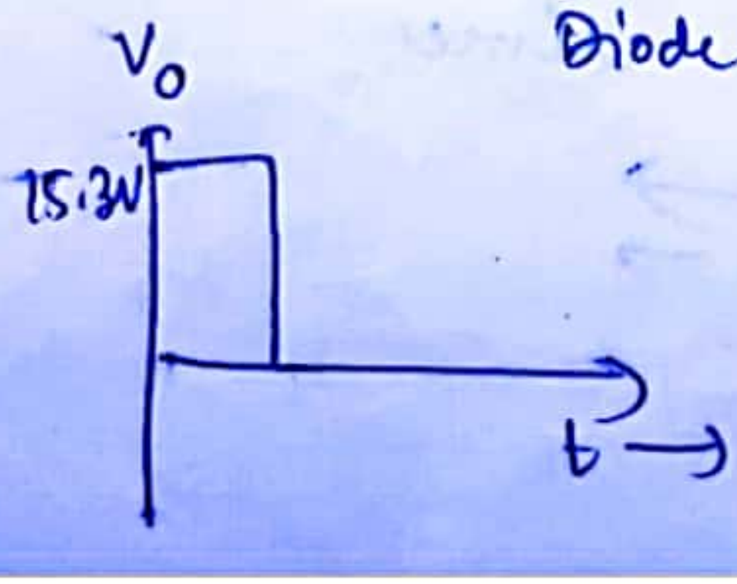
In negative half,





Diode R.B. & $I = 0$

$\boxed{V_o = 0V.}$



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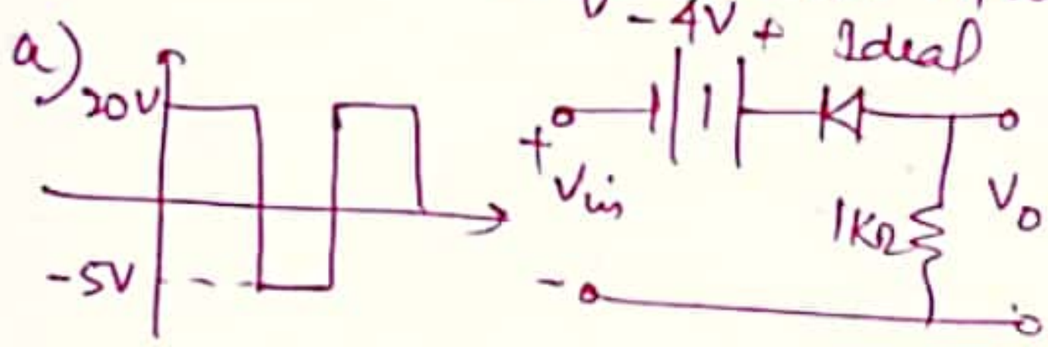
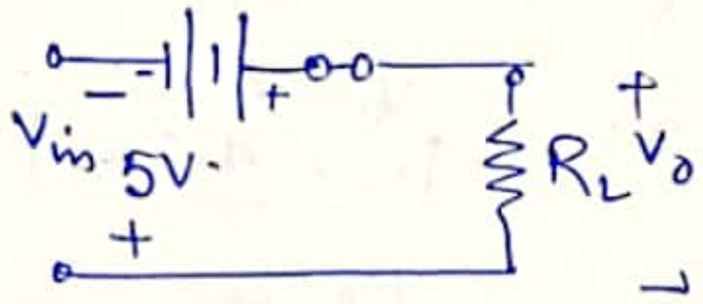
(3) Determine V_o for each n/w..

a)

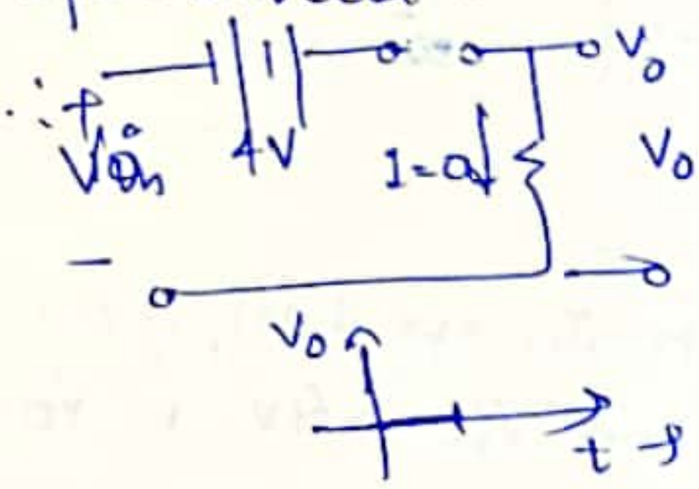


For Negative half cycle,

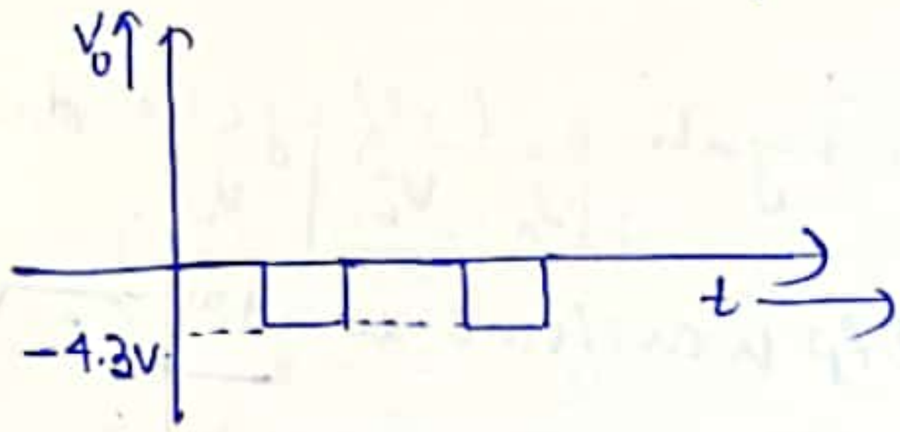


$V_o = -5 + 0.7$
$= -4.3V$.

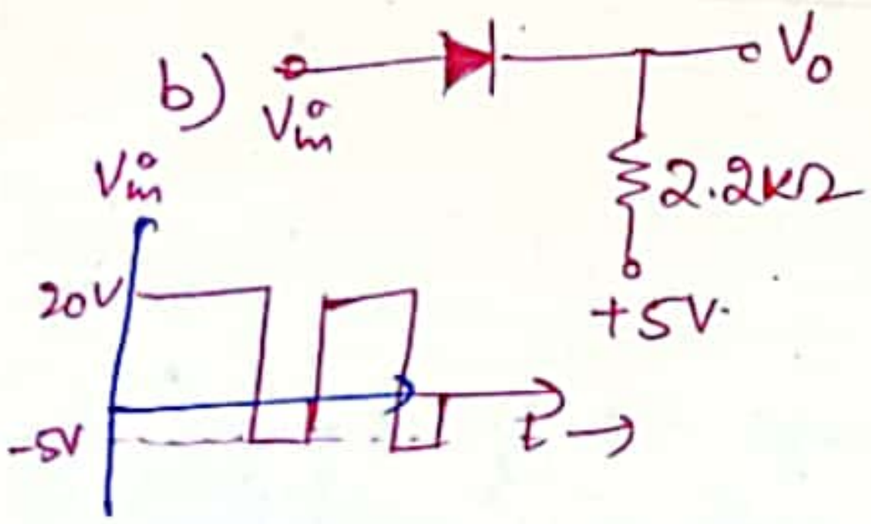
For Positive half cycle - Diode is R.B hence open circuit.



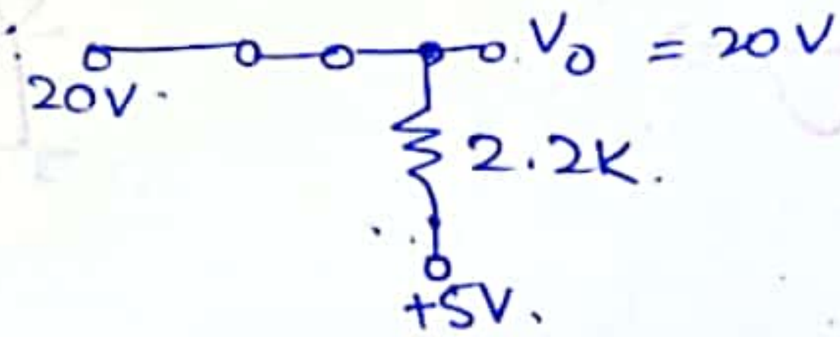
$V_o = 0$



b)

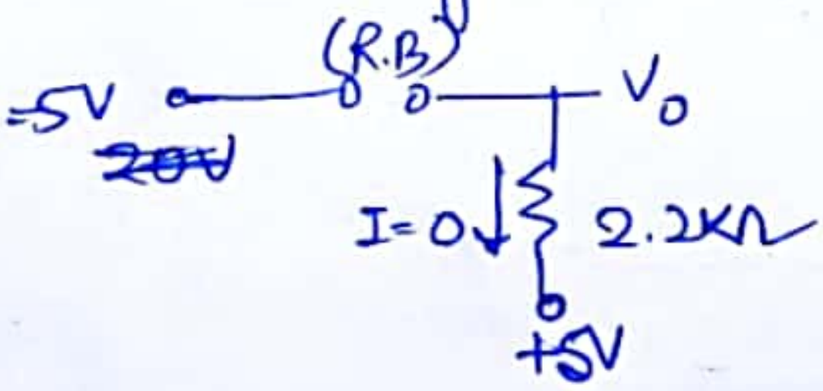


For Positive half cycle,
Diode F.B.



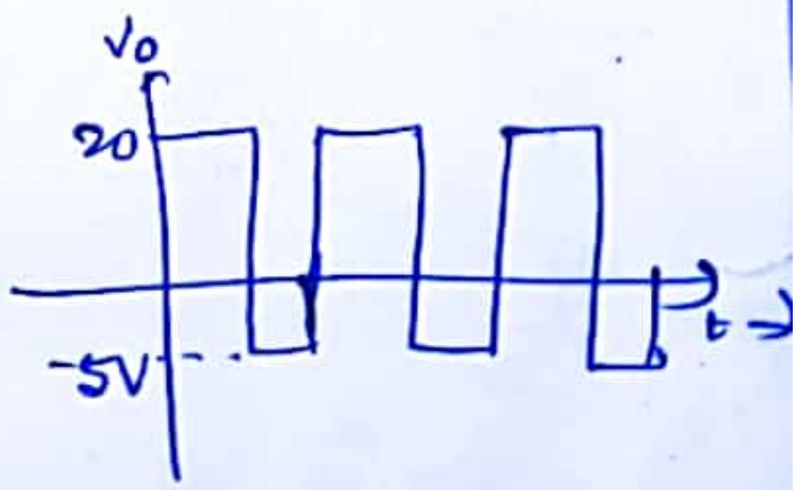
$\boxed{V_o = 20V}$

For Negative half cycle.



$V_o = 0 - 5V$

$\boxed{V_o = -5V}$



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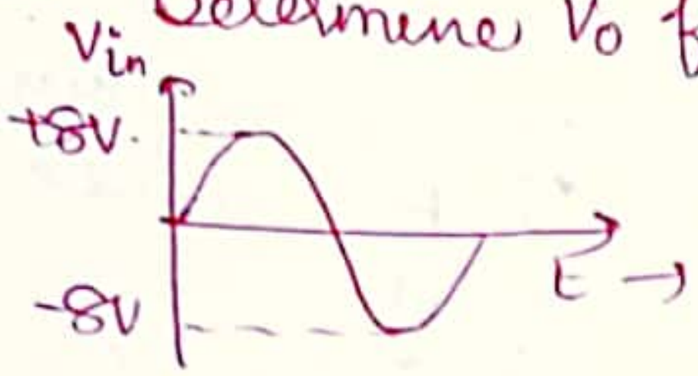
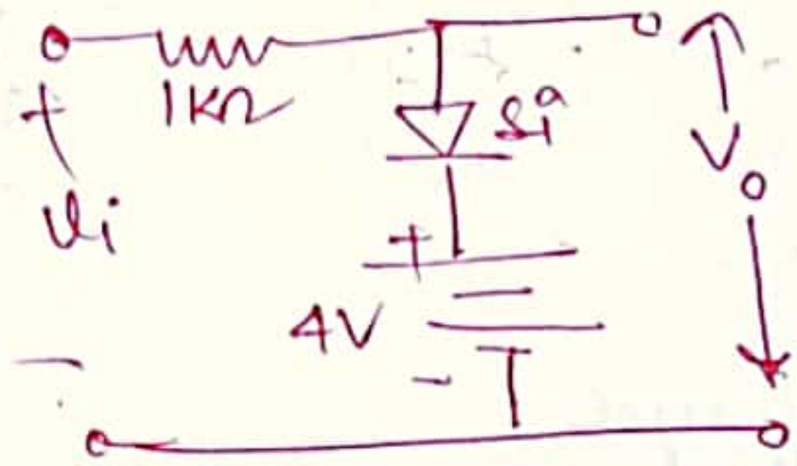
③ Determine V_o for given N/ws for the I/P shown,





In +ve halfcycle when $V_{in} < 4V$ Diode is off : $\boxed{V_o = V_{in}}$

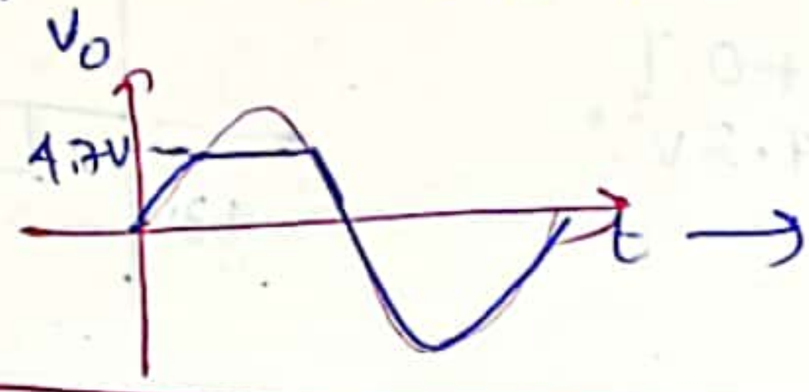
at $V_{in} > 4V$, Diode is F.B hence $V_o = 4 + 0.7$

$\boxed{V_o = 4.7V}$

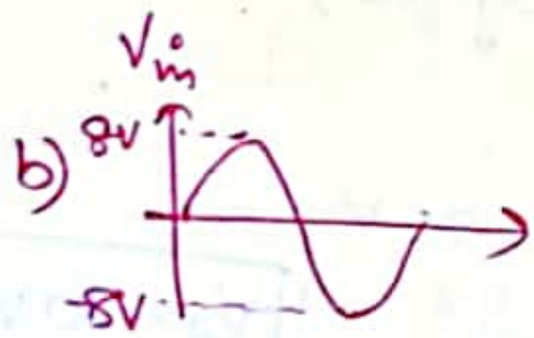
and in negative halfcycle diode is R.B hence

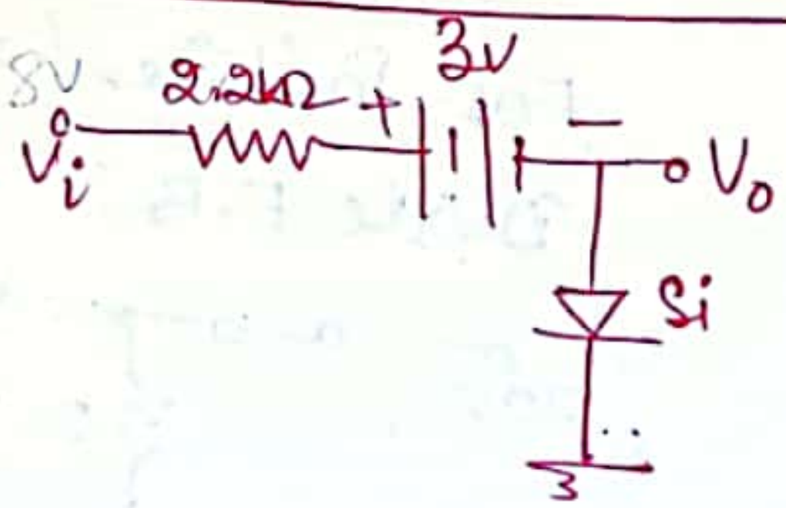
$\boxed{V_o = V_{in}}$

∴ O/P waveform is,



b)





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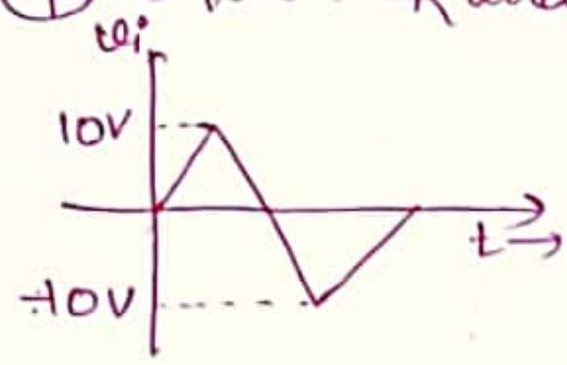
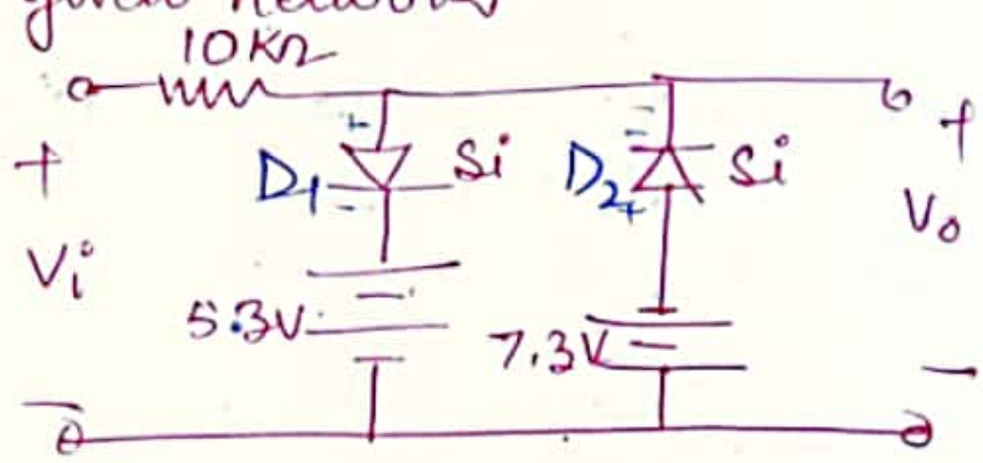
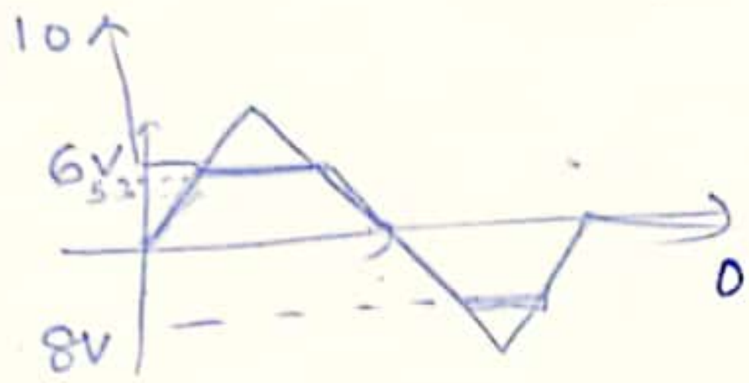
(4) Sketch I_R and V_o for given network





$V_o = V_{in}$



D_1 On when $V_{in} > 5.3V$.

$V_o = 5.3 + 0.7V$
$= 6V$.

When ~~D1~~ ~~is~~
In Positive half cycle.

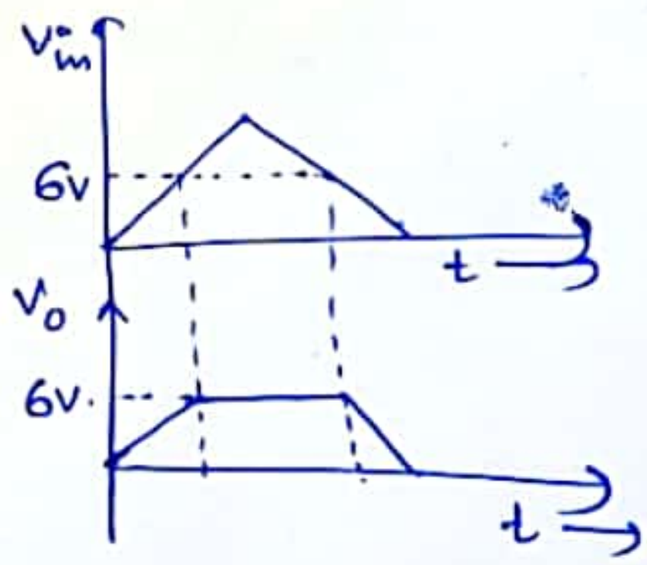
$0.7V + 5.3V \geq V_i > 0$ and
or
$6V \geq V_i \geq 0$ $D_1 \rightarrow$ OFF. $\therefore \boxed{V_o = V_{in}}$

and D_2 is off in complete +ve half cycle,

After 6V. D_1 will turn ON and.

$V_o = 0.7 + 5.3$

$\boxed{V_o = 6V}$

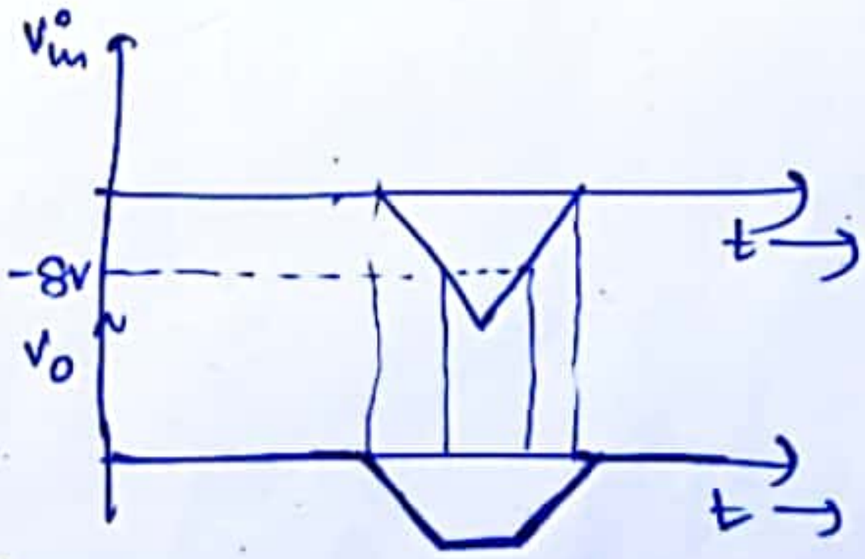


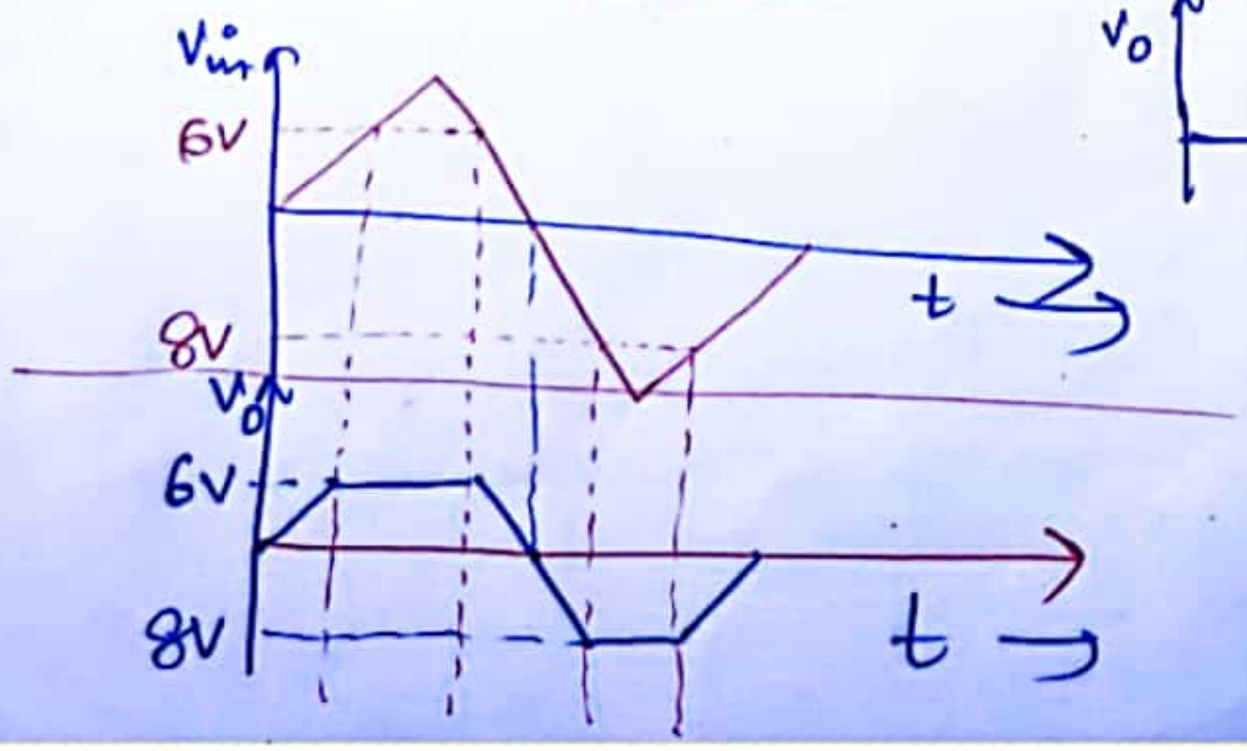
For Negative half cycle,
D_1 is off For complete time.
But D_2 is ON only during

$(-8) \leq V_o < (-10)$

$\boxed{V_o = -8V}$

Otherwise $\boxed{V_o = V_{in}}$.





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Clamper

→ A clamper is a network that shifts a waveform to different DC Level without changing the appearance of the ~~signal~~ applied signal.

→ The clamper is constructed through, a diode, resistor and capacitor.

→ The resistor and capacitor of a network must be choosen such that the time constant determine by $\tau = RC$ is sufficiently large to ensure that the voltage accross capacitor does not discharge significantly during the interval the diode is non-conducting.

→ Throughout analysis we assume that for all practical purpose capacitor fully charge or discharges in five time constant.

→ In Clamping N/w. capacitor is connected directly between I/P & O/P through resistive element parallel to the O/P signal. Diode is also used in parallel with O/P voltage.

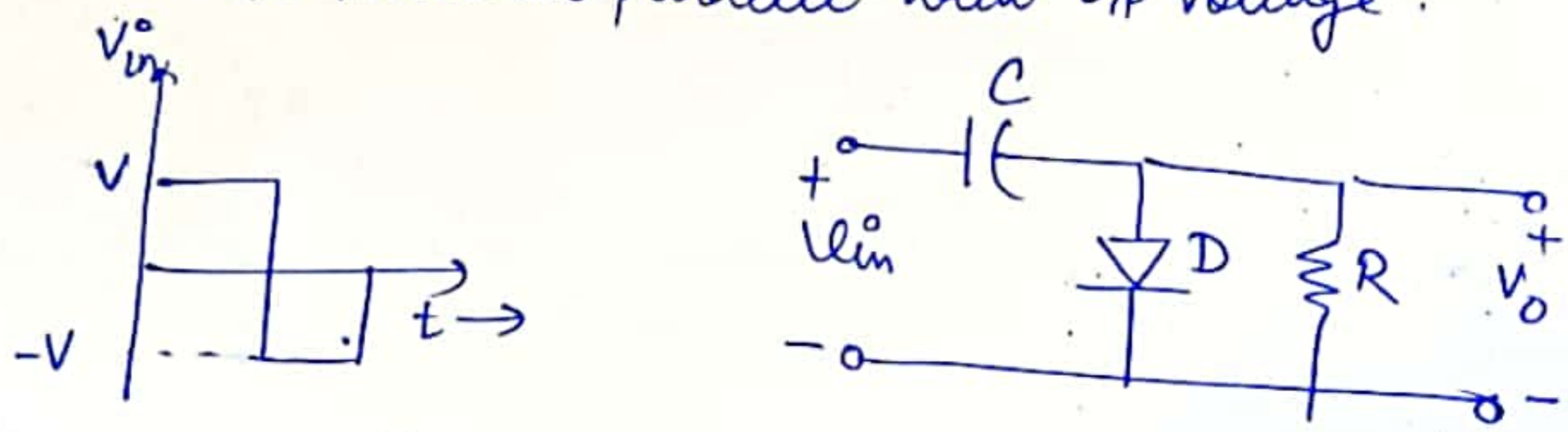

fig: Clamper Circuit

Steps for solving clamper circuits:-

① Start analysis with I/P ~~signal~~ the portion of I/P signal that will forward bias the diode.

② During the period diode is in 'ON' state, assume that capacitor will charge up ~~instantly~~ instantaneously to a voltage level determined by the surrounding N/w.

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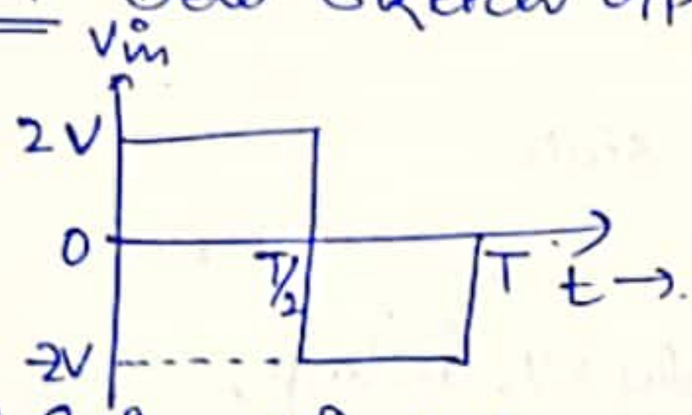
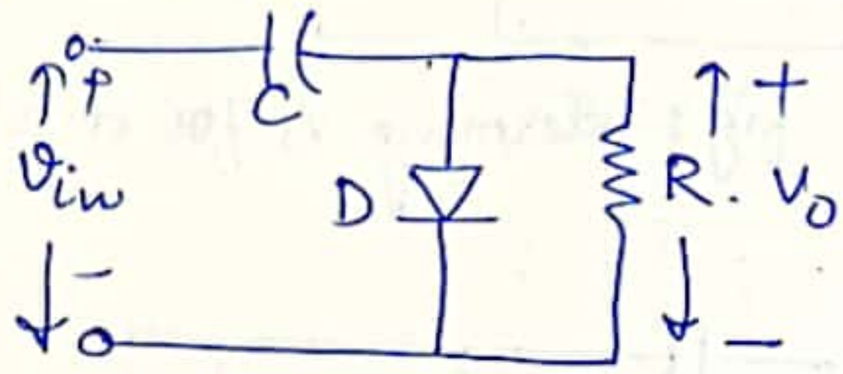
Step③ During complete analysis, take care of polarity of resulting voltage.

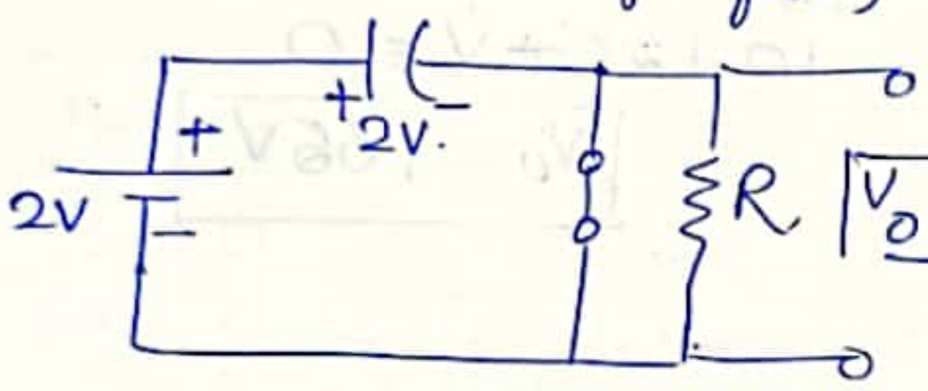
Step④ Check that total swing at the O/P matches that of the I/P.

Ex 1 ~~Dete~~ Sketch O/P Waveform (V_o).



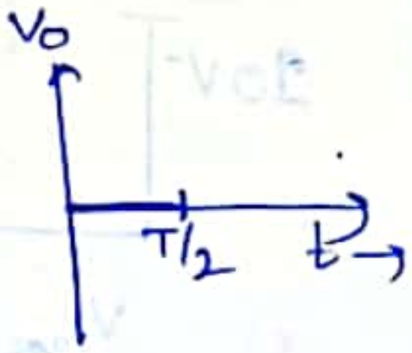


Sol^n Since Diode is F.B in Positive half cycle. hence, For Positive half cycle,

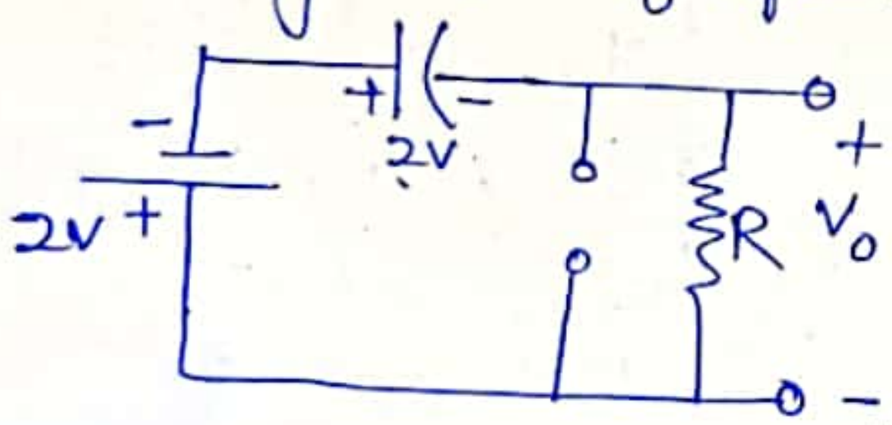


$\boxed{V_o = 0}$

$\boxed{V_o = 0}$

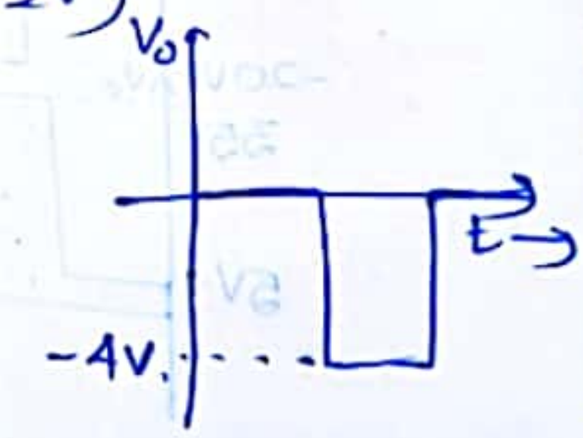


For Negative half cycle,

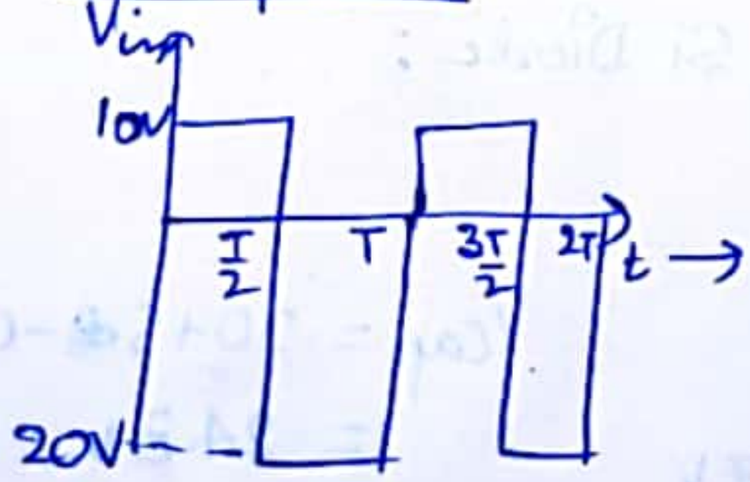


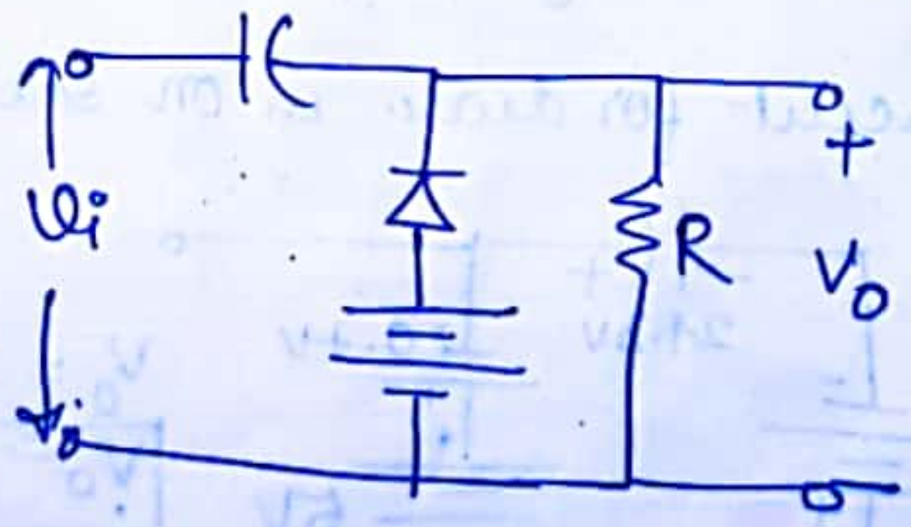
$V_o = -(2V+2V)$

$\boxed{V_o = -4V}$



Example 2:- Determine V_o for N/w.





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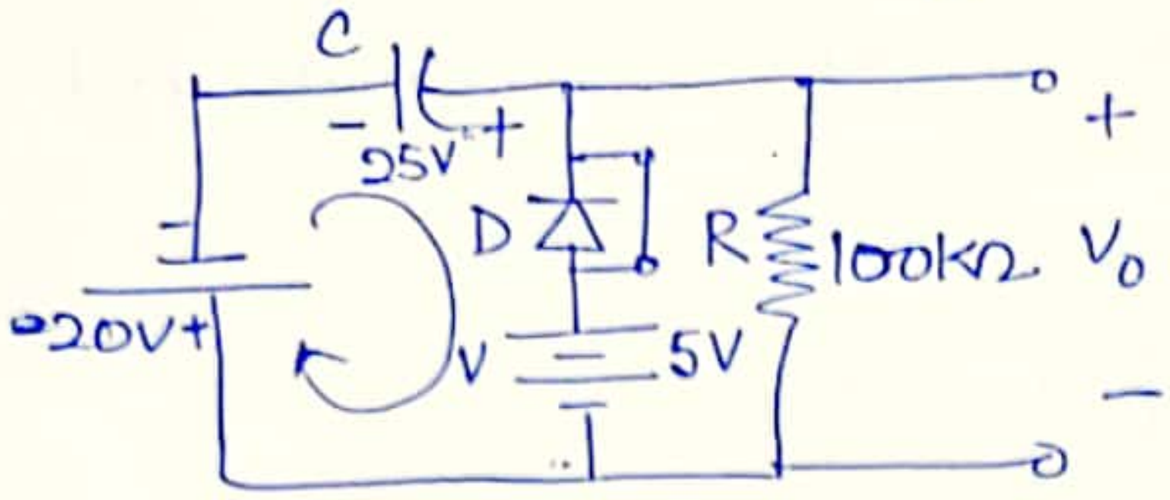
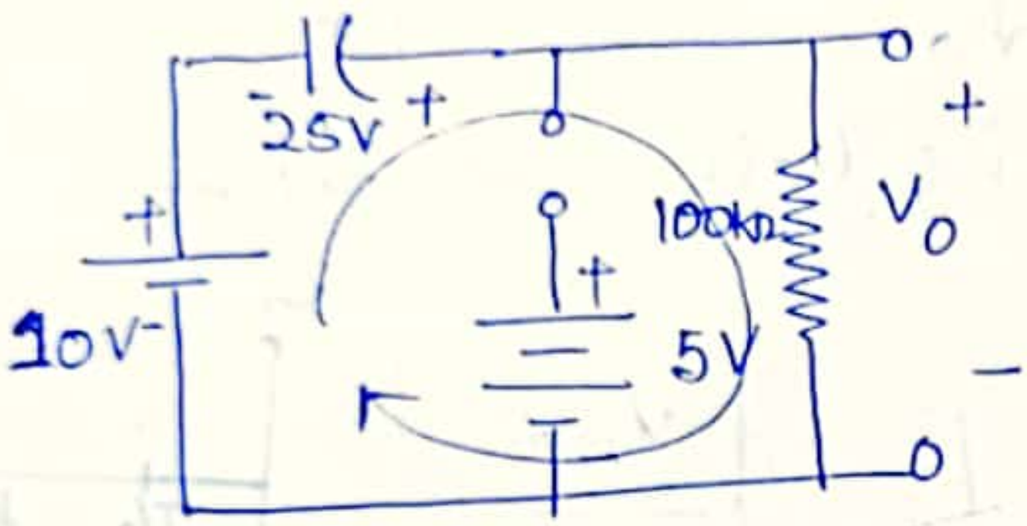
Solⁿ First check F.B condition of diode,
Diode is F.B in Negive half cycle,



$\boxed{V_o = 5V}$

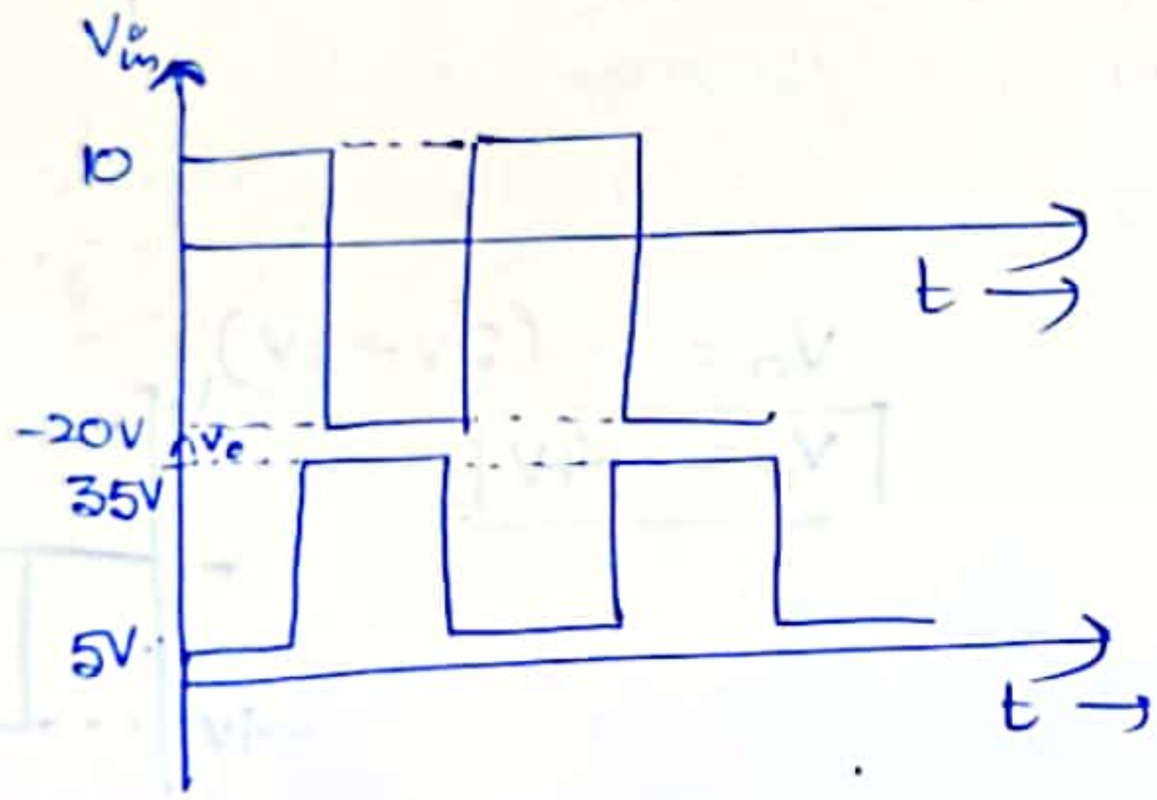
fig: Determining V_o for diode in 'on' state.



apply KVL in loop,

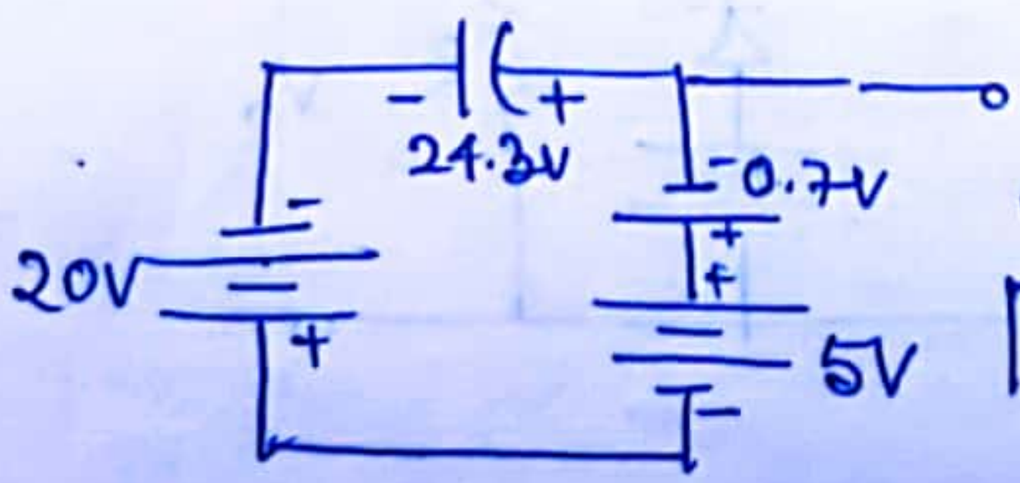
~~20+25~~
$10 + 25 + V_o = 0$

$\boxed{V_o = +35V}$



② Repeat the problem ~~with~~ using Si Diode:

→ circuit for diode in 'on' state



$V_{cap} = 20 + 5 - 0.7$
$= 24.3V$

$V_o = 5 - 0.7V$

$\boxed{V_o = 4.3V}$

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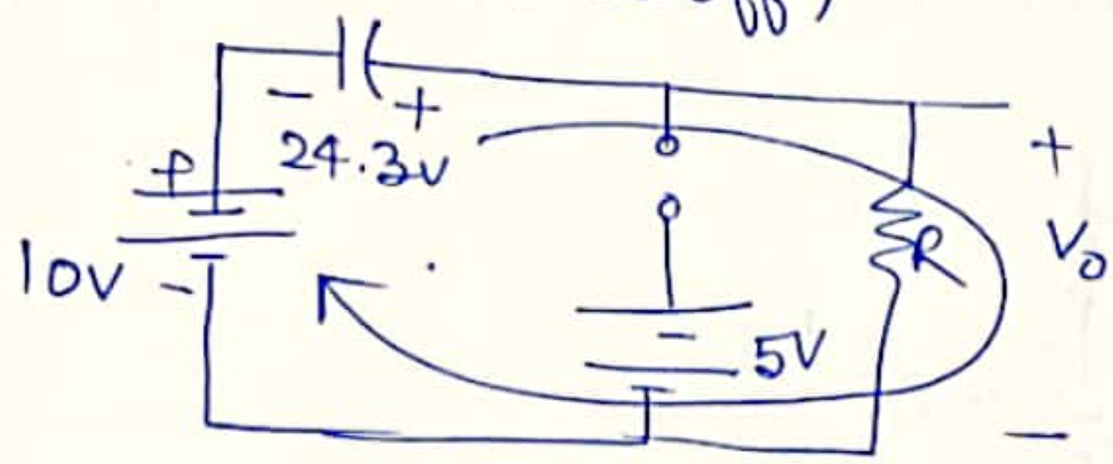
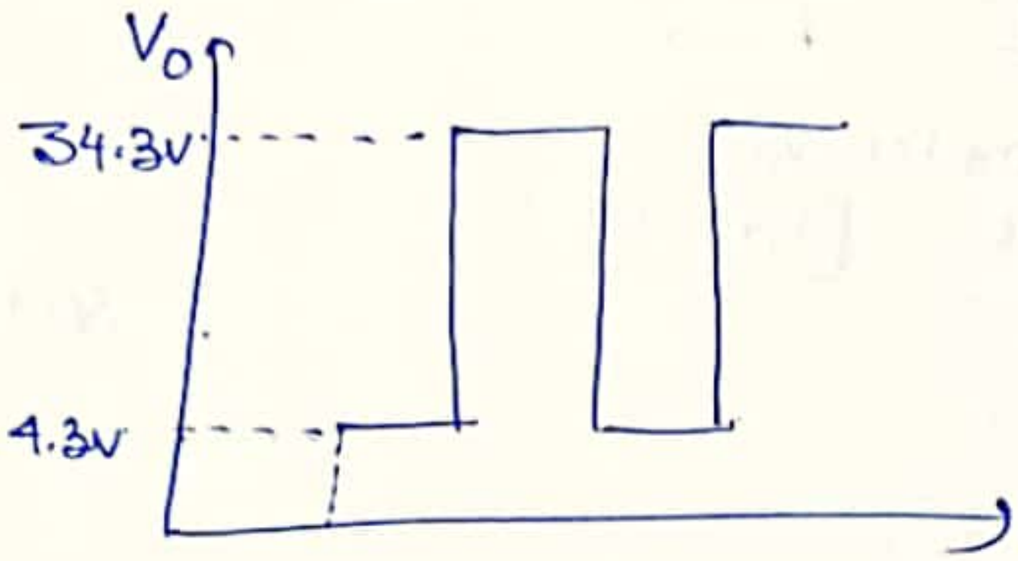
→ When circuit is off,



$V_o = 10 + 24.3V$

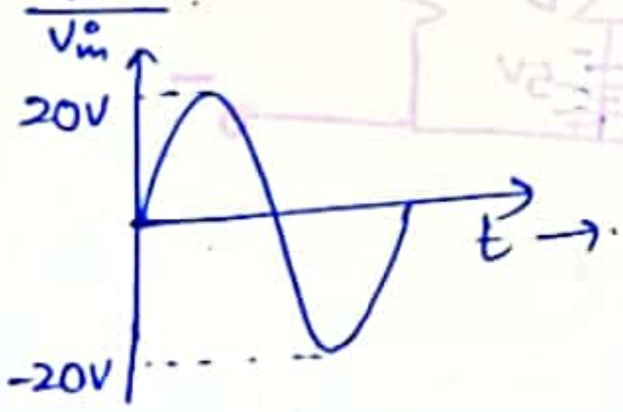
$\boxed{V_o = 34.3V}$

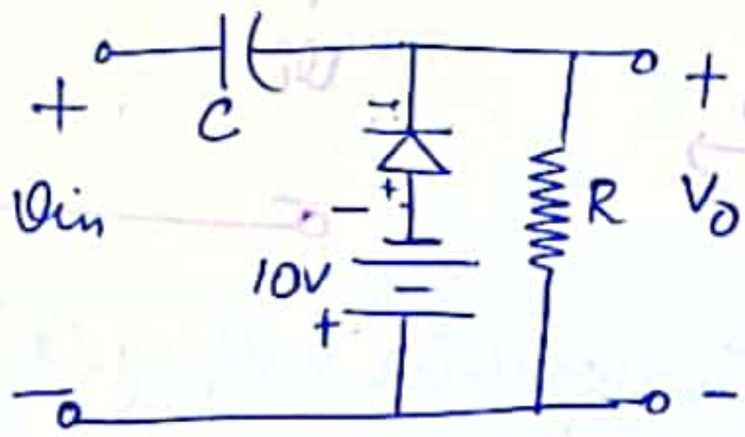


For Sinusoidal signals,

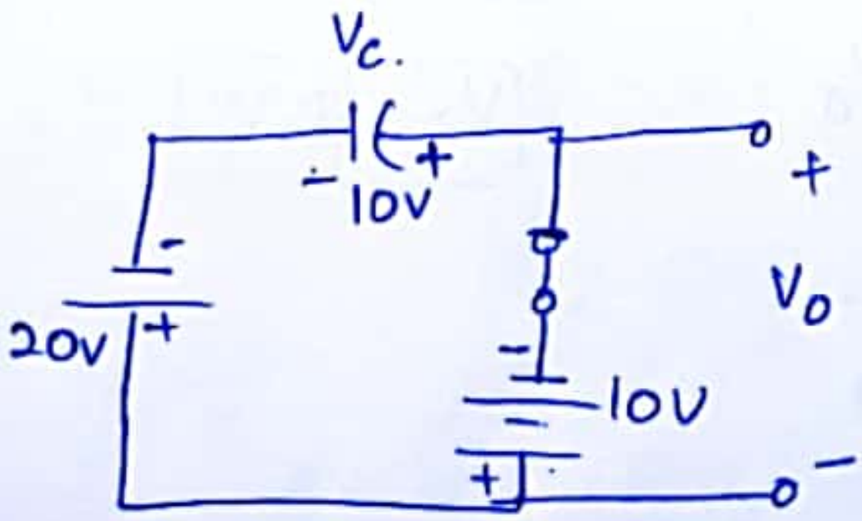
Replace Sinusoidal signal with square wave of same peak values. Resulting O/P will form an envelope of the sinusoidal response.

Ex. ③





Circuit when diode is in 'on' state, (Negative cycle)



$\boxed{V_o = -10V}$

Voltage accross capacitor,

$\boxed{V_{cap} = 10V}$

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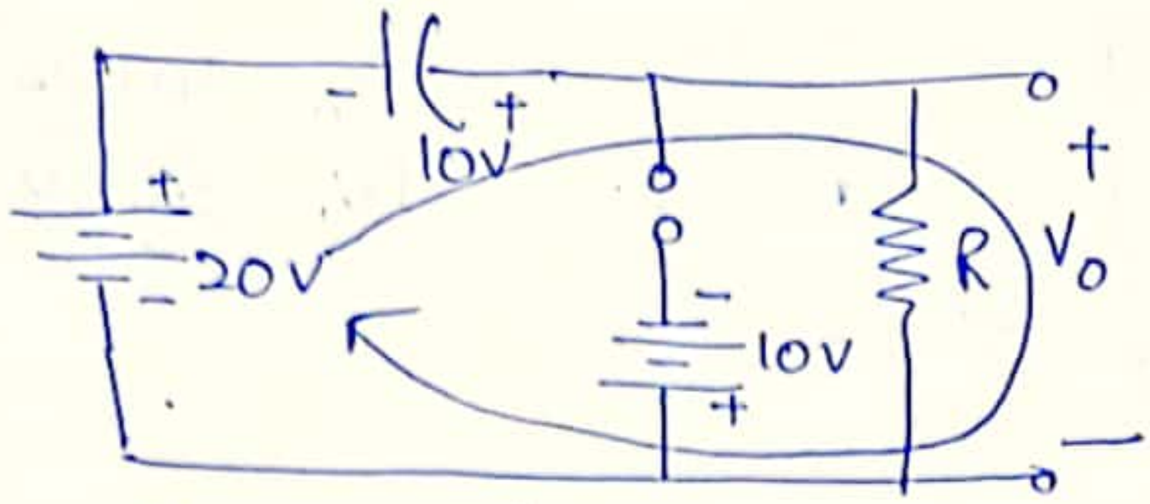
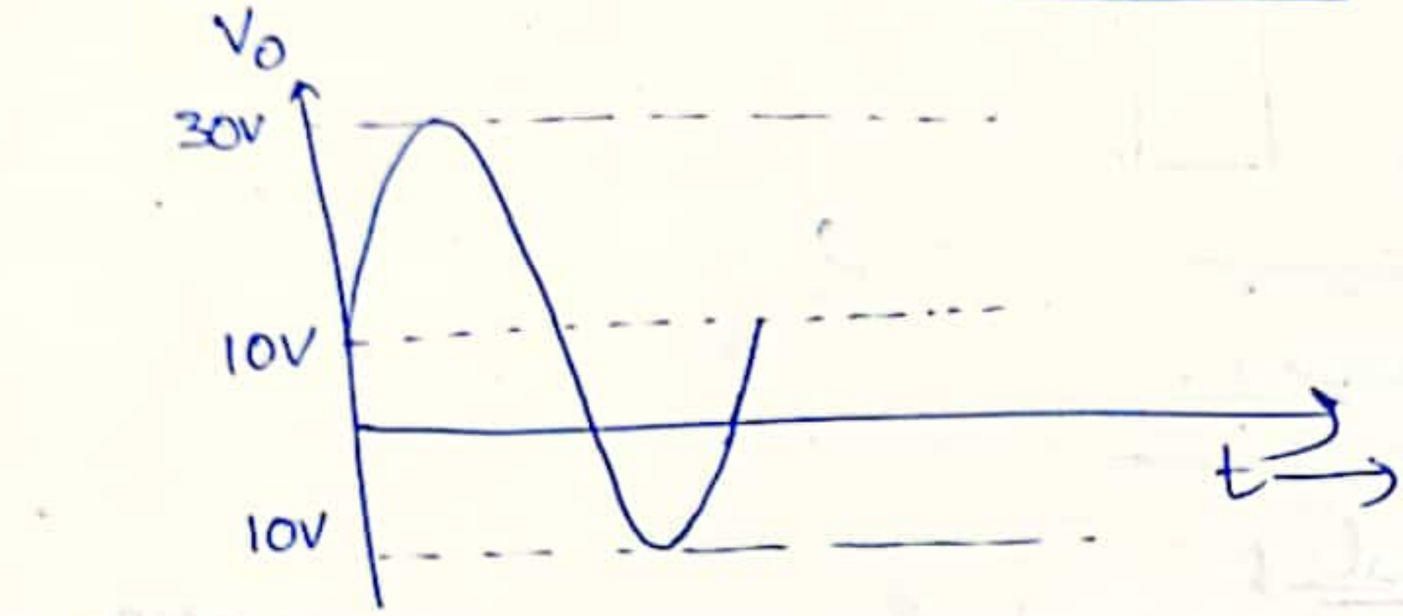
circuit when diode in on-state (+ve half cycle).



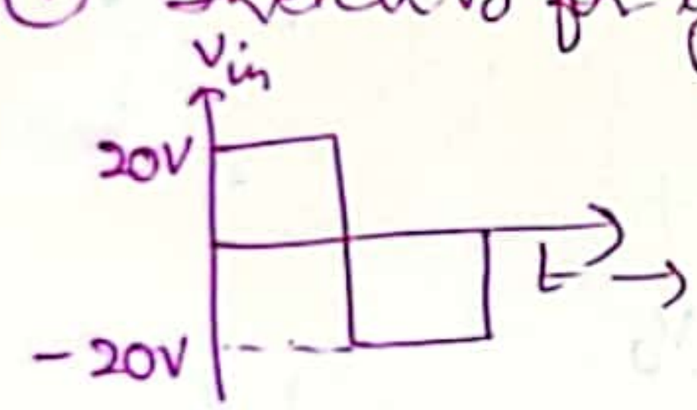
apply KVL. $20+10-V_o=0$

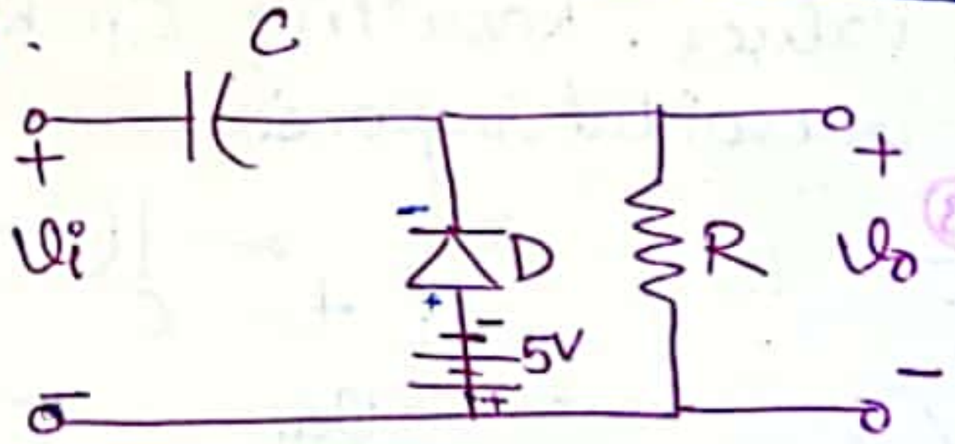
$\boxed{V_o=30V}$

$30+10=40$

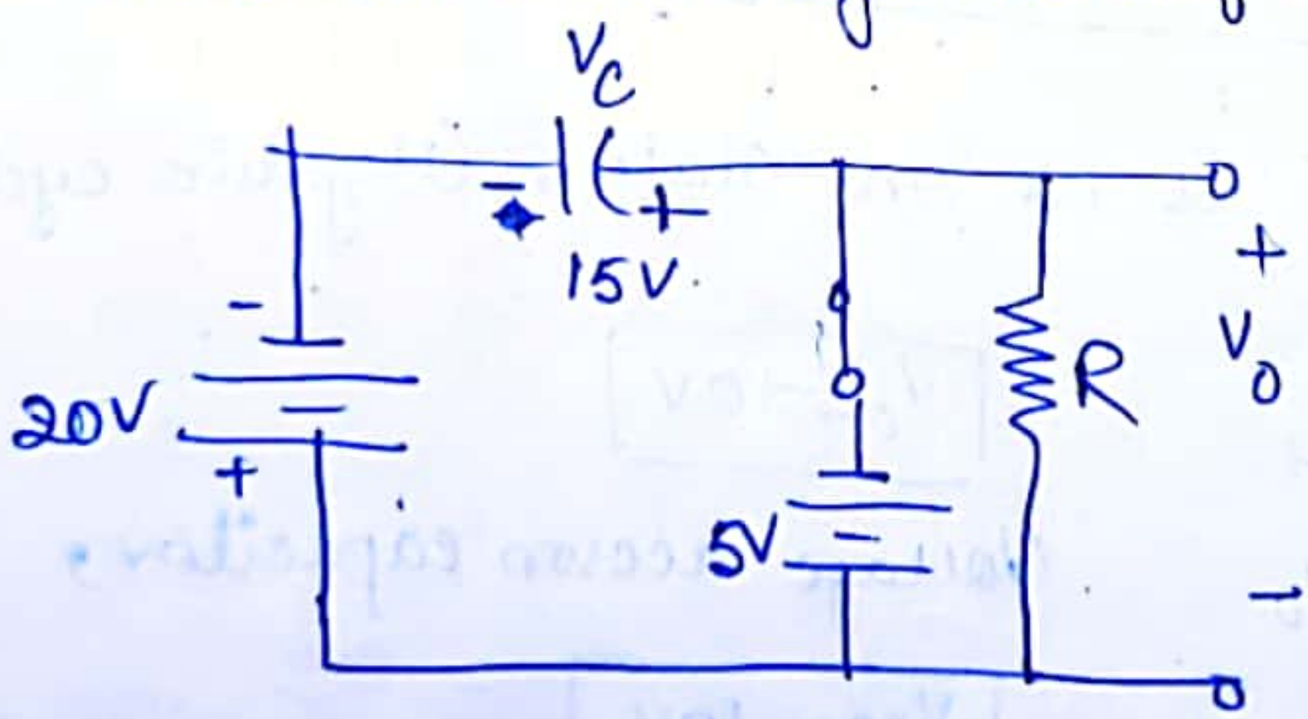


④ Sketch V_o for given N/w.





Diode is on in negative half cycle,



$\boxed{V_o=5V}$

$\boxed{V_C=15V}$

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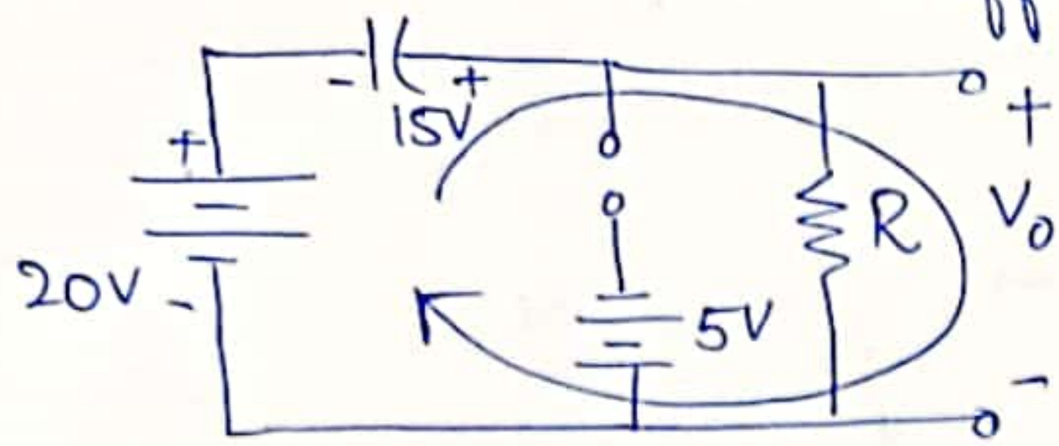
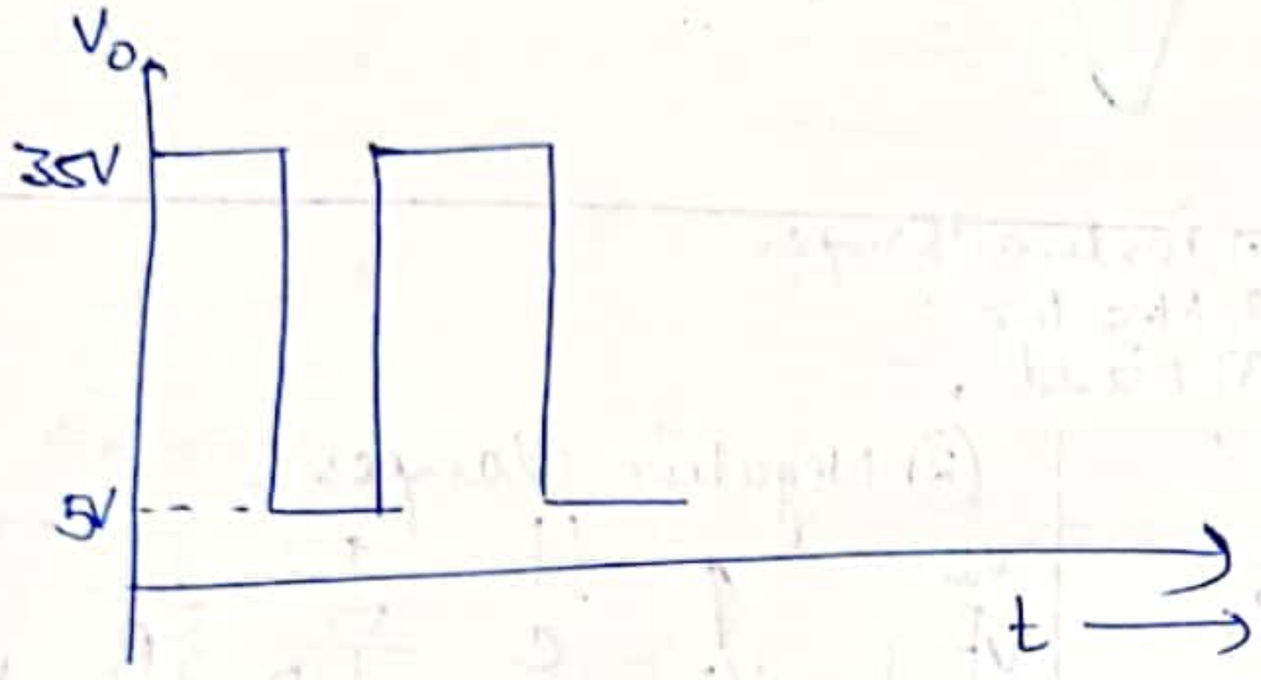
Circuit when diode is off,



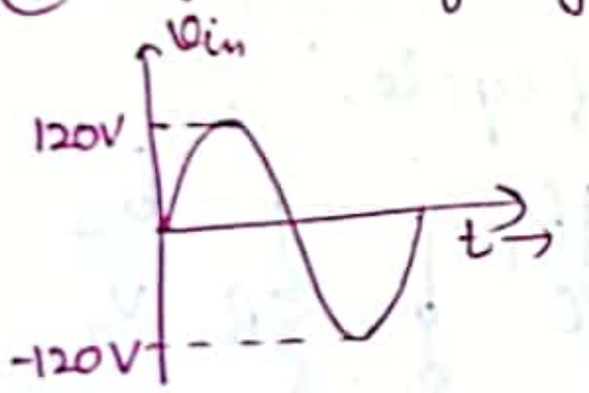
apply KVL,

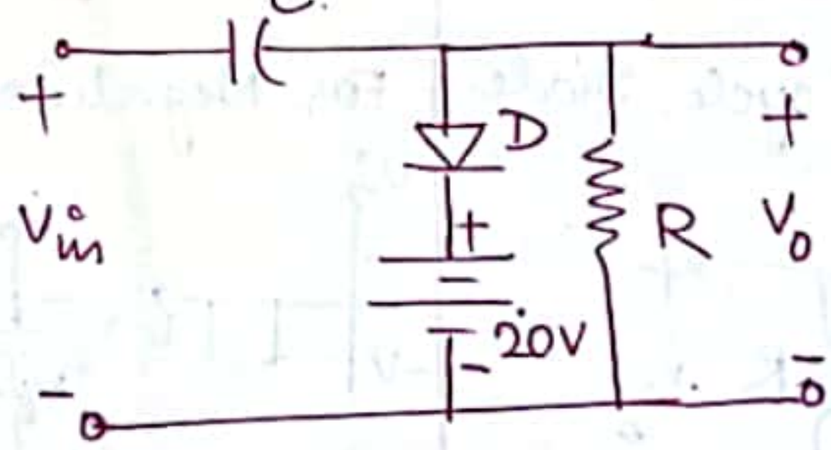
$20+15-V_o=0$

$\boxed{V_o = 35V}$

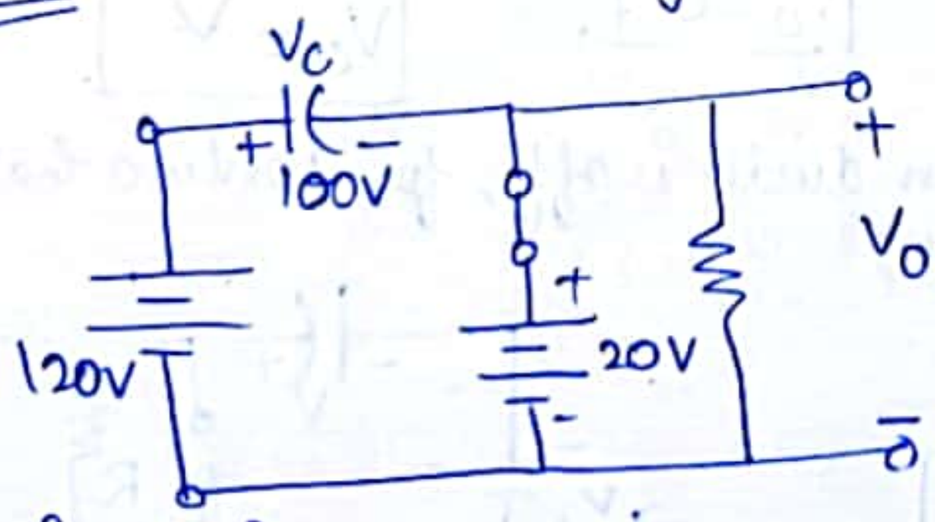


(5) Sketch V_o for given network:





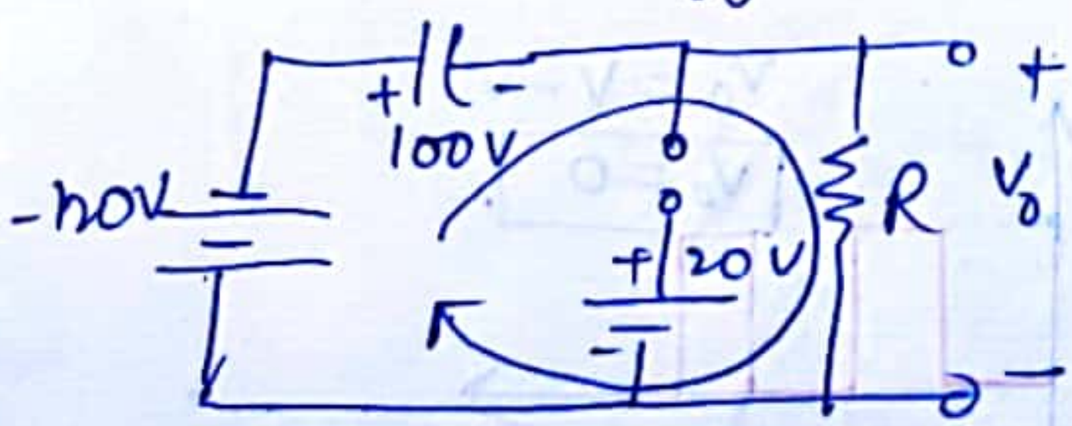
Sol^n Diode is on- in positive half cycle,



$\boxed{V_o = +20V}$

$\boxed{V_C = 100V}$

When Diode is in off state (negative half cycle),



apply KVL,

$120+100+V_o=0$

$\boxed{V_o = 220V}$

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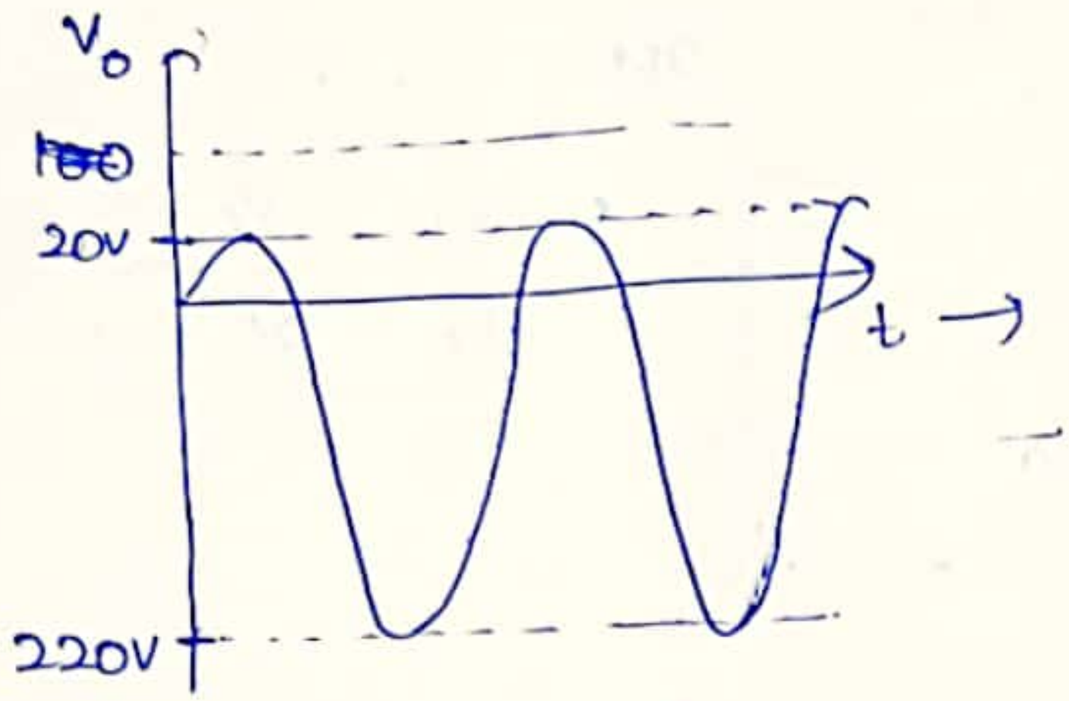
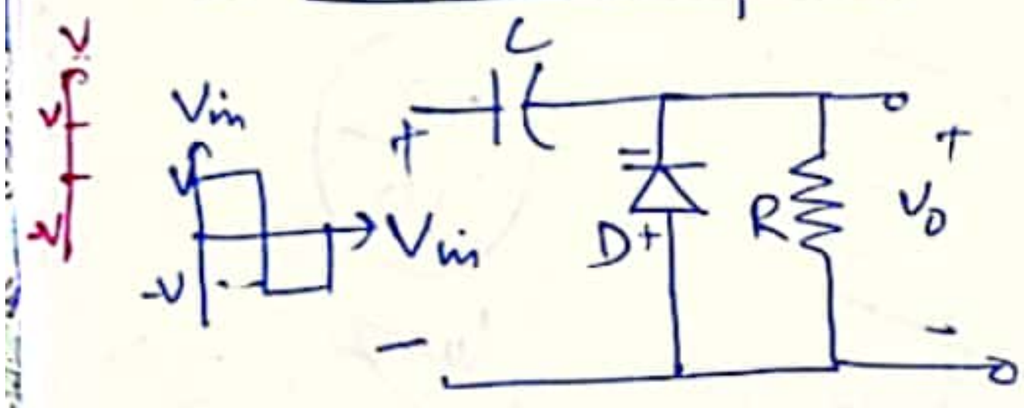
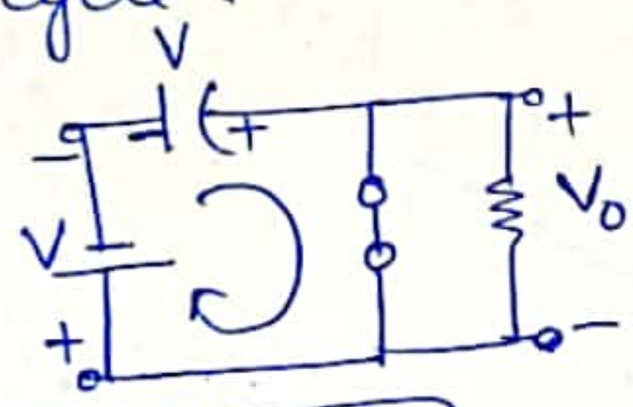


Type of clampers
1) Positive Clamper
2) Negative "
3) Biased "

① Positive Clamper.

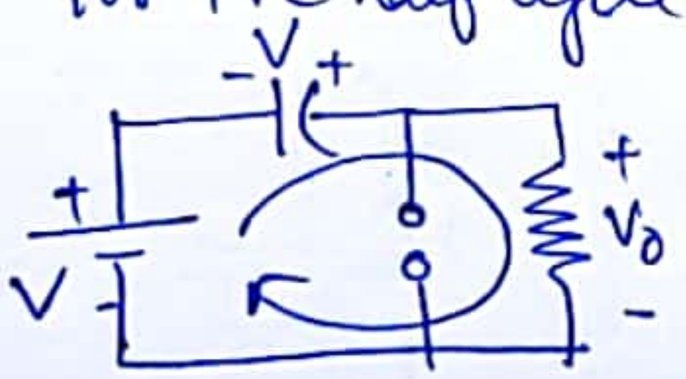


Diode is F.B in Negative half cycle.

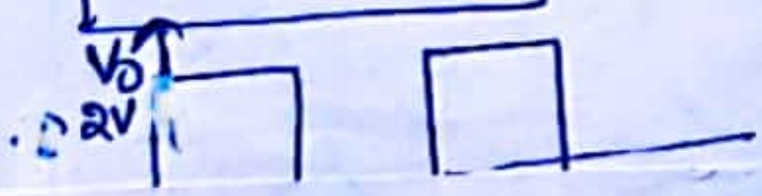


$V_o = 0$

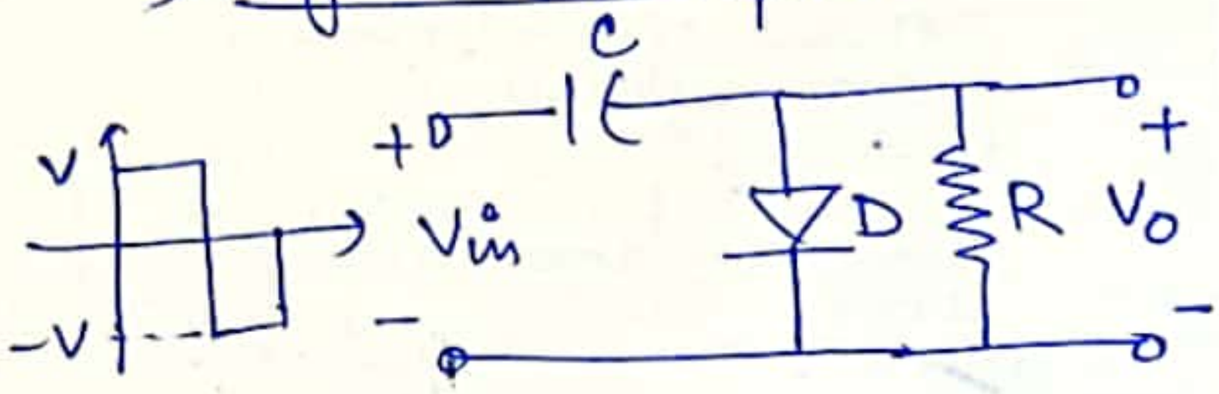
For +ve half cycle,



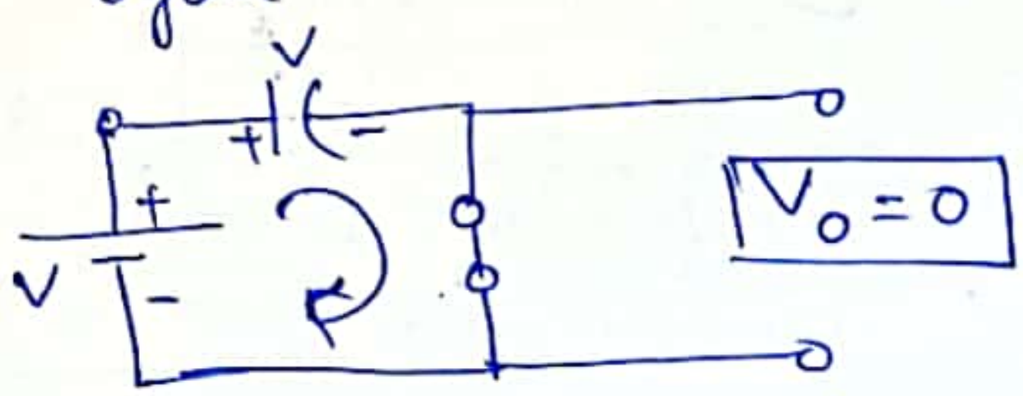
$V_o = +2V$



2) Negative Clamper

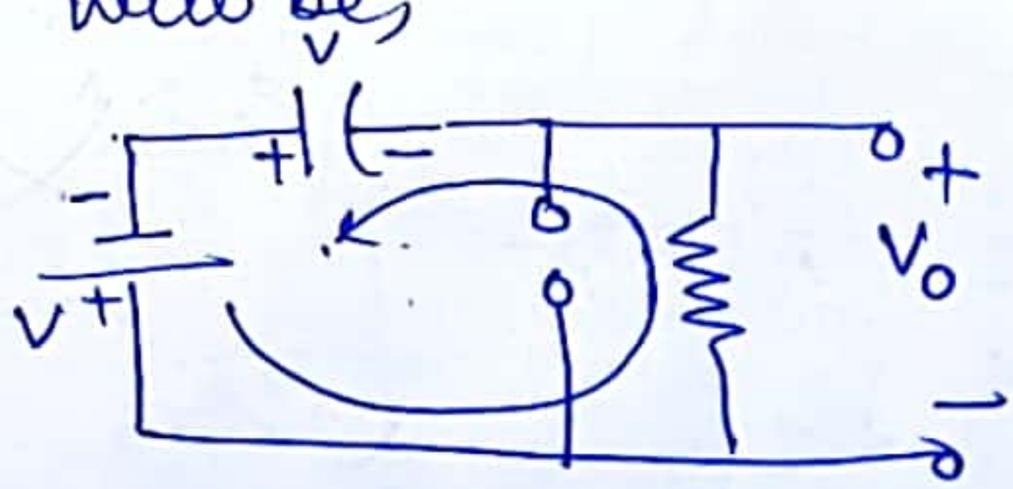


Diode is F.B in positive half cycle.

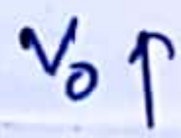


$V_o = 0$

For Negative cycle circuit will be,



$V_o = -2V$



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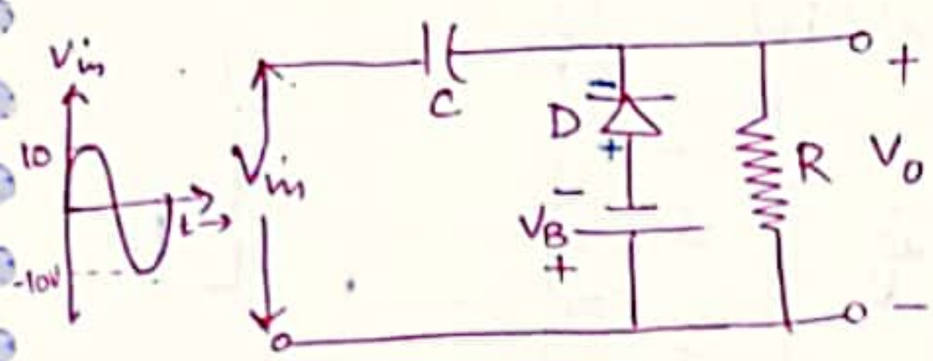
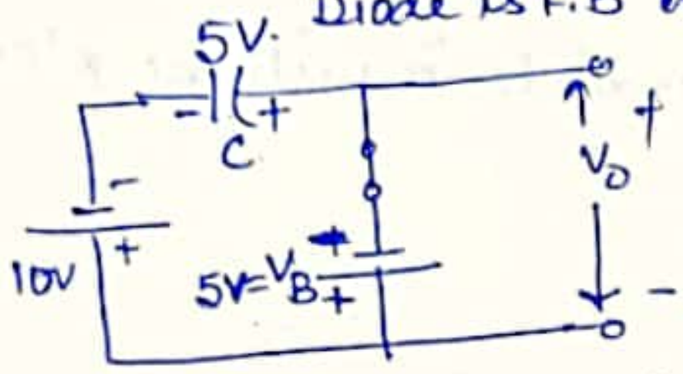
Biased Clamper:-

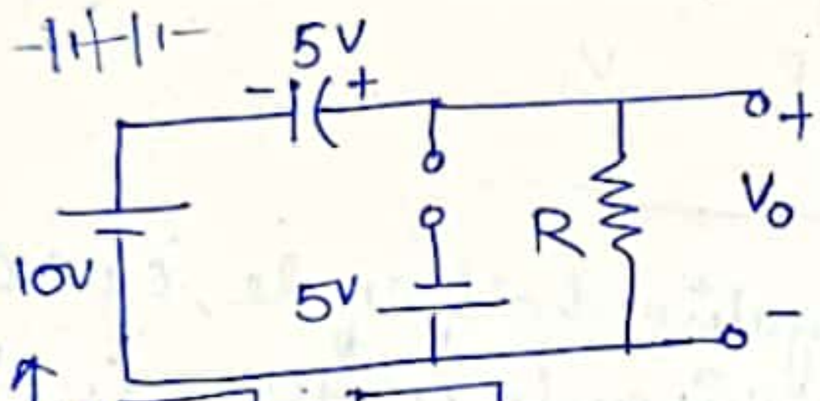


~~When diode is F.B in ve half cycle,~~
Diode is F.B in negative half cycle.



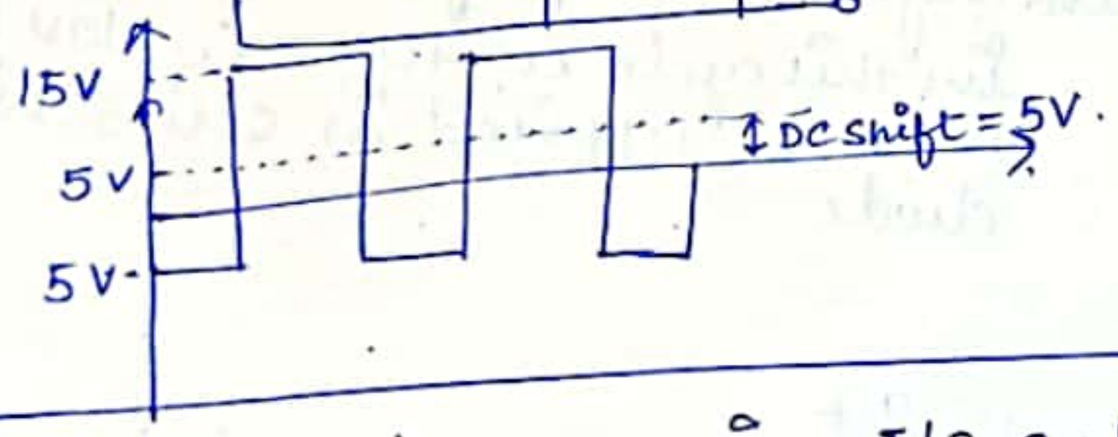
$\boxed{V_o = -5V}$

Diode circuit for Negative half cycle,



$V_o = 10V + 5V$

$\boxed{V_o = 15V}$.



Design of clamper using I/P and O/P Waveform

Step ① Draw all the primary elements (source I/P, capacitor and resistor) except diode.

Step ② If O/P Waveform ~~sh~~ ~~es~~ has positive dc shift place diode like it. If O/P waveform has Negative DC shift then place diode like.

Step ③ When diode is FB if O/P is zero then don't place battery otherwise place a battery with same voltage at (which equal to Vo).

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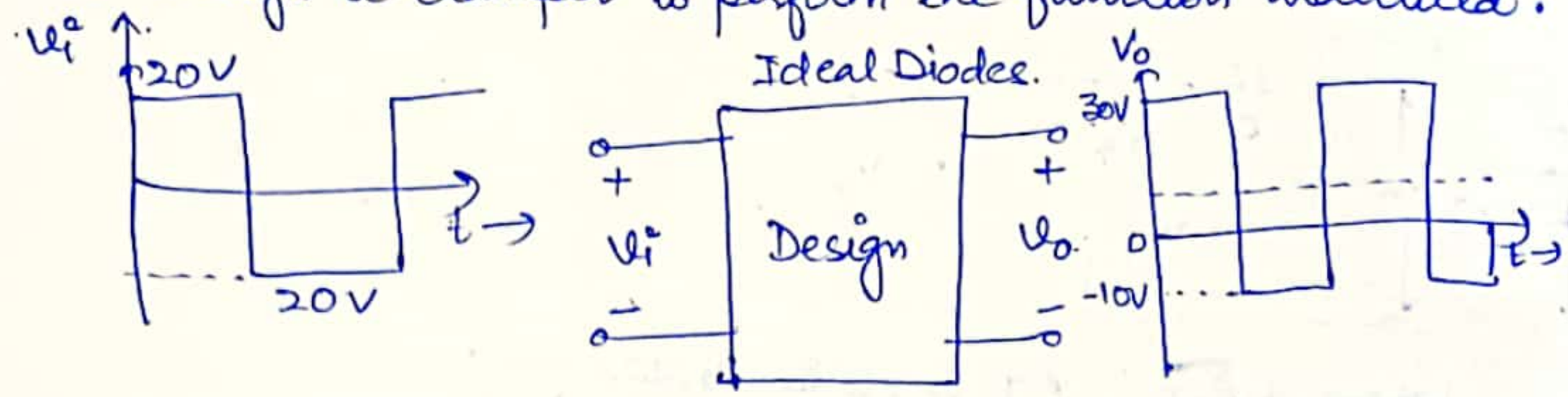
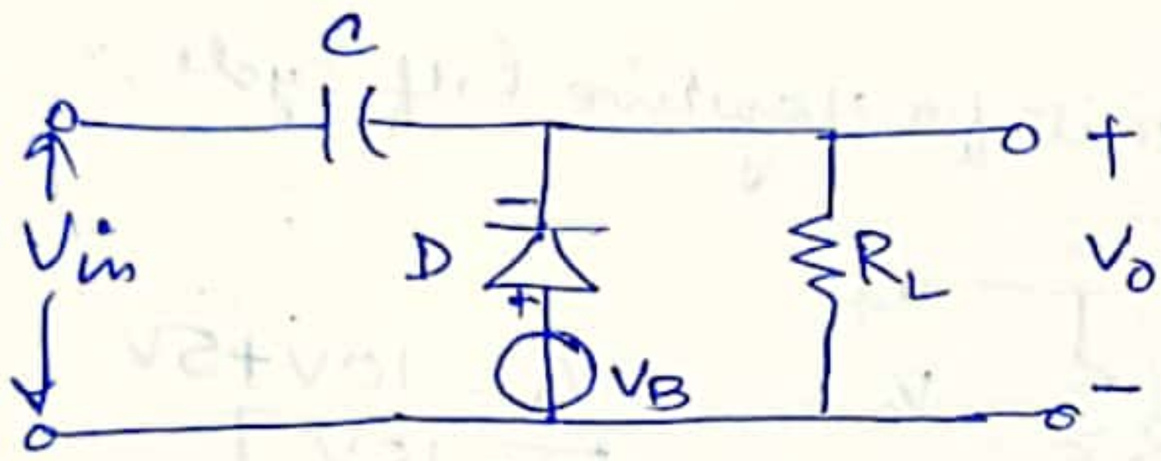
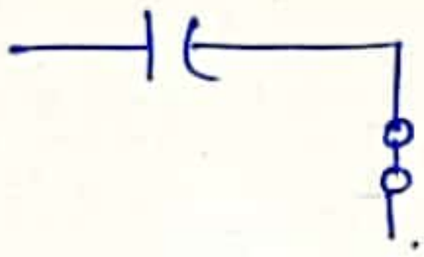
Ques① Design a clamper to perform the function indicated.

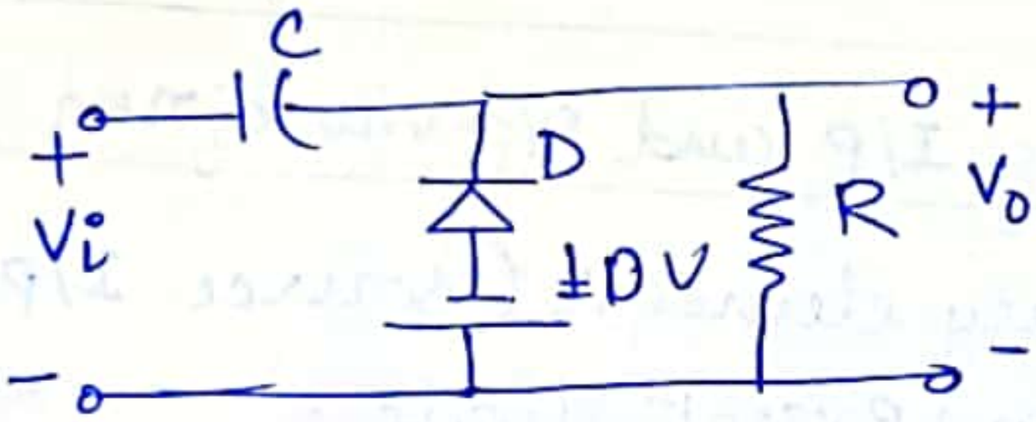


Positive ~~Sta~~ DC shift hence, ~~a~~ diode ~~is~~ will be placed in this manner .

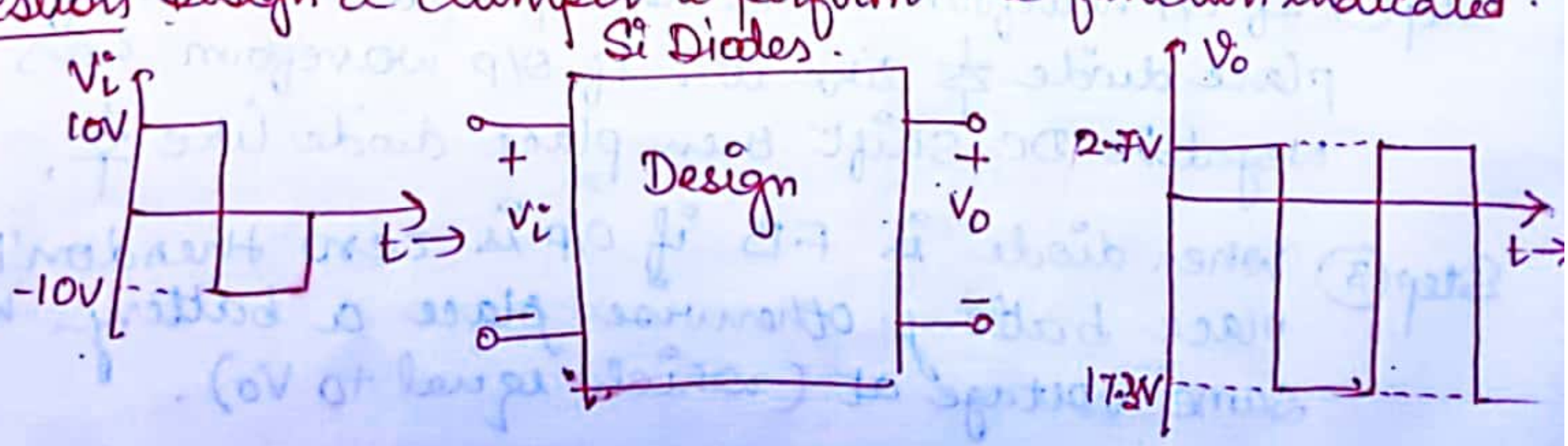


∴ Diode is F.B in Negative half cycle, O/P voltage in this cycle is -10V ∴ -10V battery must be applied in series with diode.





Question Design a clamper to perform the function indicated.



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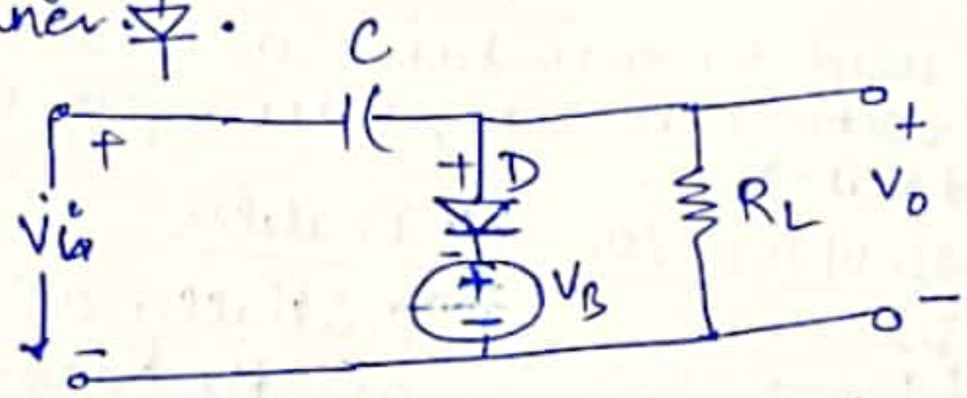
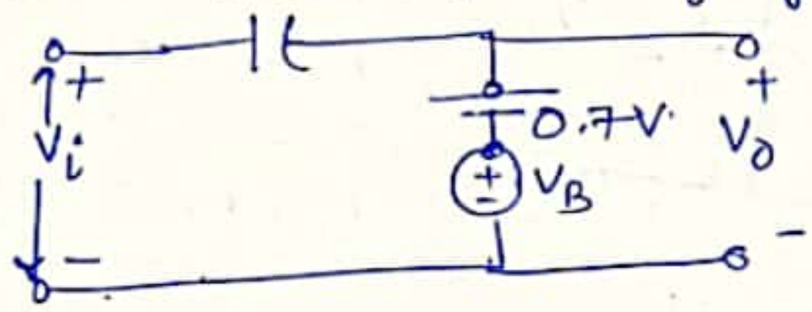
Negative DC shift hence diode is connected in manner.



Diode is F.B in +ve half cycle,



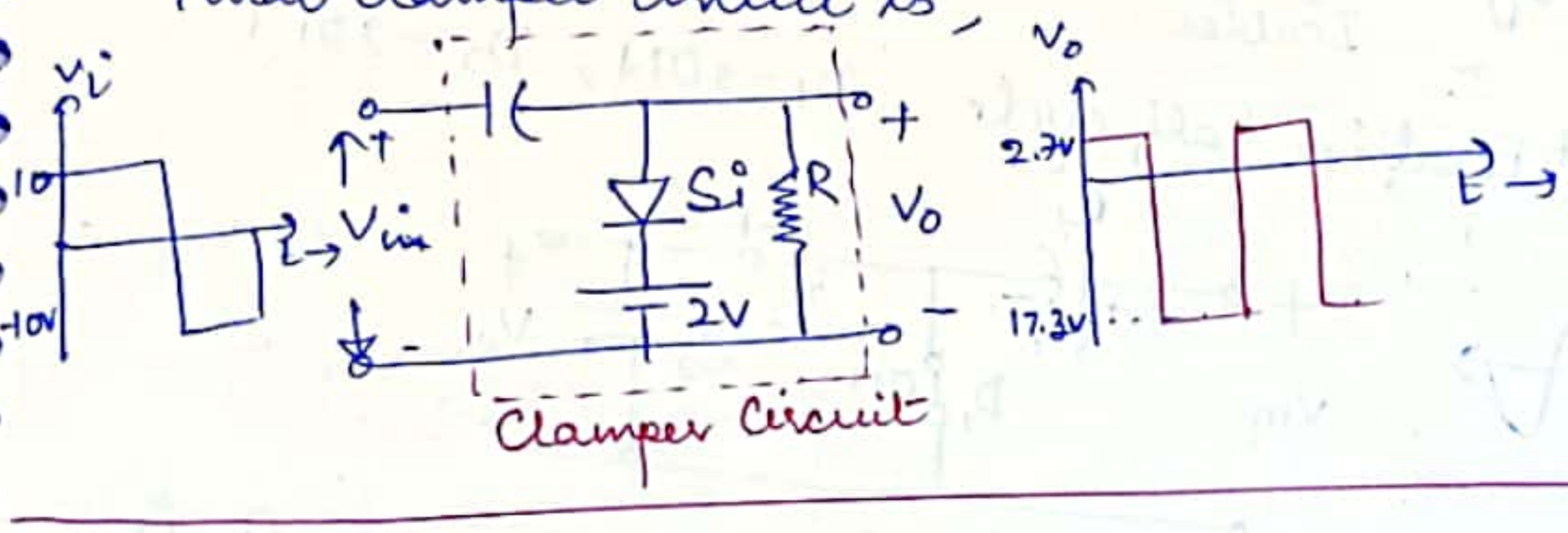
In positive half cycle,

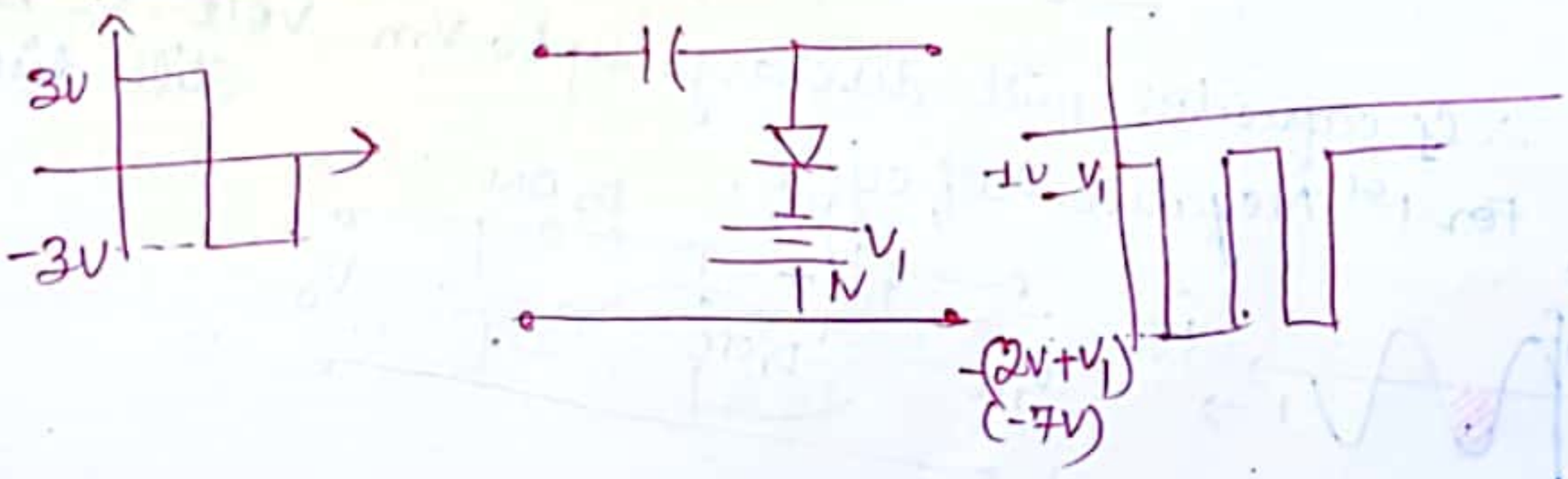
$V_o = 2.7V$

$V_o = 0.7 + V_B$

$\boxed{V_B = 2.V}$

Final clamper circuit is,





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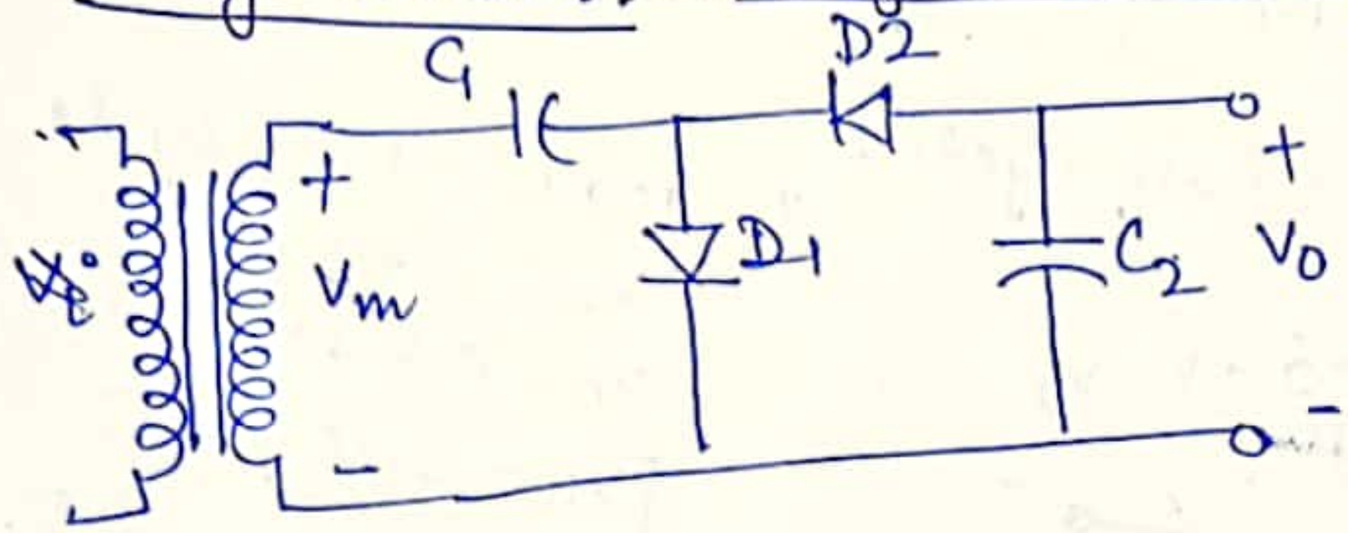
Voltage Multiplier:-

These circuits are used to maintain a relatively low transformer peak voltage to two, three, four or more times the peak rectified voltage.

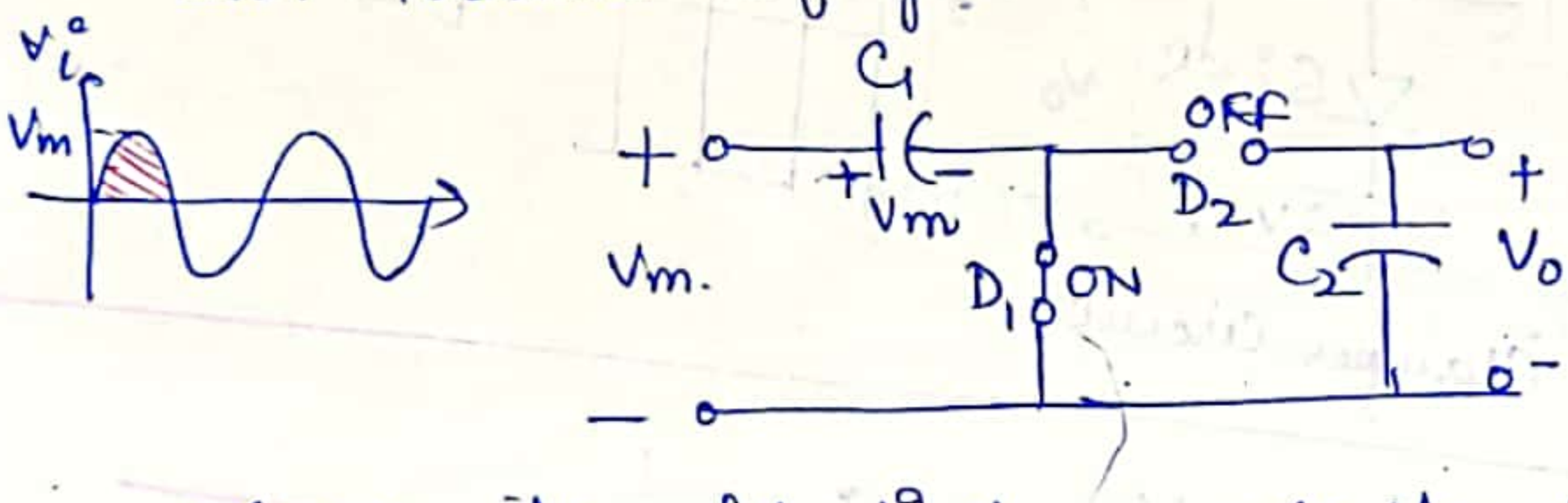
Voltage Doubler:- Half Wave Voltage Doubler.



Initially all capacitor are discharged.

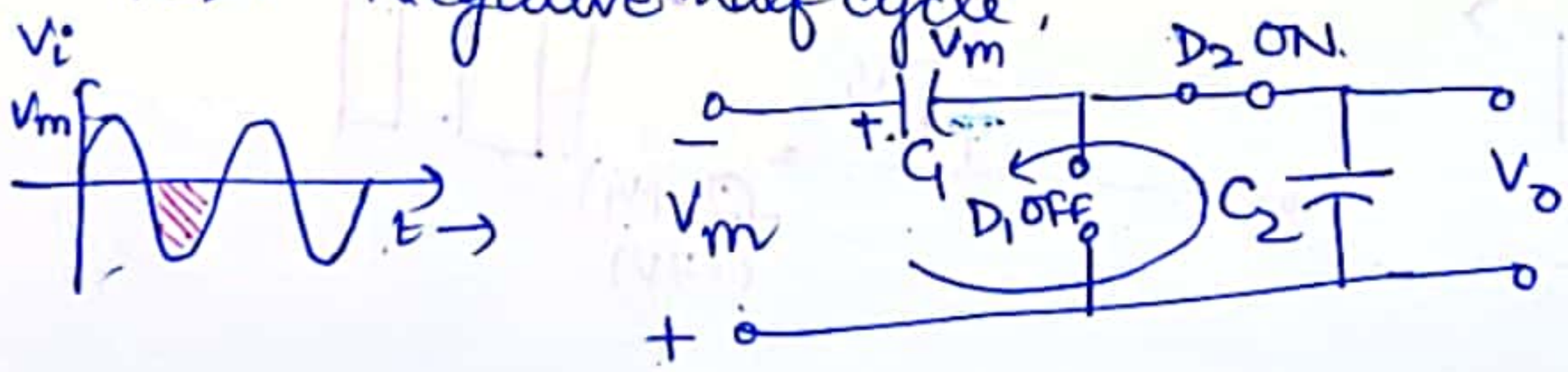
fig:- Half wave voltage Doubler.

In 1st Positive half cycle. $D_1 \rightarrow ON$, $D_2 \rightarrow OFF$



∴ C_1 capacitor will discharge upto V_m volt. C_2 is still discharge.

For 1st Negative half cycle,



apply KVL. $-V_m - V_m - V_o = 0$

$$\boxed{V_o = -2V_m}$$

We can see that O/p voltage is double of I/p voltage. and PIV of both diodes are $2V_m$.

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Full Wave Voltage Doubler

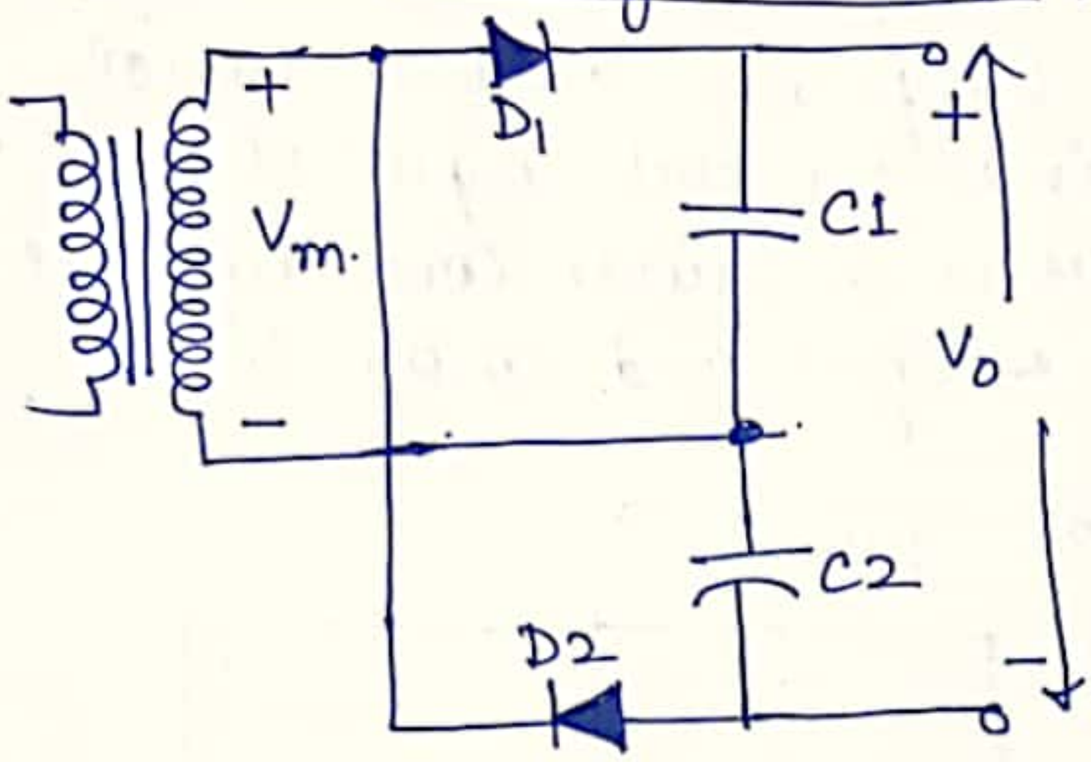
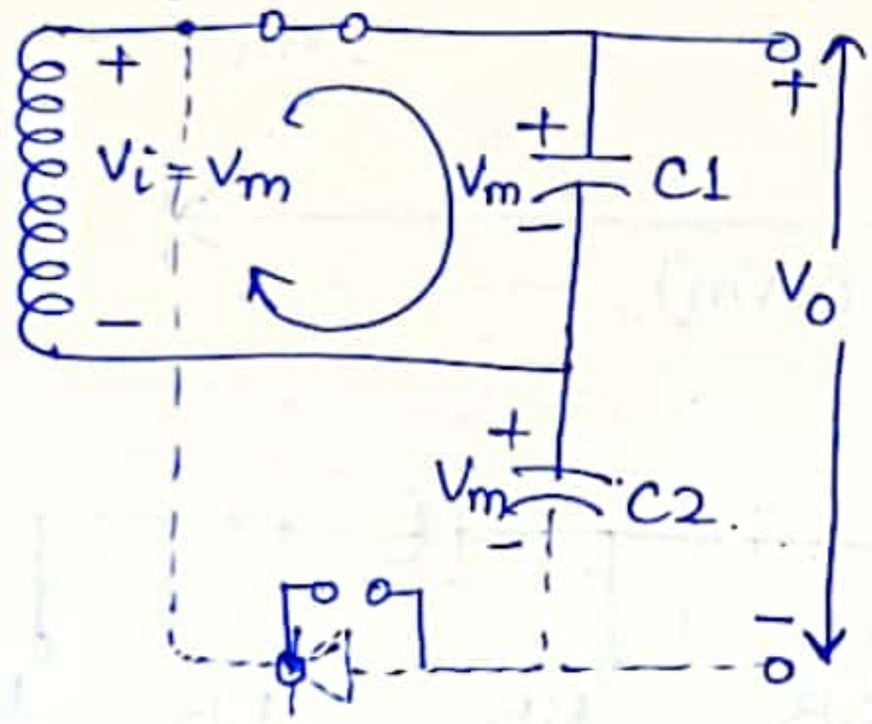


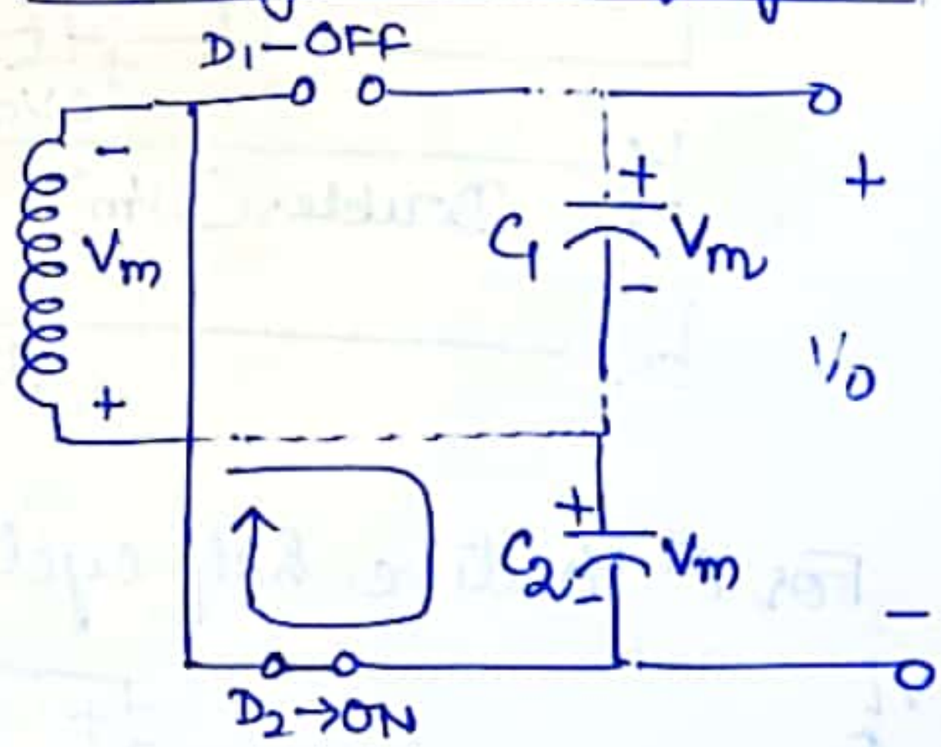
fig :- Voltage Doubler (full Wave).

For Positive half cycle

D_1 ON, D_2 OFF,



For Negative half cycle.



If there is no load then $V_o = 2V_m$. However if load is connected the voltage will be less than that ($2V_m$).

$\boxed{\text{PIV across each diode} = 2V_m}$

The full wave doubler has advantage that conventional center-tapped full wave rectifier does not require center-tap transformer.

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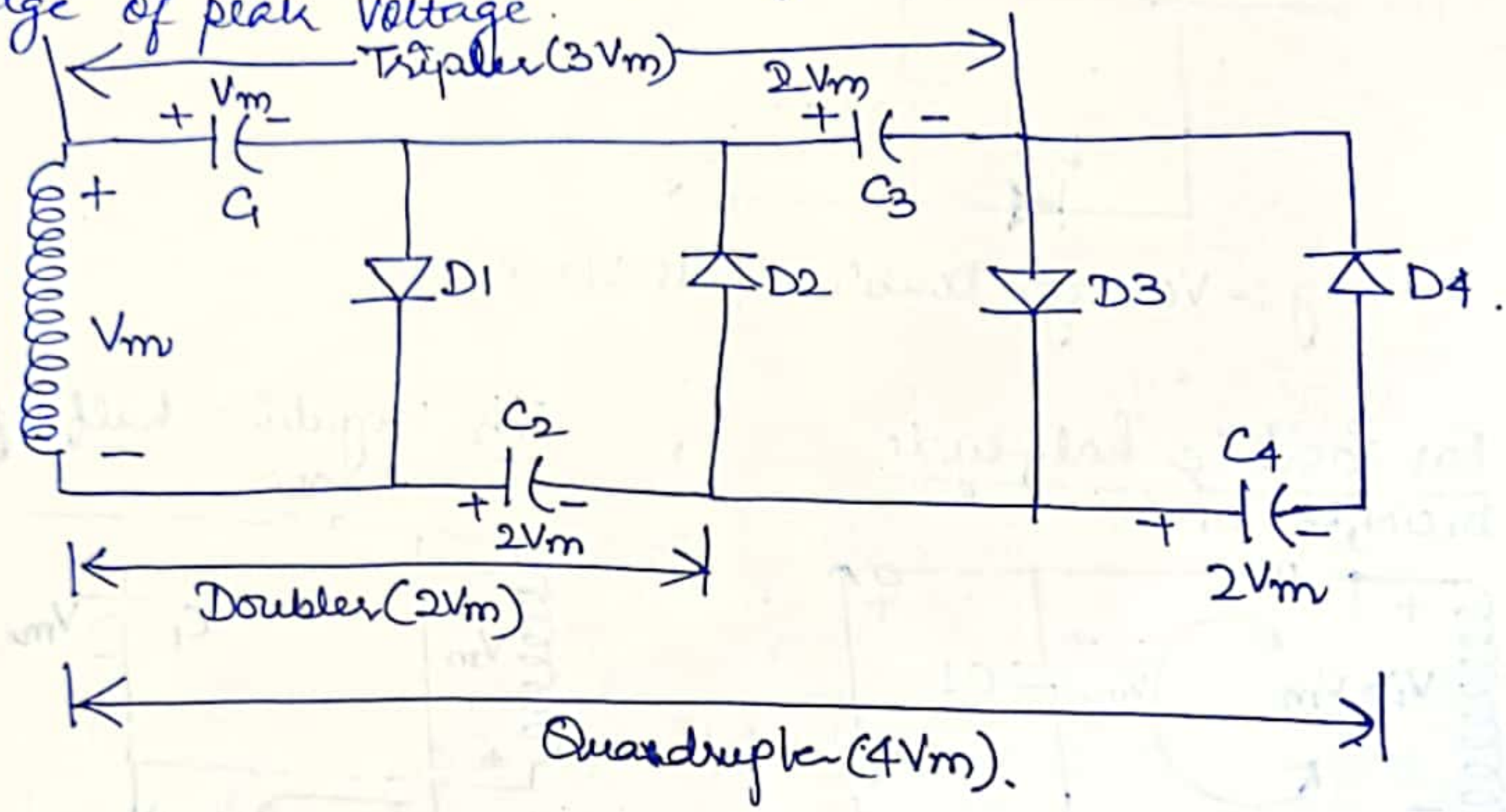
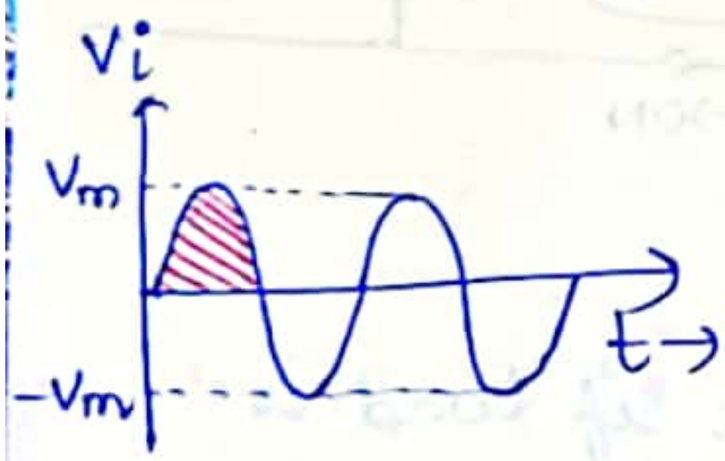
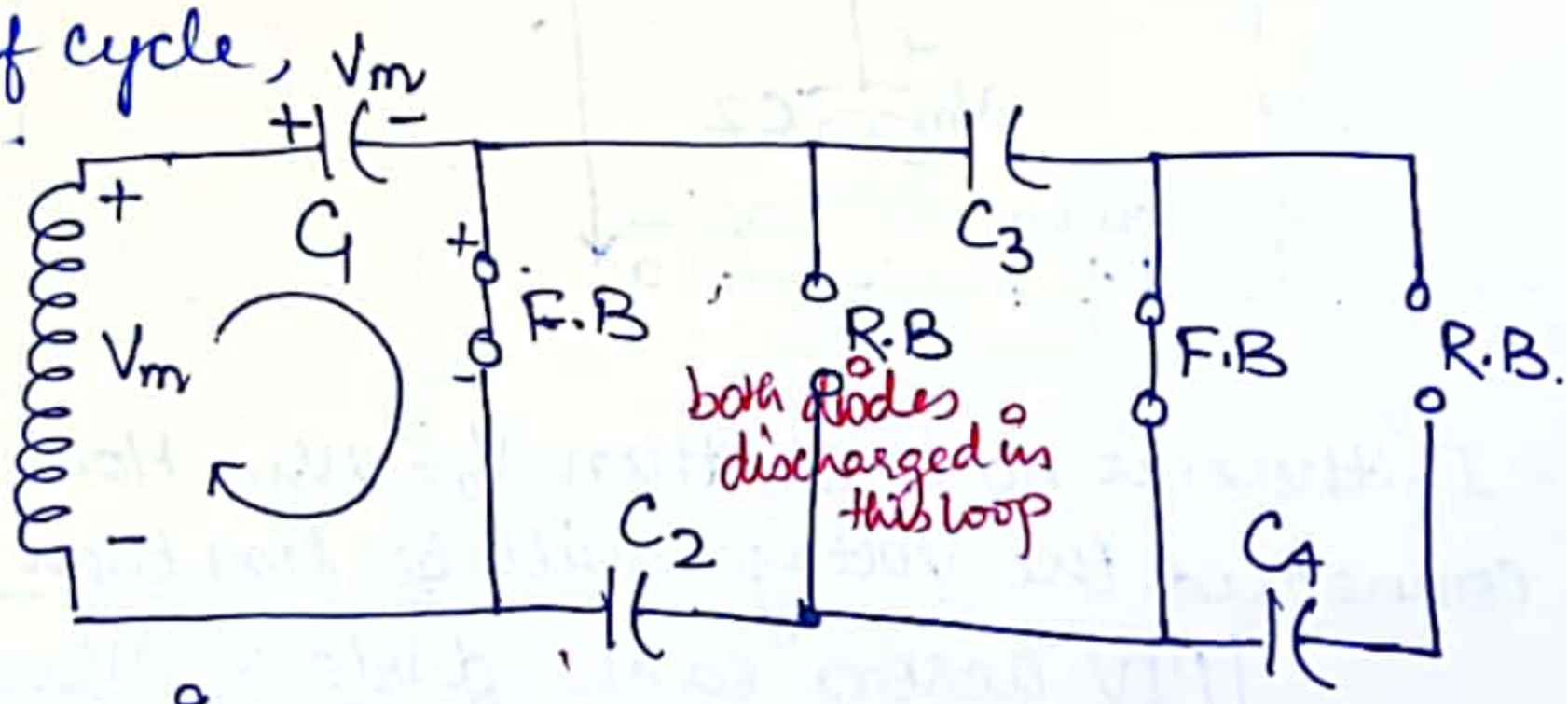
Voltage Tripler & Quadrupler:-

It is an extension of halfwave doubler which develope three and four times the peak input voltage. By Following the same patterns of diode connection we can generate five, six, seven, eight and so on times voltage of peak voltage.



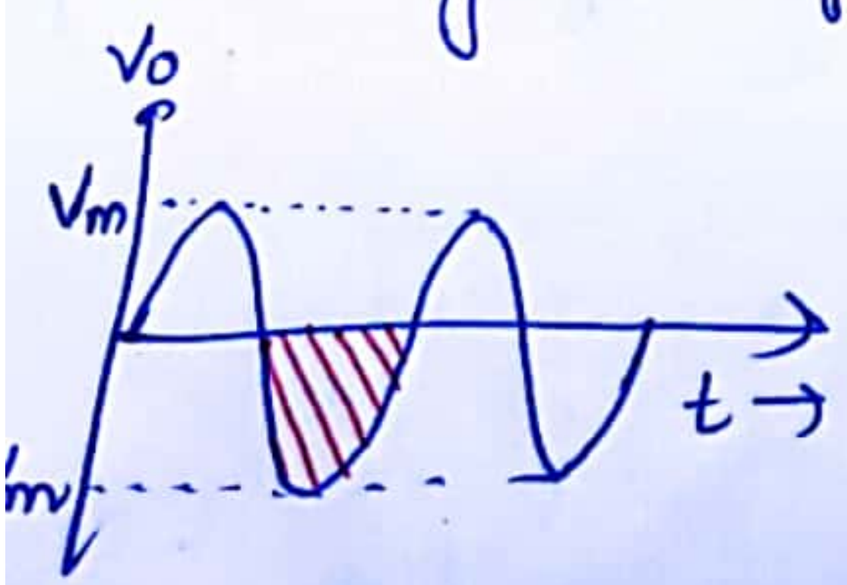
For 1st Positive half cycle,

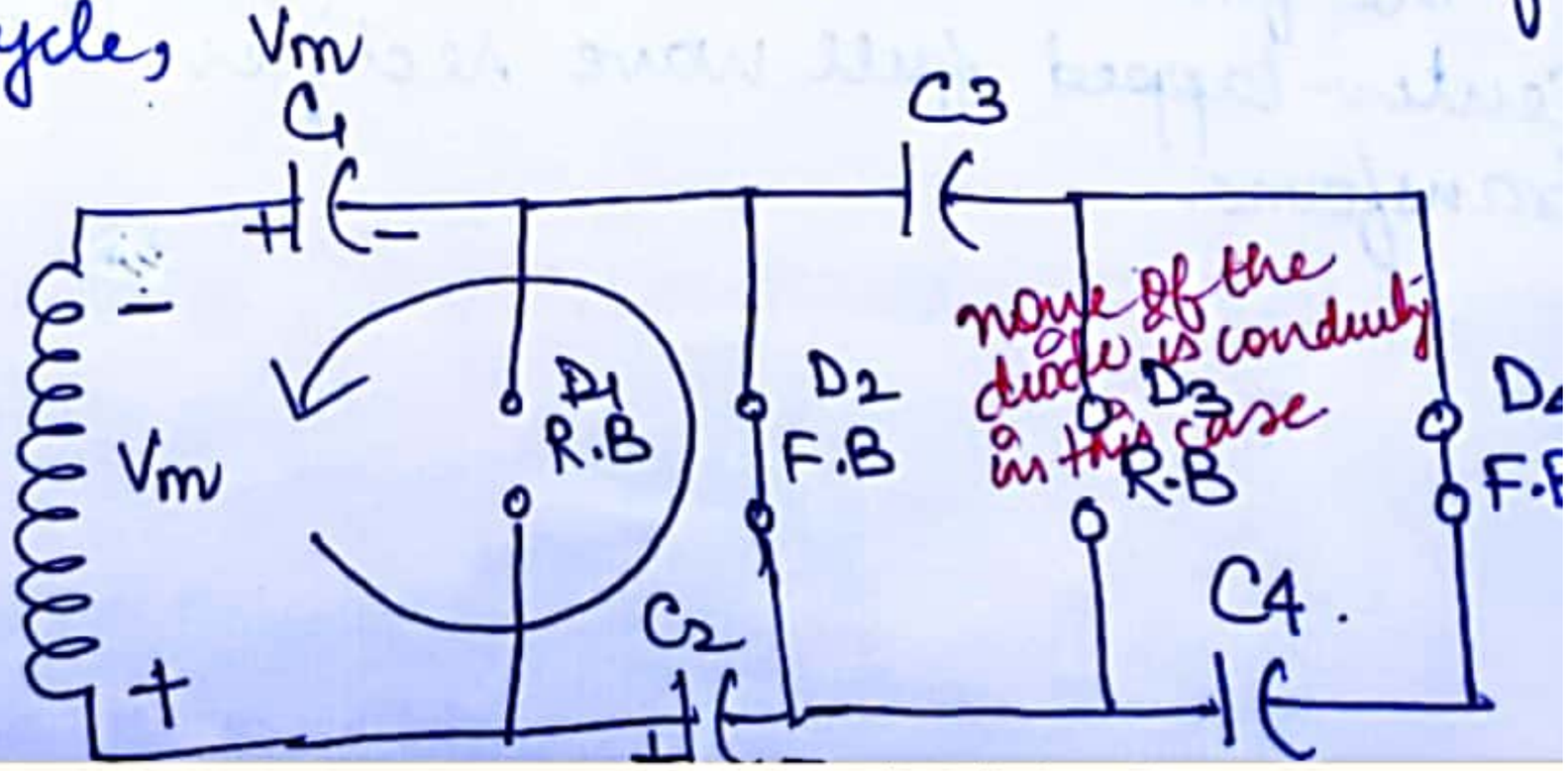




C1 is charged to Vm after 1st Positive half

For 1st negative half cycle,





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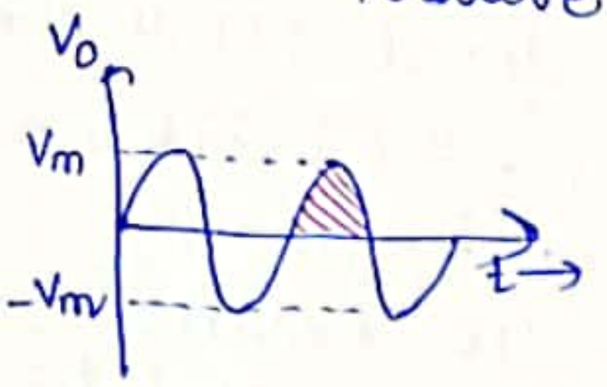
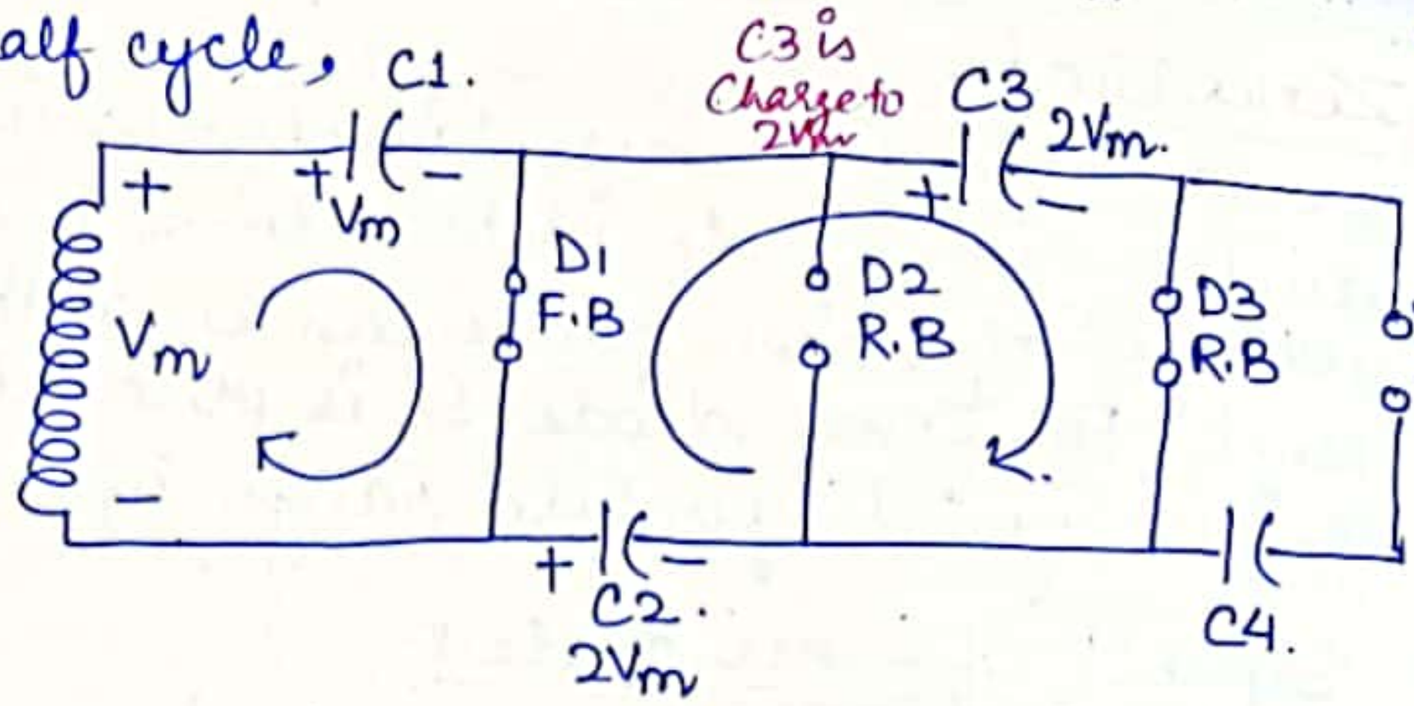
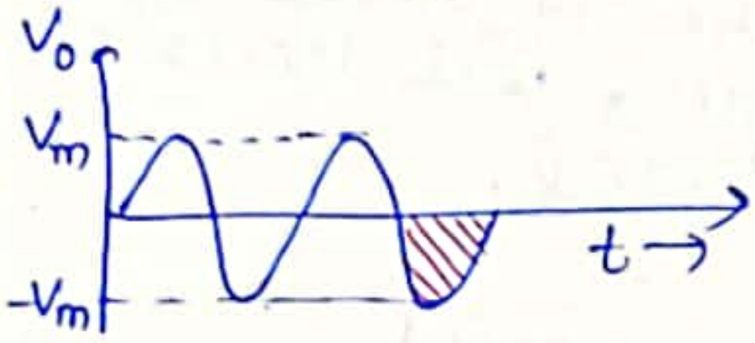
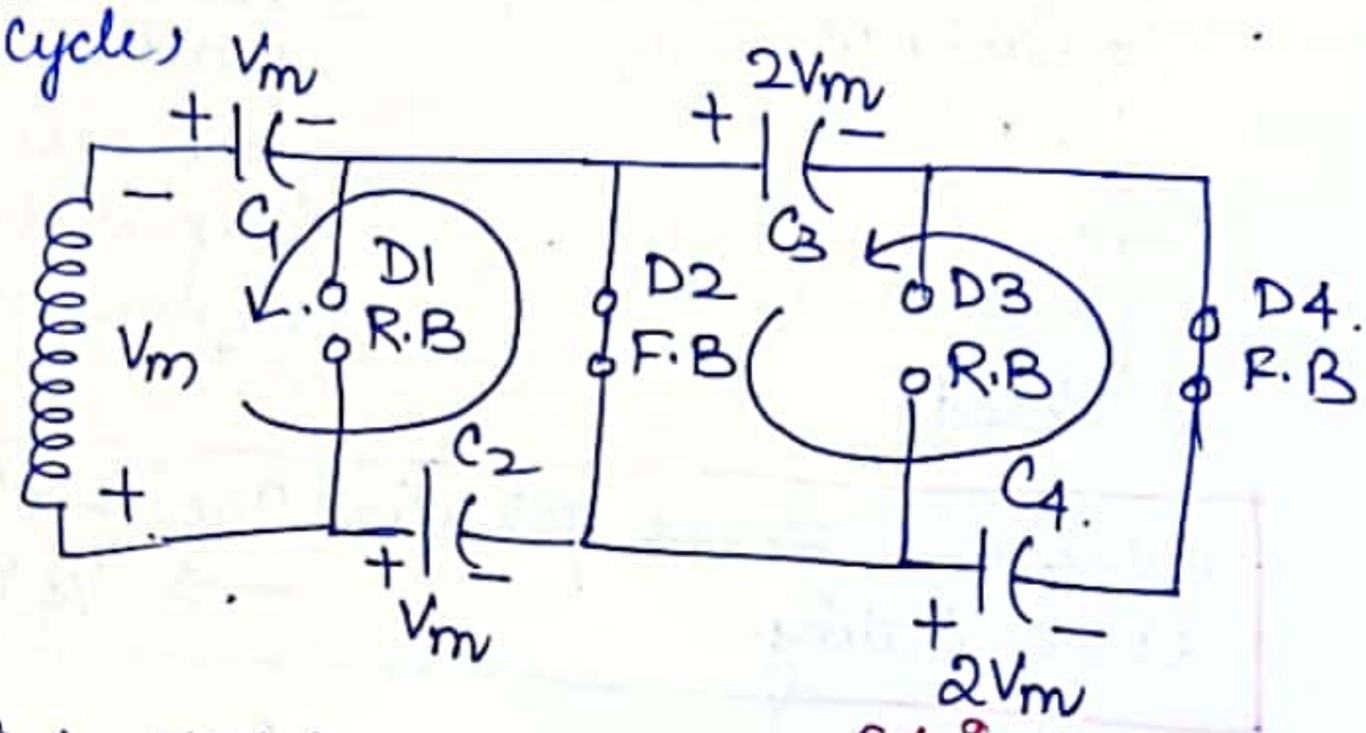
For 2nd Positive half cycle,





For 2nd Negative half cycle,





C4 is charged to 2Vm.

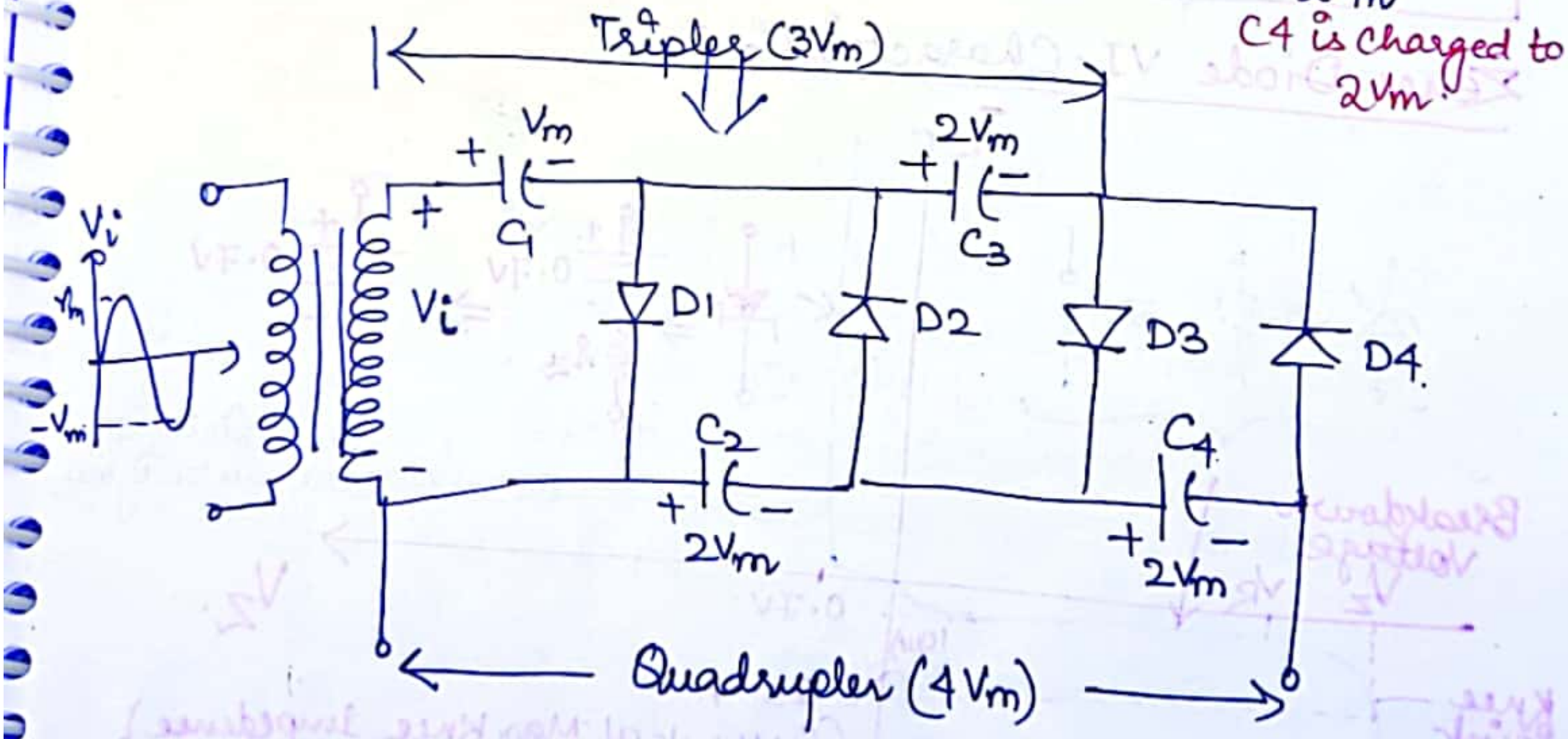


fig:- Tripler & Quadrupler circuit.

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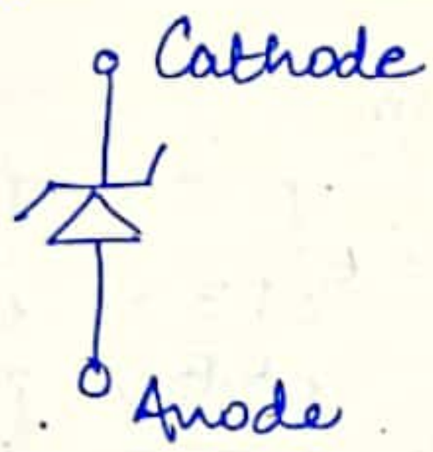
Zener Diode

Zener Diode is reverse biased heavily-doped PN junction diode which operate in breakdown region. The breakdown voltage of zener diode can be controlled by doping level. For Zener diode Si is preferred to Ge because of its high temperature range and current capabilities.

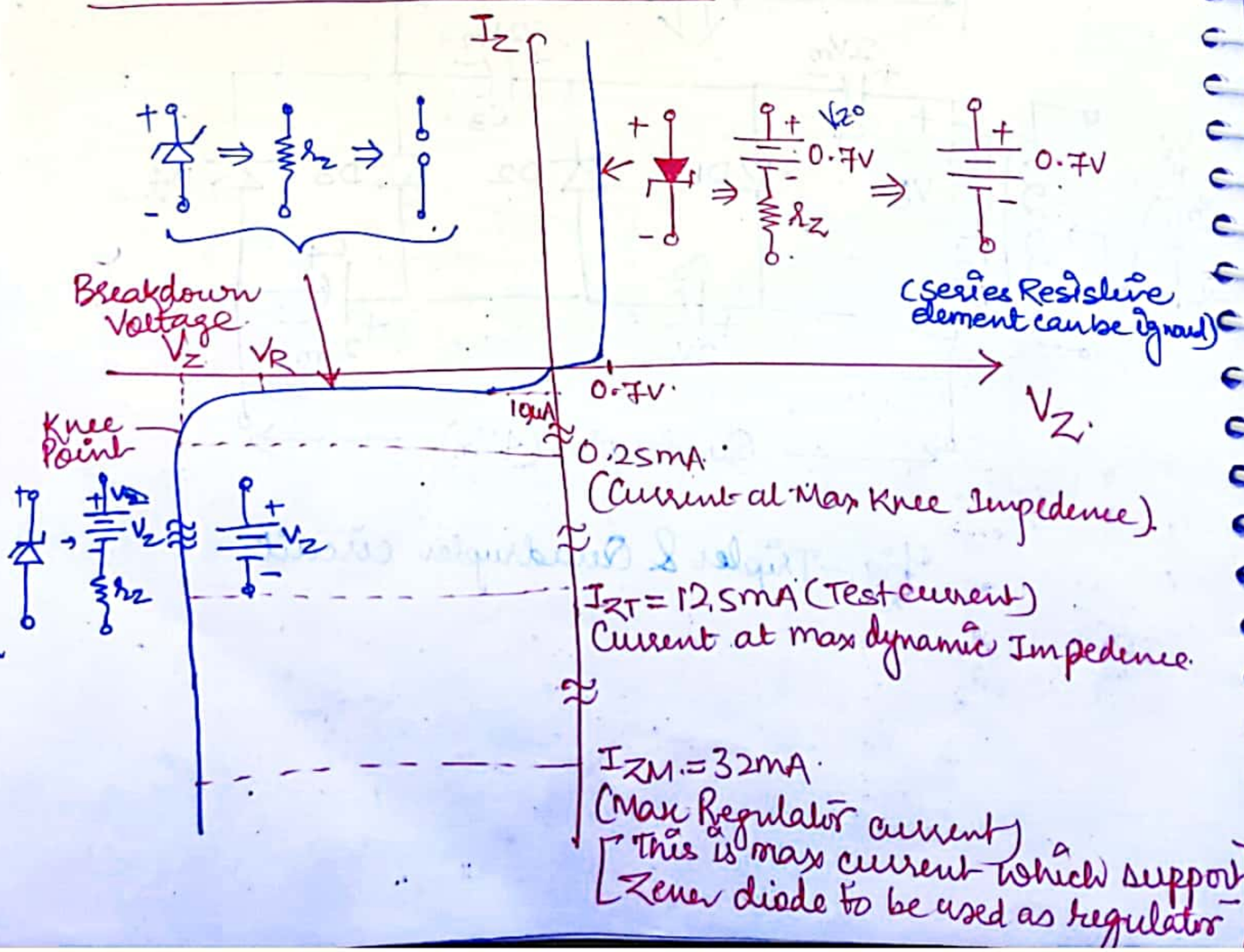
Symbol of zener diode :-



* An increase in doping produces an increase in the number of added impurities, will decrease zener potential.

available zener potential are	1.8V to 200V
Power Rating	→ 1/4 W to 50W.

Zener Diode VI-Characteristic :-



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In Forward bias region :-

Diode behave like a normal p-n junction diode. The equivalent model is shown in V-I-characteristic.

In Reverse bias region:-

The equivalent model of reverse bias region below V_Z is very large resistor R_Z (as for standard diode). For most applications, This resistance can be so large and can be replaced by open-circuit equivalent.

At a certain value of reverse voltage, the reverse current increases suddenly and This indicate that breakdown occur. That breakdown voltage is called as Zener breakdown voltage or Zener Voltage (V_Z).

V_Z can be controlled by doping of P and n regions.

In Zener region voltage accross Zener diode remain same but current changes depending on the supply voltage.

Knee value indicate that diode will start to show very high series resistive element that may not be ignored.

Breakdown Region :-

If reverse bias applied to the pn junction is increased a point will reach when junction breaks down and reverse current rises sharply to a value limited only by external resistance connected in series. This specific value of reverse bias voltage is called as Breakdown Voltage (V_Z).

Breakdown voltage depends on width of depletion layer which depends on doping level.

Following two processes cause junction Breakdown due to increase in R.B voltage.

1) Zener Breakdown
2) Avalanche Breakdown.

Note :- Zener Potential of zener diode is very sensitive to temperature operations.

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Zener Breakdown :-

It is observed in zener diode when V_Z less than 5V. or b/w 5 to 8V. In this,

When reverse voltage is applied accross zener diode, it causes very intense electric field accross. very narrow depletion region field intensity is typically of the order of 3×10^5 V/cm. Such strong electric field is strong enough to pull some valance electrons into conduction band by breaking their covalent bonds A large number of such free electron will constitute large reverse current through zener diode and due to that breakdown occur. This is known as Zener effect.

Avalanche Breakdown in zener diode :-

Avalanche Breakdown is observed in zener diode when V_Z is higher than 8V. Eventhough the mechanism of breakdown is changed, the device is still called zener diode.

In reverse bias the current flows only due to minority carriers. ~~Due to~~ with increase in R.B potential acceleration in these carrier increases. which further increase kinetic energy associated with carrier. Due to this additional aquired energy the valance electron will break their covalent Bonds and jump into conduction band to become free ~~for~~ for conduction. They will knock out some more valance electron by means of collisions. This phenomenon is called as Carrier multiplication.

In very short time, a large number of free minority carrier electrons & holes will available for conduction. This is called as avalanche effect.

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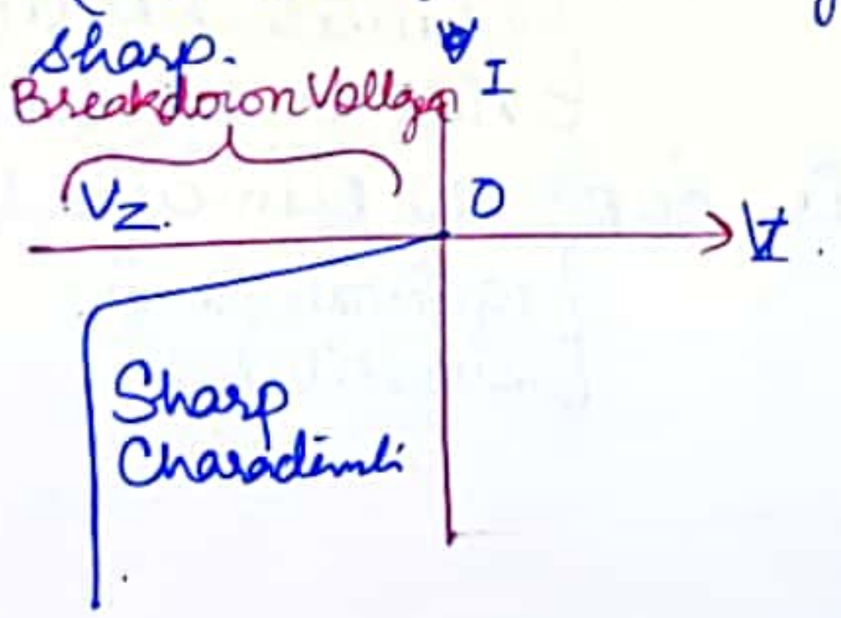
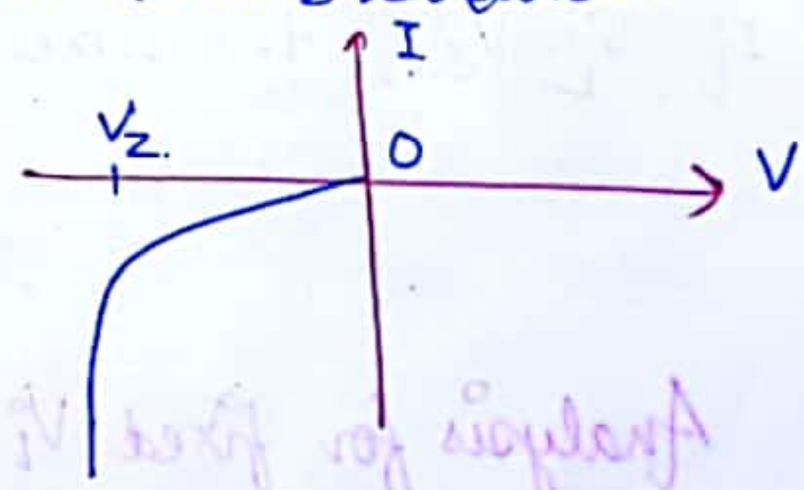
Application of zener diode:-

1. Voltage regulator
2. as peak clipper in wave shaping
3. For fixed reference voltage in Tx biasing ckts
4. For meter protection against damage from accidental application of excessive voltage.

Comparison of Zener & Avalanche Breakdown.

Zener Breakdown	Avalanche Breakdown
(1) This is observed in zener diodes having V_Z between 5 to 8 V.	(1) It is observed in zener diode having V_Z greater than 8V.
(2) The valance electrons are pulled into conduction Band due to intense electric field appearing accross the narrow depletion layer.	(2) The valance electrons are pushed into C.B due to energy imparted by colliding accelerated minority carriers.
(3) V-I Characteristic with zener breakdown is very sharp. 	(3) The avalanche breakdown increases gradually in VI Ch. It is not as sharp as with zener breakdown. 
(4) Breakdown Voltage ↓ with increase in temp. (Negative Temp Coefficient)	(4) Breakdown voltage increases with increase in temp. (Positive temp Coefficient)

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Zener Diode as Voltage regulator

The use of zener diode as regulator is so common. The ~~so~~ three conditions for analysis of voltage regulator are considered. It provide zener diode response in different operating condition.

~~Vi and R fixed~~

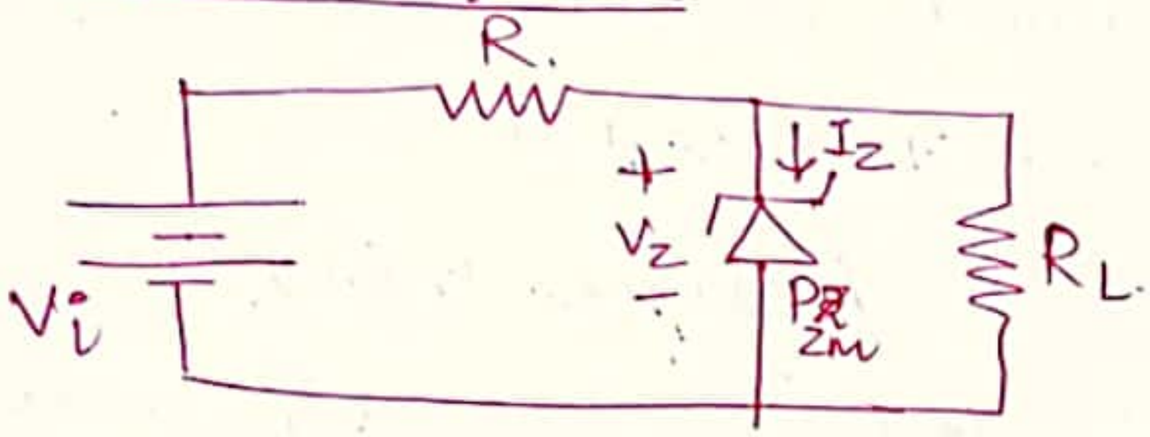


fig:- Basic Zener Regulator

~~In this case V_i and R. both are fixed.~~

~~Two~~ In analysis of voltage regulator two steps will be follow:

Steps for Analysis of Regulator circuit:

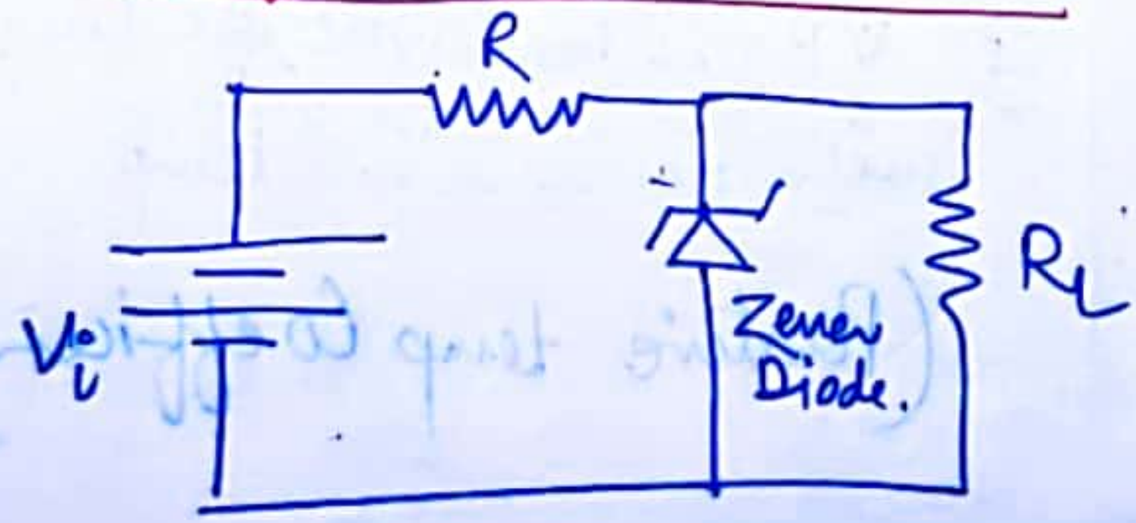
① Determine the state of zener diode by removing it from N/w. and calculate the voltage across the resulting open circuit.

② Substitute the appropriate equivalent circuit for desired unknown.

If $V_L \geq V_Z$, the zener diode is ON, { the appropriate equivalent Model will be substituted

If $V_L < V_Z$, the zener diode is OFF { the Open-circuit equivalence is substituted

Analysis for fixed V_i & R :-



Step 1

Determine state of Zener diode.

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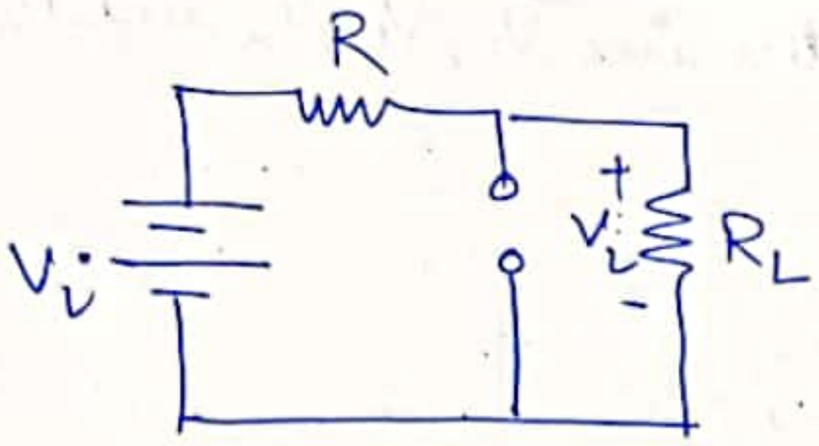
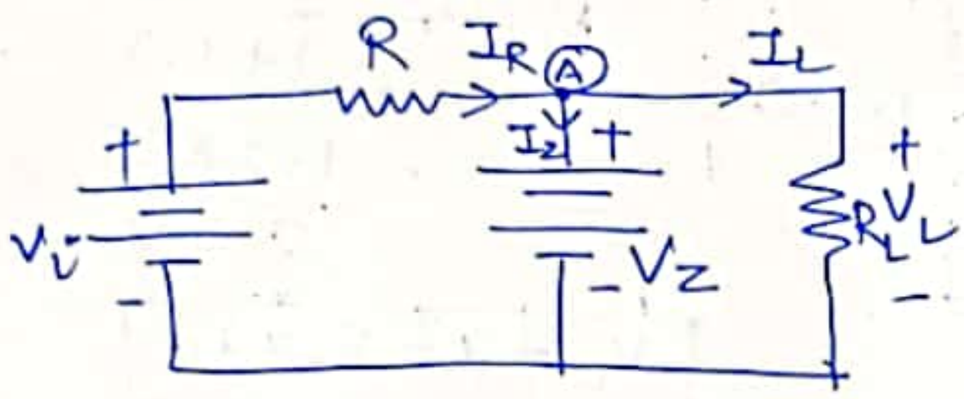


$$V_L = \frac{R_L}{R+R_L} \times V_i$$ { by Voltage Divider Rule

$$\boxed{V_L = \frac{R_L V_i}{R+R_L}}$$

If Diode is ON., then replace it by equivalent N/w.



by KCL at node A.

$$I_R = I_L + I_Z$$

$$\boxed{I_R = I_L + I_Z}$$

$$I_L = \frac{V_L}{R_L}, \quad I_R = \frac{V_i - V_L}{R}.$$

$$\therefore I_Z = I_R - I_L$$

$$\boxed{I_Z = \frac{V_i - V_L}{R} - \frac{V_L}{R_L}}$$

Power dissipated at zener diode, $\boxed{P_Z = V_Z I_Z}$

★ This P_Z value must be less than P_{ZM} of device.

Note :- First step is only for determining the state of zener diode. If diode is on then voltage accross zener diode is not V. Its will be V_Z and It will then 'lock in' at this level. And never reach the higher level of V volts.

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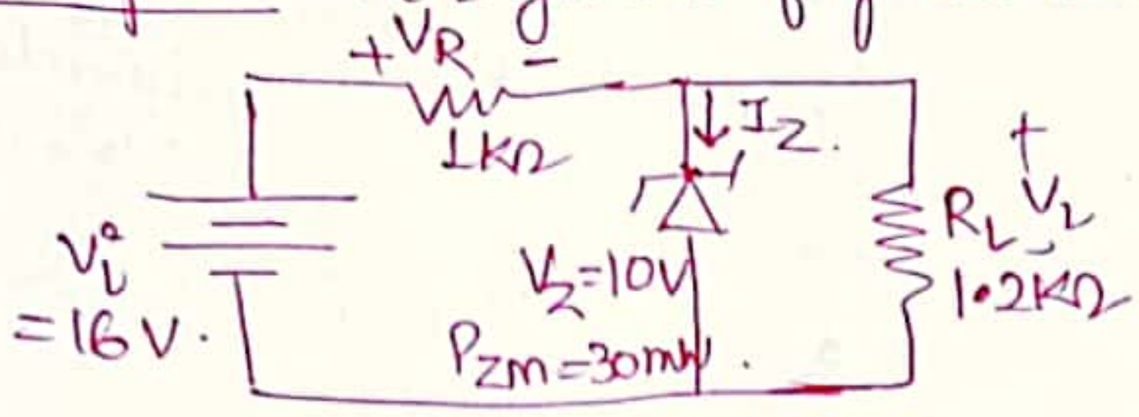
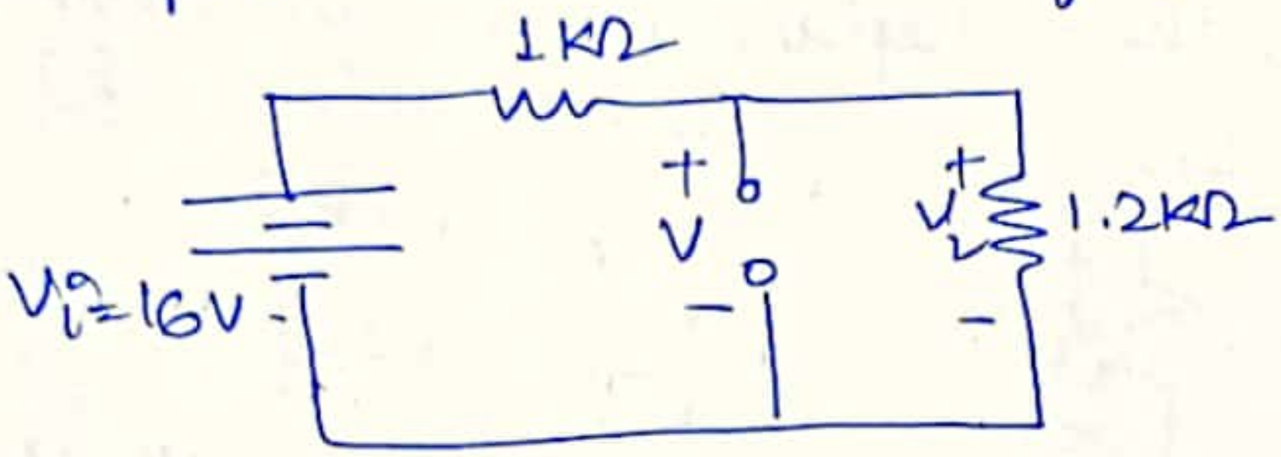
Example ① For given figure determine V_L, V_R, I_Z and P_Z



Step ① :- Determine state of zener diode,



$$V_L = V = \frac{1.2 \times 16}{1+1.2}$$

$$= \frac{1.2 \times 16}{2.2V}$$

$$\boxed{V_L = V = 8.73V}$$

Since $V < V_Z$, zener diode will be off for all time and that branch will be open-circuited hence,

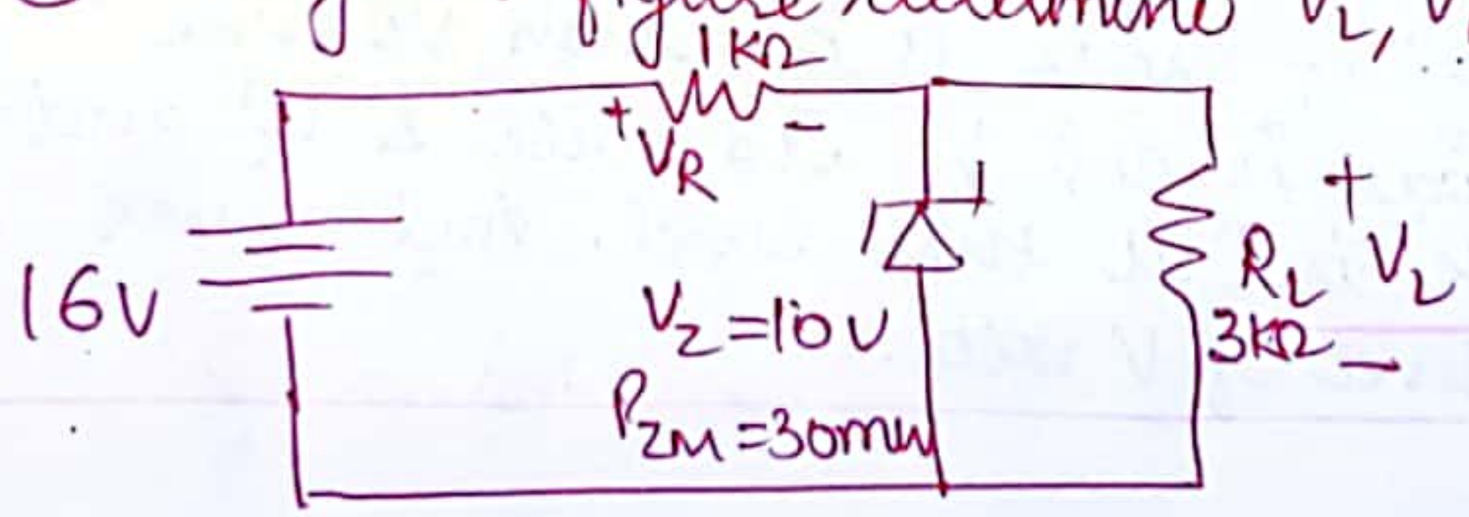
$$\boxed{V = V_L = 8.73V}$$

$$\boxed{I_Z = 0} \quad \therefore \boxed{P_Z = 0}$$

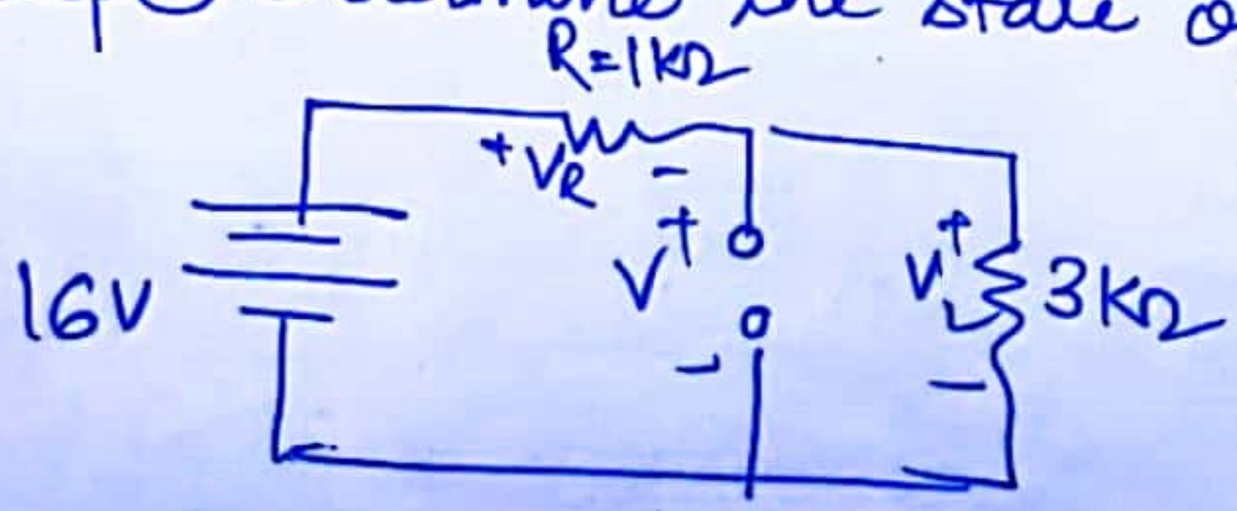
$$V_R = 16 - 8.73 = 7.27V$$

$$\boxed{V_R = 7.27V}$$

② For given figure determine V_L, V_R, I_Z & P_Z



Step ① Determine the state of diode,



$$V_L = \frac{16 \times 3}{4}$$

$$V_L = 12V$$

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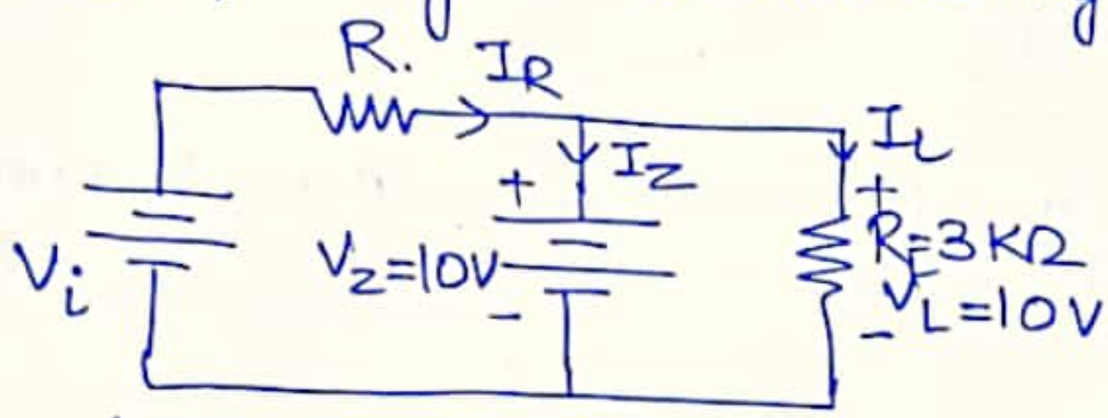
$\because V > V_Z$ hence zener diode is <u>ON.</u>

by replacing zener diode by its equivalent circuit,



$\boxed{V_L = V_Z = 10V}$

$I_R = \frac{16-10}{R} = \frac{6}{1K\Omega} = 6mA$

$\boxed{I_R = 6mA}$

$I_L = \frac{V_L}{R_L} = \frac{10}{3K\Omega}$

Load Current $\boxed{I_L = 3.33mA}$

$I_Z = I_R - I_L$

$= 6mA - 3.33mA$

Zener Current $\boxed{I_Z = 2.67mA}$

$V_R = 16 - 10$

$\boxed{V_R = 6V}$

$P_Z = V_Z \times I_Z$

$= 10 \times 2.67\ mW$

Power dissipation $\boxed{P_Z = 26.7\ mW}$

This value of P_Z is less than P_{ZM}.

Fixed V_i and Variable R_L

Due to offset voltage V_Z, there is a specific range of resistor value that will ensure that the Zener is in 'on' state. Too small a R_L will result in a voltage V_L across the load resistance less than V_Z and Zener device will be in OFF state.

~~For~~ To determine minimum Load resistance. Zener diode turns on. $\therefore V_L = V_Z = \frac{R_L V_i}{R_L + R}$

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

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For min value of R_L, maximum current flows to load.

$$I_{Lmax} = \frac{V_L}{R_L} = \frac{V_Z}{R_{Lmin}}$$

Once zener diode is on, the voltage accross R remains fixed at $V_R = V_i - V_Z$

and I_R remains fixed at $I_R = \frac{V_R}{R}$

Zener current $I_Z = I_R - I_L$

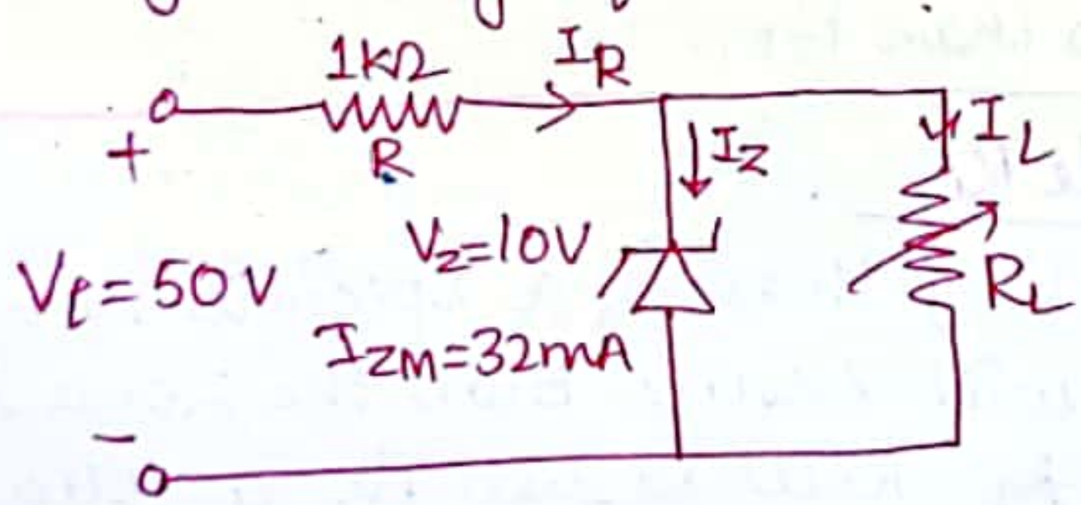
I_L is max when I_Z minimum and I_L min when I_Z is max since I_R is constant.

$$I_{Lmin} = I_R - I_{ZM}$$

Maximum Load Resistance. $R_{Lmax} = \frac{V_Z}{I_{Lmin}}$

---

(3) determine the range of R_L and I_L that will result in V_{RL} being maintained at 10V. Determine maximum wattage rating of diode?



$$R_{Lmin} = \frac{R \times V_Z}{V_i - V_Z}$$

$$= \frac{1K\Omega \times 10}{50-10}$$

$$= \frac{1}{4} \times 1K\Omega$$

$$R_{Lmin} = 250\Omega$$

$V_R = V_i - V_Z$

$= 50 - 10$

$V_R = 40V$

$I_R = \frac{40}{1K\Omega} = 40mA$

$I_R = 40mA$

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Minimum Level I_L,

$$I_{Lmin} = I_R - I_{ZM}$$
$$= 40mA - 32mA = 8mA$$

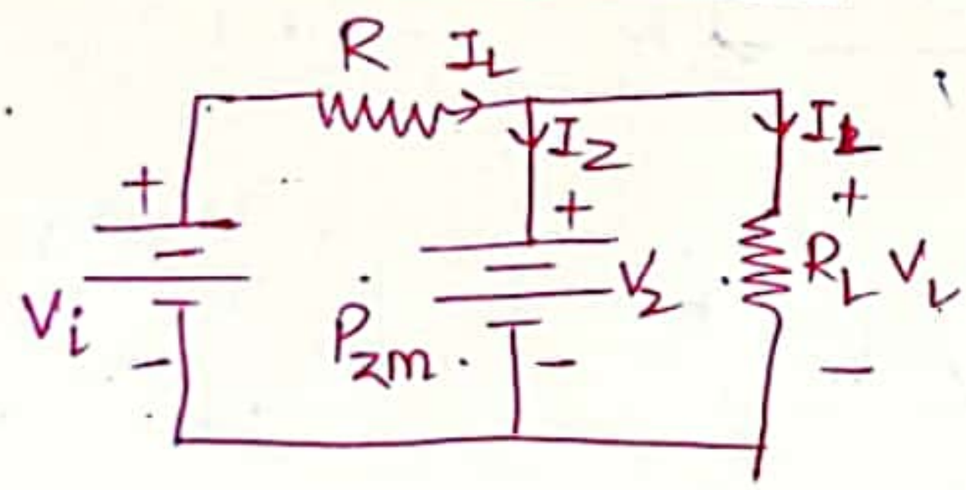
$$\boxed{I_{Lmin} = 8mA}$$

Maximum value of $R_{Lmax} = \frac{V_Z}{I_{Lmin}} = \frac{10V}{8mA}$

$$\boxed{R_{Lmax} = 1.25K\Omega}$$

Power Rating $= V_Z I_{ZM}$
$= (10V)(32mA)$
$= 320mW.$

Fixed R_L, Variable V_i



V_i must be sufficiently large to turn the Zener diode on. The minimum turn on voltage

$V_i = V_{imin}$

$V_Z = \left(\frac{R_L}{R+R_L}\right) V_{imin}$

$$\boxed{V_{Lmin} = \frac{(R_L + R) V_Z}{R_L}}$$

V_i is max when I_Z is max. $I_{ZM} = I_R - I_L$

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

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

$$\boxed{V_{imax} = I_{Rmax} R + V_Z}$$

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Question :- Determine the range of values of V_i that will maintain the zener diode in "on" state.

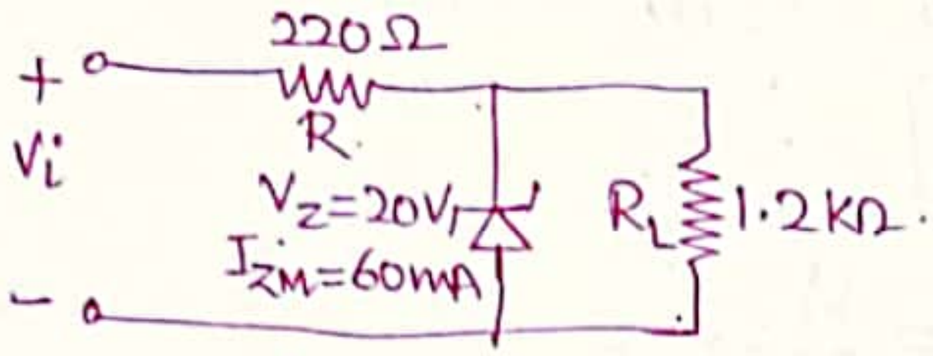

fig:

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

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

$$\boxed{V_{imin} = 23.67\,V}$$

$$I_L = \frac{V_L}{R_L} = \frac{20}{1.2K} = 16.67\,mA$$

$$\boxed{I_L = 16.67\,mA}$$

$$I_{Rmax} = I_{ZM} + I_L = 60mA + 16.67\,mA$$

$$\boxed{I_{Rmax} = 76.67\,mA}$$

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

$$= 16.87\,V + 20\,V$$

$$\boxed{V_{imax} = 36.87\,V}$$

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Special purpose diodes Principle of LED

LED (Light Emitting Diodes):-

Due to increase use of light in displays of calculators, watches and all forms of instrumentation, the interesent in structure ~~of~~ of device which emit light when properly biased is also increased.

There are two common devices that perform these functions, 1) LED (Light Emitting Diodes).
2) LCD (Liquid Crystal Display).

LED:- ⇒ The LED is a diode that provide visible or invisible (infrared) light when energized. (When electrical energy) applied to it.

⇒ In forward bias p-n junction recombination of holes and electrons takes place. (This recombination require energy possessed by unbounded free electron be transferred to another state.)

⇒ In all semiconductor pn junction some of the energy is given ~~on~~ off in the from of heat or in the form of light.

⇒ In Si & Ge diodes greater % of energy converted during recombination at the junction, in the form of heat and emitted light is insignificant. Due to this Si & Ge are not used in construction of LEDs.

Color	Construction	typical Forward Volta
Amber	AlInGaP	2.1V
Blue	GaN	5V
Green	GaP.	2.2V
Orange	GaAsP	2V
Red	GaAsP	1.8V
White	GaN	4.1V
Yellow.	AlInGaP.	2.1V

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Construction of LED :-

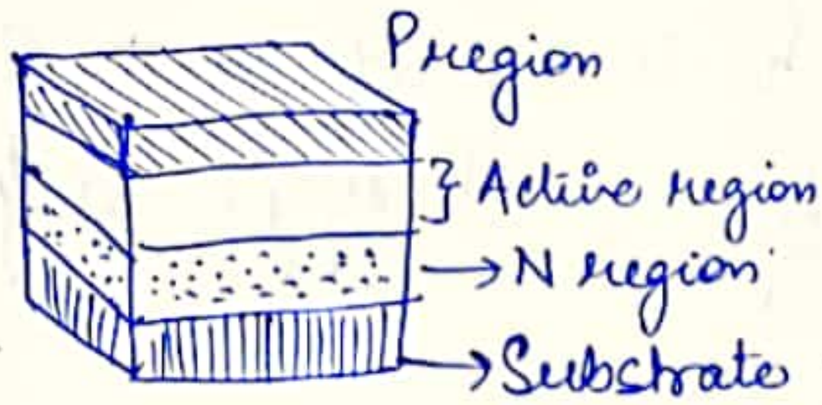

fig: Construction of LED

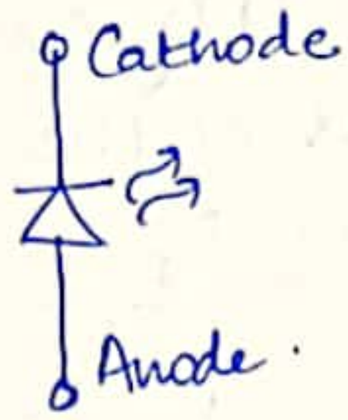

fig:- Symbol

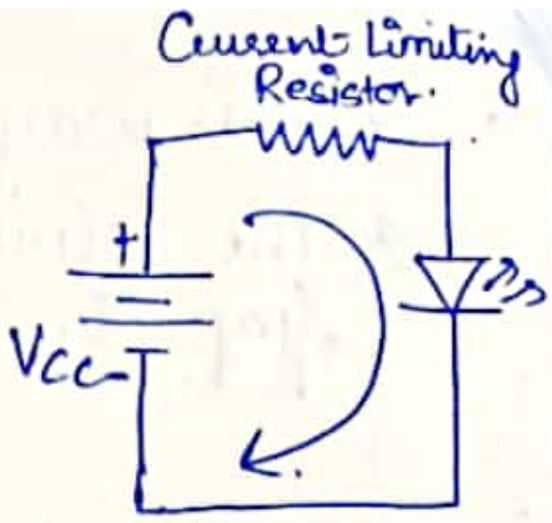

fig: LED Biasing

* Popular method of LED construction is to deposit three semiconductor layers on substrate.
* The active region exists between the P and N regions which emit light in all the directions when electron hole pair recombine.
* The Drawback of this structure is ~~emission~~ emmission of light in all directions. This can be solved by placing it in a small reflective cup so as to focus the light in desired direction. Such structure is called as Cup-type construction.

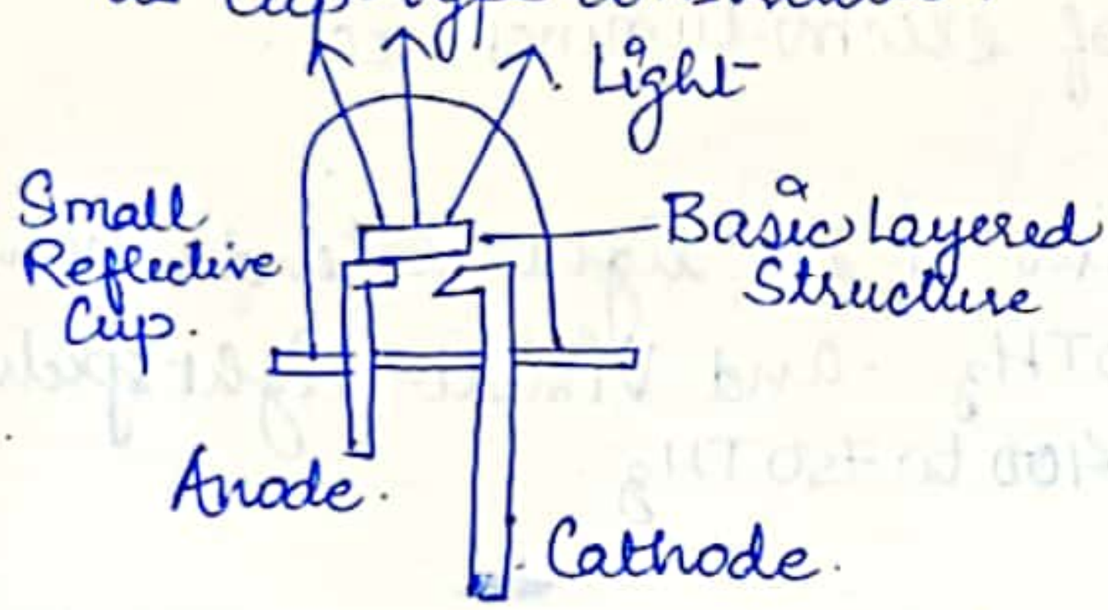

fig:- Cup-type-Construction

Through this (Cup-type) methode we get focused light in desired direction.

Principle of LED operations :-

* When LED is forward biased, the electron in N-region will cross the junction and recombine with holes in P-type material.
* These free electrons resides in C.B. which has higher energy level than holes in V.B.
* When recombination takes place these electrons give ~~ab~~ away the excess energy in form of light. This process is called as electroluminesence.

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* This way LED emits light.
* The colour of the light will depends on Forbidden gap (Eg).

$$E_g = h\nu = \frac{hc}{\lambda}$$ → Energy Band gap.

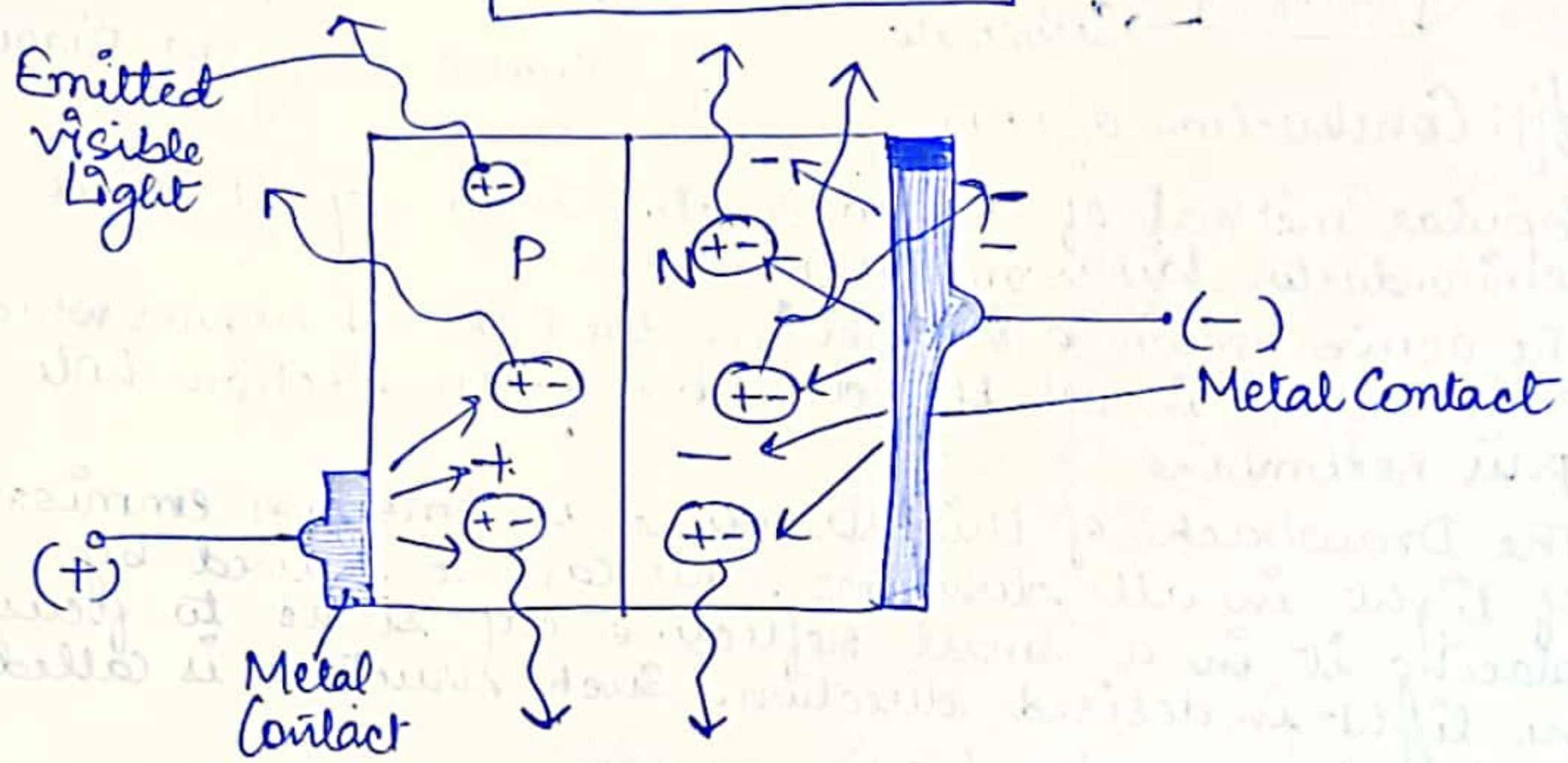

fig:- Process of electro-luminescence.

* The frequency spectrum of IR light extends from about 100THz to 400THz. and visible light spectrum extend from about 400 to 750THz.

Advantage of LED:-

1. Light weight & small in size.
2. They have longer life as compared to lamps
3. By controlling current flow through diode, we can control the brightness of LED's.
4. Suitable at high operating speeds.

Drawback or disadvantage

1. If current exceeds the limit, it can damage LED easily.
2. Luminous efficiency of LED's is low.

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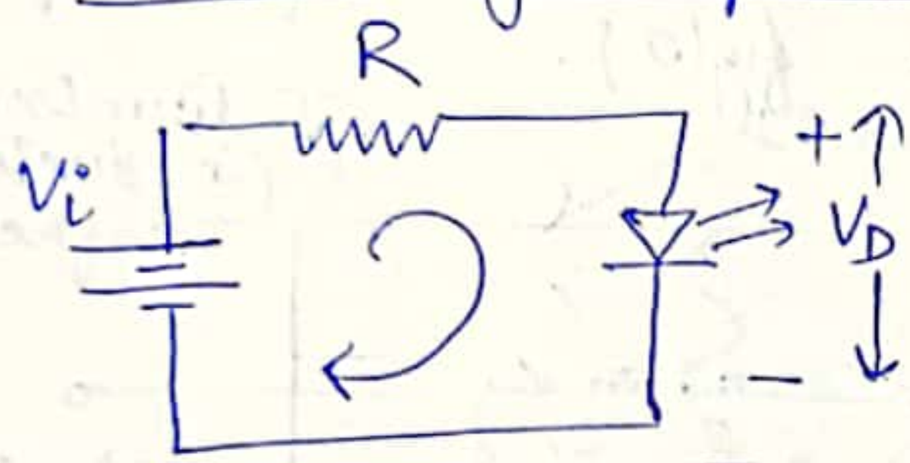
③ O/P power is affected by change in temperature.

Application:-

① Infrared remote control.
② Used as indicator in various electronic devices.
③ 7-segment & alphanumeric displays.
④ In image sensing circuits
⑤ Used in field of optical communication

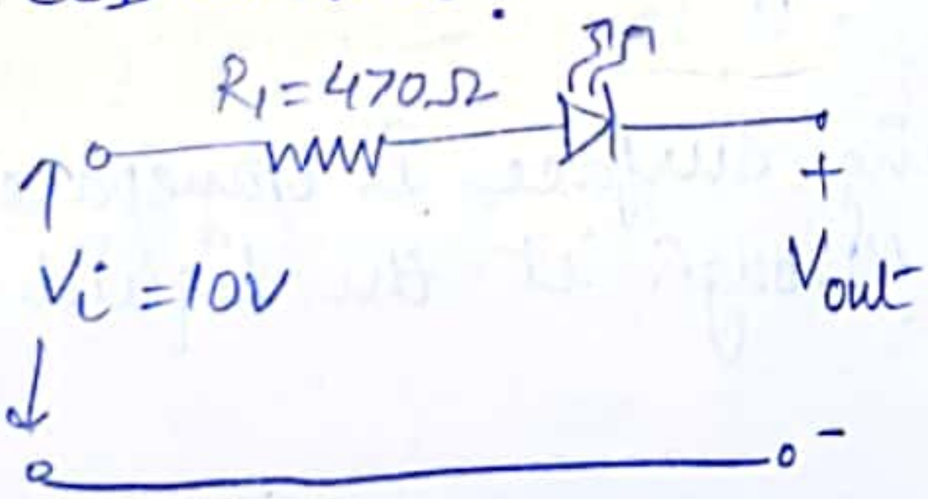
LED Voltage drop and current.



LED also have a certain Forward voltage drop like normal p-n junction diode.

$$\boxed{I = \frac{V_i - V_D}{R}} \quad \text{or} \quad \boxed{I_F = \frac{V_F - V_D}{R}}$$

Numerical:- The LED has 1.5 V min drop & 2.3V as maximum drop. If supply voltage is 10V and R_1 is 470Ω. What are min & maximum value of LED current?



Solution- $I = \frac{V_i - V_D}{R_1}$

$$I_{min} = \frac{10 - 2.3}{470} = 16.4mA$$

$$I_{max} = \frac{10 - 1.5}{R_1} = 18.1mA$$

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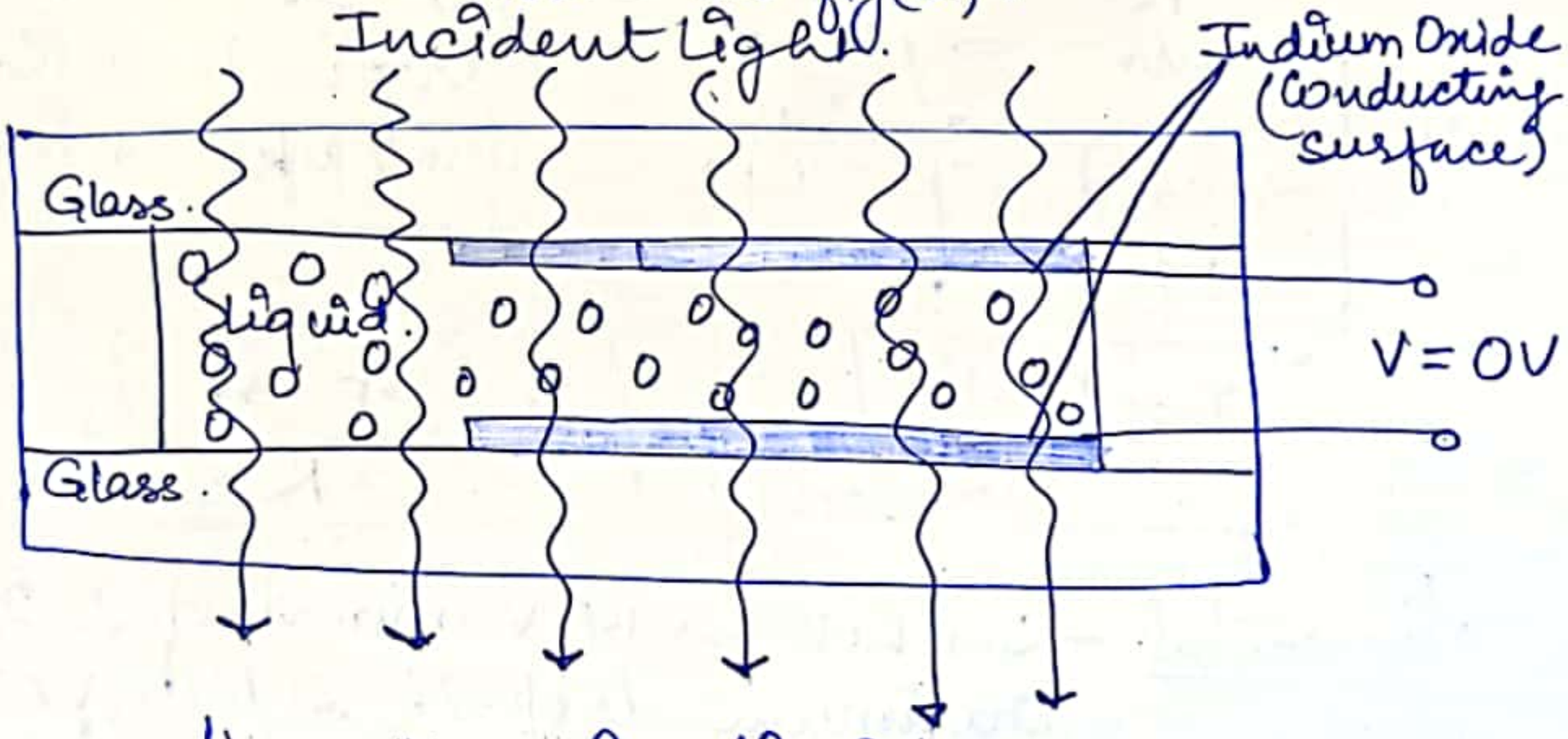
Liquid Crystal Display :-

LCD has the distinct advantage of having low power requirement than the LED, typically on the order of μW. for display compared to mW for LED. But it require external light source and is limited to a temp range of about 0°C to 60°C.

* Liquid Crystal is a material that flows like a liquid but its molecular structure has some properties normally associated with solids.

There are two type of Displays,
1) Dynamic Scattering Display :-

* For light scattering unit, the numeric liquid crystal is used, which is shown in fig(a).



fig(a). Numeric liquid crystal with no applied bias.

Indium oxide conducting surface is transparent when incident light pass through it the liquid structure will appear clear.

* If voltage is applied across conducting surface, the molecular arrangement is disturbed which result regions stablished with different indices of refraction

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Incident light therefore reflected in different directions at the interface between regions of different indices of refraction. This process is known as dynamic scattering.

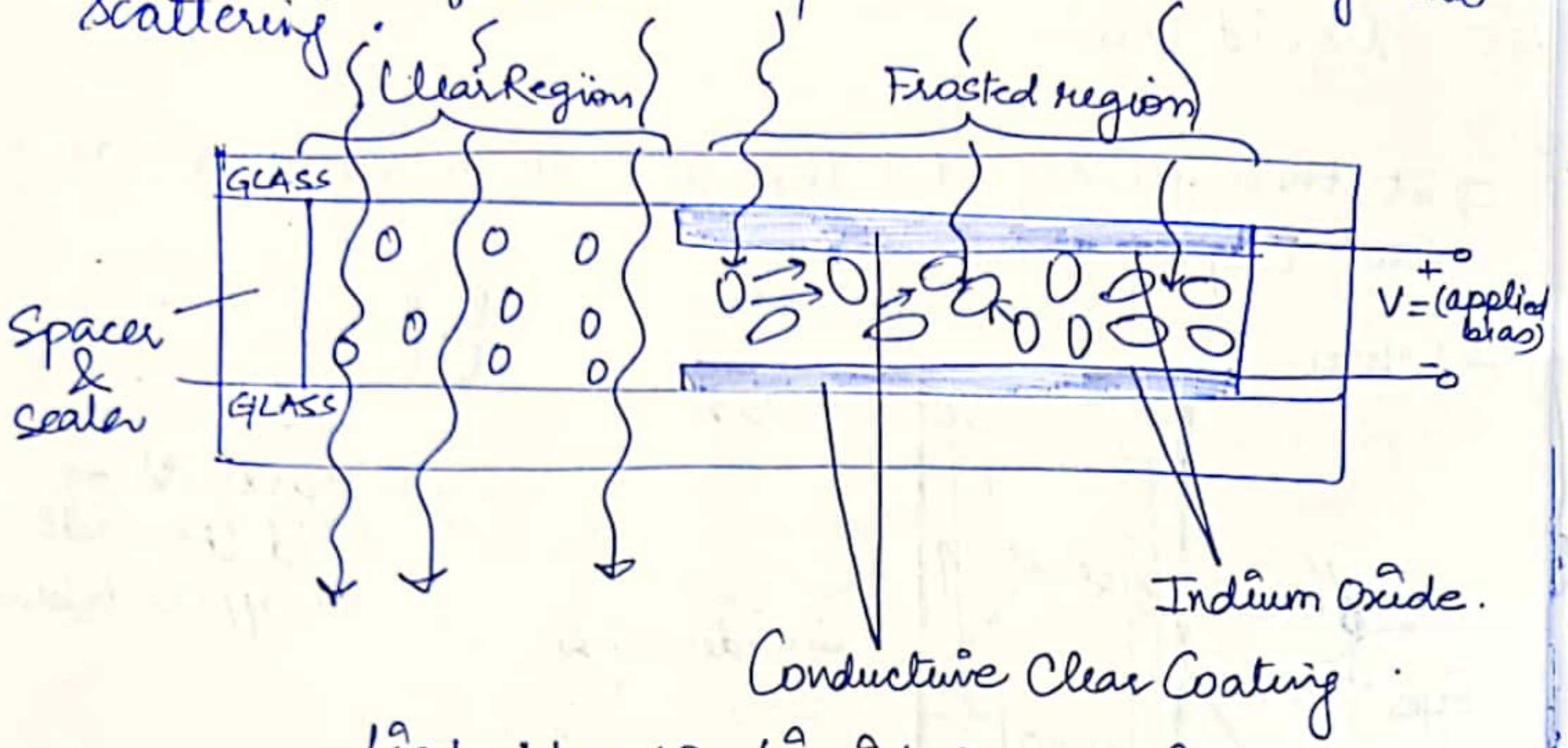

fig b- Nematic Liquid Crystal with applied bias.

When dynamic scattering display energized, ~~molec~~ molecules of energized area of display become random & scattering light in all directions and unenergized area remains clear.

Field Effect Display:-

① It has same segmented appearance & thin appearance of liquid encapsulated liquid crystal but its mode of operation is different.

② Construction of Field Effect Display is shown in fig(c) It consists of two glass plates, liquid crystal fluid sandwitched between them. It also consists polarizing filter and transparent conductor.

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⇒ When electrical excitation is not provided the light incident on front plate and go through polarizing filter. Light get twisted 90° while passing through liquid crystal.

⇒ It then get reflected through back mirror to viewer and display remains clear.

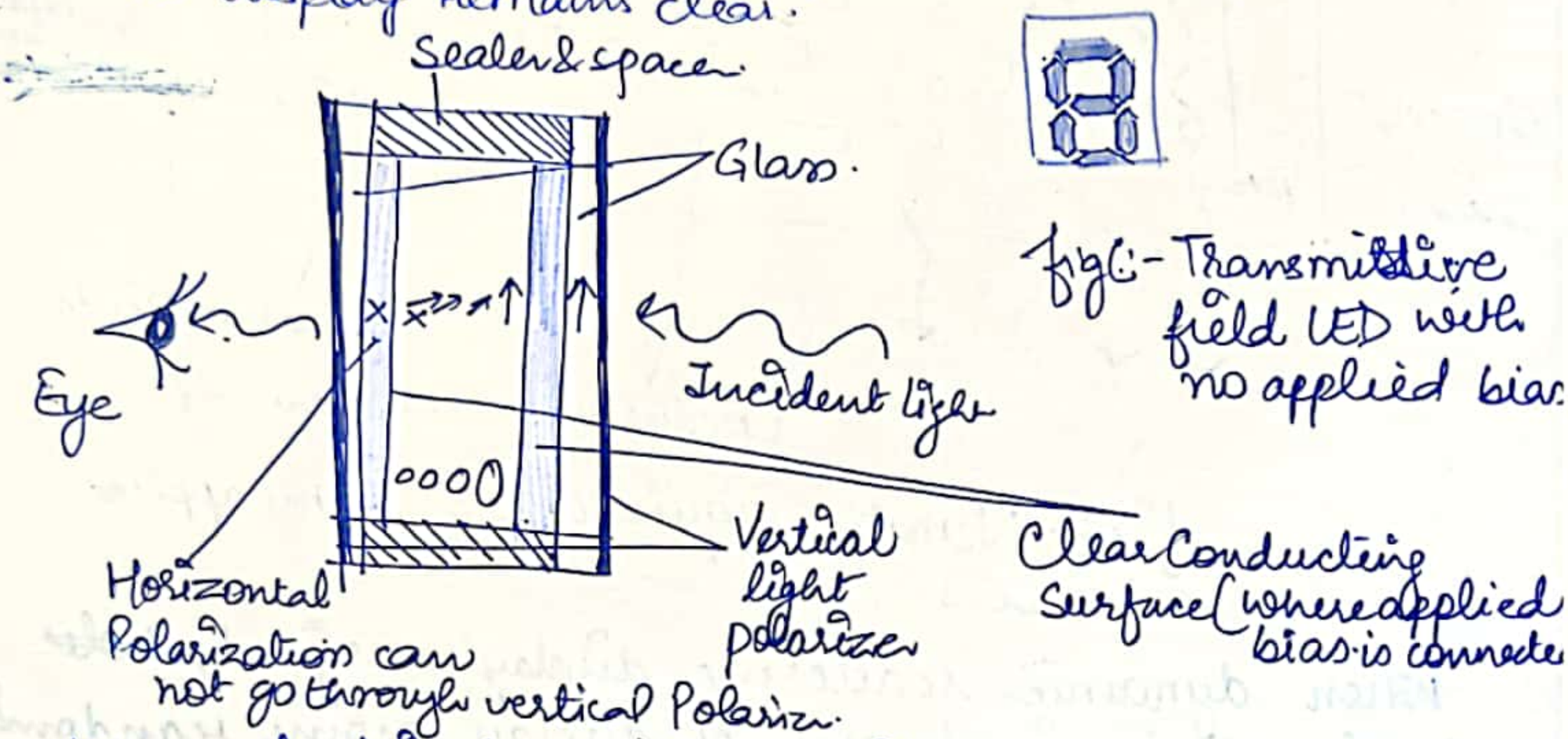

fig 6:- Transmissive field LED with no applied bias

⇒ When electrical excitation is provided, the crystal molecule will get aligned and light passing through them will not be twisted at all.

The light is then absorbed by rear polarizer & dark dig appear on light background.

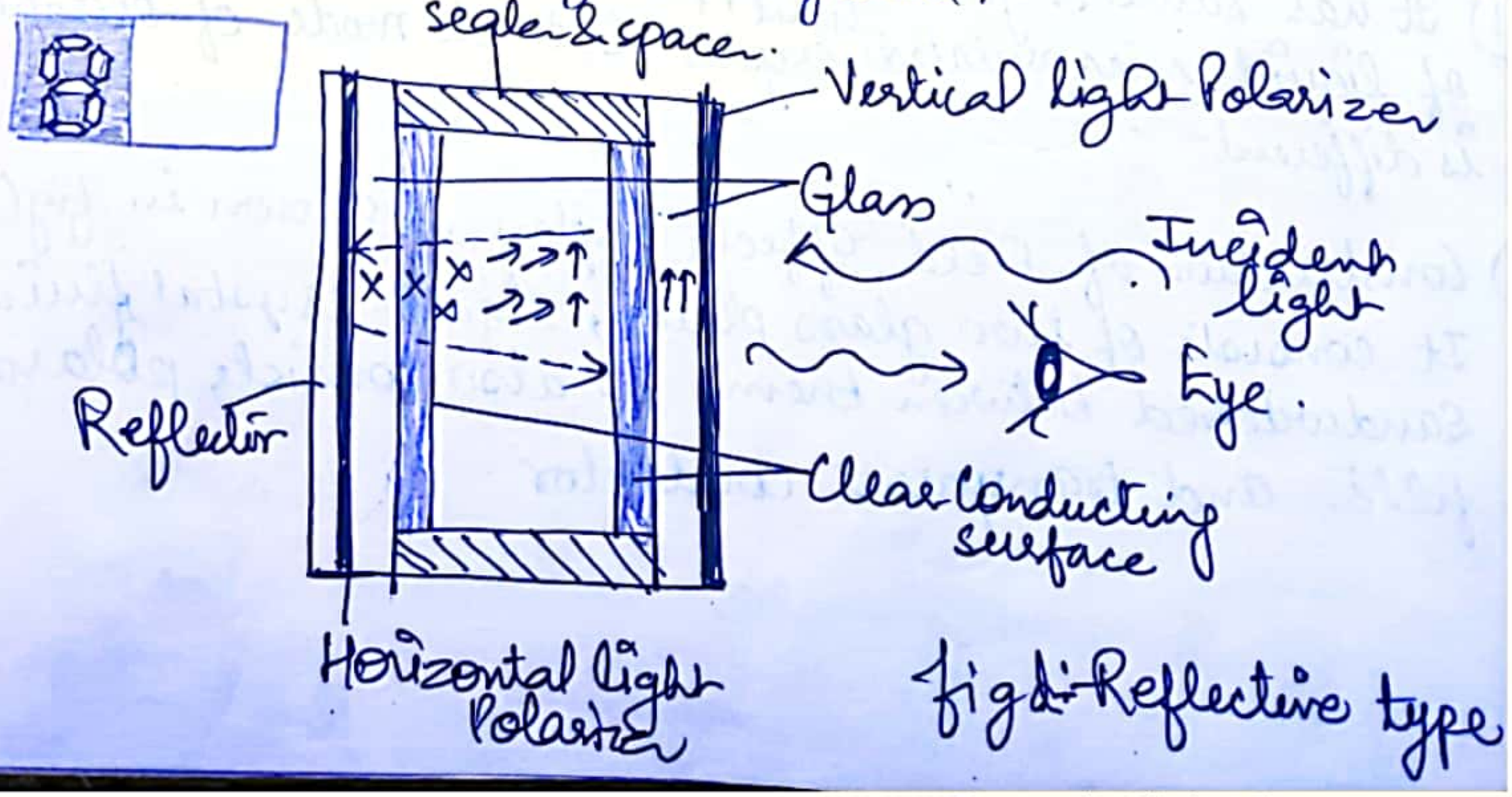

fig 7:- Reflective type

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Advantage:-

1. Less power per digit is required so power saving takes place.
2. They have good contrast & uniform brightness.
3. They have low threshold voltage & require low operating voltage.
4. All segments have uniform brightness.
5. Low cost.

Disadvantage:-

1) Small operating temp
2) Low switching speed.
3) Backlight is necessary.
4) Poor reliability

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