Lecture - 01

UNIT-1 - Semiconductor Diodes & Applications

What is Electronics ?

Electronics is the branch of science that deals with the study of flow and control of elections (electricity) & the study of their behavior & effects in vaccum, gases & semiconductor, & with devices using such electons.

CLASSIFICATION OF MATERIALS:

materials are classified in three different categories

(a) conductor (b) Semiconductor (c) Insulator.

Conductor: Allow easy flow of an e- from one atom to another atom when the proper application of voltage.

Example - Gold, copper, steel etc, sodium, magnesium etc.

Semiconductor: Conductivity lies between conductor & Insulator.

Example - Si, Ge, GaAs etc.

Insulator: Prevent the flow of energy between two objects

Example :- Glass, Plastic etc.

Classification based on valence electrons -

Valence e^- :- Electron in the outermost orbit of an atom are known as valence electron.

1. No. of valence e^- in atom < 4 "conductor"

   Ex - Sodium (1) [11e- 2 8 1]

   Magnesium (2) [12e- 2 8 2]

2. No. of valence e- in atom = 4 "Semiconductor"

   Ex - carbon (4) [6e- 2 4] { not a semiconductor }.

   Silicon (14) [14e- 2 8 4]

Group 14 elements acts as semiconductor.

NOTE: Why carbon is not a semiconductor?

This is because the atoms or molecules in carbon are closely packed to each other whereas Si & Ge acts as semiconductor materials.

3. No. of valence e^- in atom > 4 "Insulator":

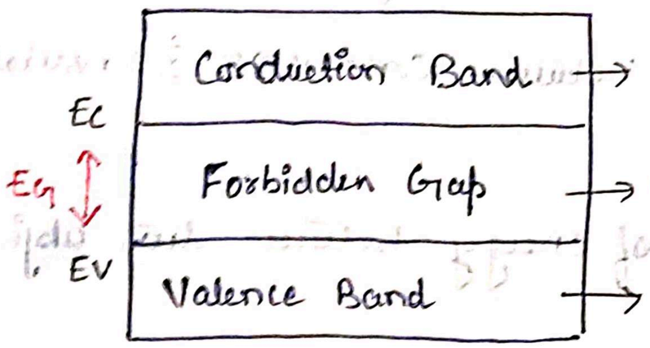
Ex- Nitrogen (5) [2 5]

Sulphur (6) [2 6]

Classification of materials based on Energy Band:

Ques Classify the materials with help of Energy Band? (AKTU QUESTION)

ENERGY BAND:



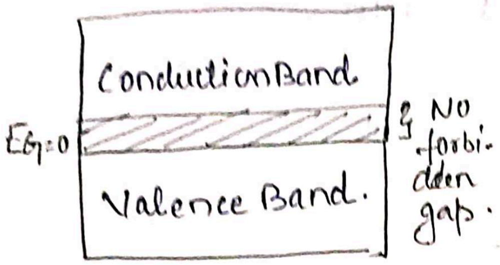
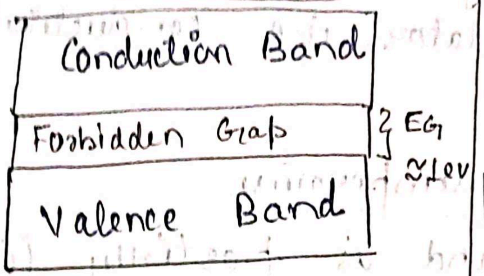
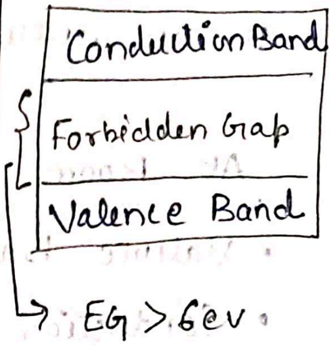
Conduction Band → Range of energy possessed by free e^-

(e^- in C.B are free or weekly held with nucleus. Hence these e^- can easily move around by applying Electric field).

Forbidden Gap → Energy gap in which NO e^- exist.

Valence Band → Range of energies possessed by Valence electrons.

(e^- in V.B are normally in their normal orbit around nucleus & a very large amount of energy must be applied in order to extract an e^- from V.B)

CONDUCTOR	SEMICONDUCTOR	INSULATOR
1. In conductor there is no gap between Valence Band & Conduction Band. $\boxed{EG = 0}$ 	1. In Semiconductor there is a gap of around 1 ev between Valence Band & Conduction Band. $\boxed{EG \approx 1ev}$ 	1. In Insulator there is a gap of around 6ev which is very high  $\boxed{EG \approx \alpha > 6ev}$
2. Due to zero forbidden gap e^- are available in the conduction band at low temperature. So allow electric current to pass.	2. Their conductivity lies in between Conductor & insulator at 0 K° → act as Insulator at room temp → act as Conductor as covalent bonds breaks & move e^- from V.B to C.B EG Si : 1.1 ev EG Ge : 0.7ev	2. Have No free charge at low temperature. On increasing temp. its conductivity can be improved. But EG is large So, it is difficult to move e^- from valence Band to Conduction Band
3. Example - Copper, Aluminium etc.	3. Example - Si, Ge etc.	3. Example - Rubber, glass, wood etc.

Ques - Explain the effect of temperature on conductivity of semiconductor ?

At low temperature -

- Valence band is completely filled
- Conductn band is completely empty

So at very low temperature (0K) semiconductor behaves as an insulator i.e conductivity is zero.

At Room temperature -

- Valence band is partially filled.
- Conduction band is also partially filled

And as we know forbidden gap between valence band & Conduction band is narrow. As temperature increases conductivity of semiconductor increases - the valence e⁻ start acquiring additional energy & close the narrow gap to enter into conduction band.

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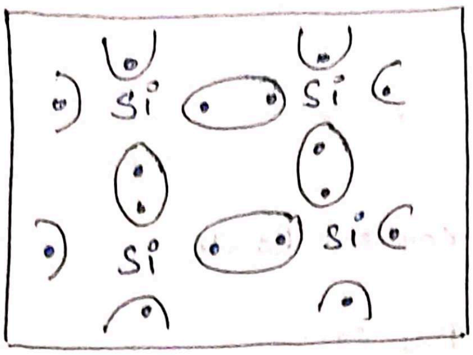
v. imp. CLASSIFICATION OF SEMICONDUCTOR : (AKTU Question)

The semiconductors are classified into two categories as

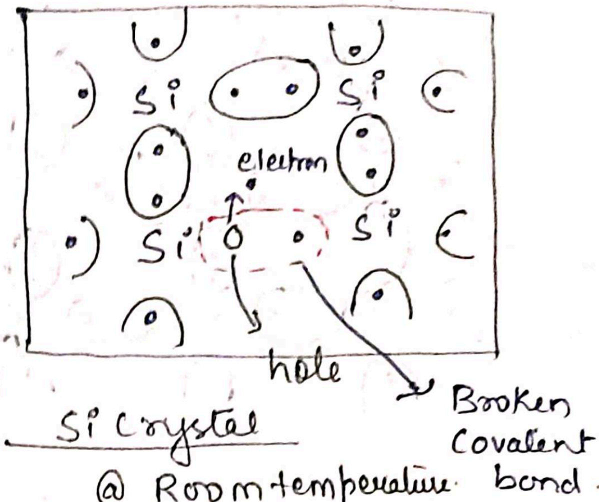
(i) Intrinsic Semiconductors

(ii) Extrinsic Semiconductors.

INTRINSIC SEMICONDUCTOR - A semiconductor in pure form is called intrinsic semiconductor. They behave as a Insulator at 0°K as no free e⁻ available (all are tightly bounded). But at room temperature some of the valence electron gain enough thermal energy to break up the covalent bonds. The process of ionization create a vacancy in the bond between the atoms. (this vacancy is hole). Due to movement of electrons & holes, electricity conducts.



Si crystal @ 0K



Si crystal @ Room temperature

• → electron
o → hole.

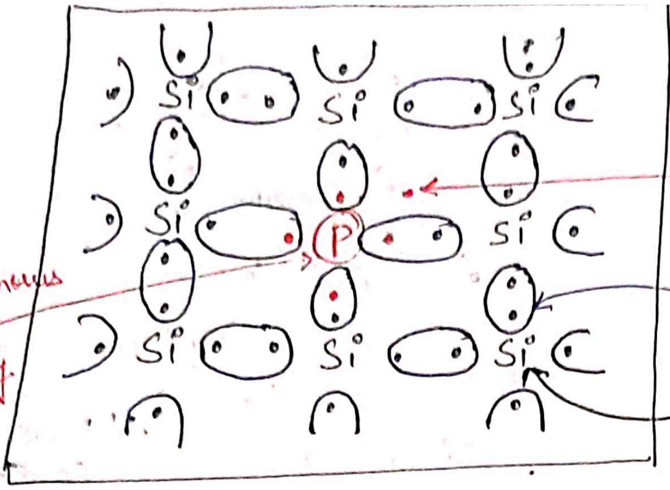
EXTRINSIC SEMICONDUCTOR -

An intrinsic semiconductor is converted into extrinsic semiconductor by adding impurities to a semiconductor is called Doping. & impure semiconductor is called Extrinsic semiconductor.

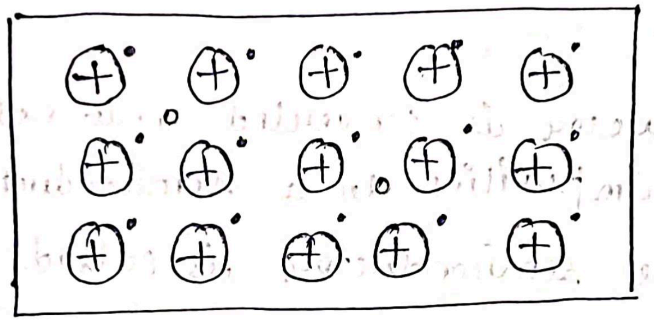
Depending on the type of impurity added extrinsic semiconductor are further classified as-

(i) n type semiconductor.
(ii) p type semiconductor.

N-Type Semiconductor - When a pentavalent impurity (donor impurity) is added to pure semiconductor (Si or Ge) the resulting semiconductor is n-type. As pentavalent atom (Phosphorus, Arsenic, Antimony) have 5 valence e⁻. Therefore in n-type semiconductor, by adding 'P' [donor atom - because it is ready to give a free e⁻ to a semiconductor] to intrinsic semiconductor, 4 valence e⁻ of 'P' form covalent bonds with 4 valence e⁻ of Si (neighbouring atom) & 5th valence e⁻ doesn't form covalent bond. Thus this additional e⁻ which can enter the conduction band very easily to become a free e⁻.
Here Pentavalent impurity provide charge carrier (e⁻) for conduction.



N-Type Semiconductor



There are three particle in N-Type semiconductor.

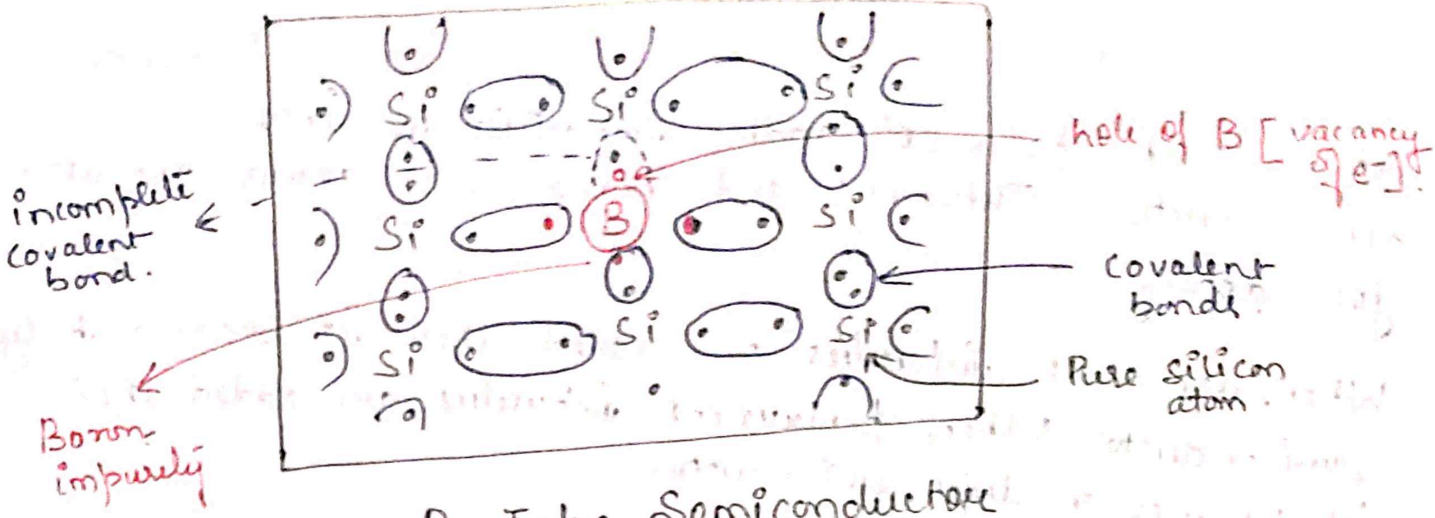
⊕ Donor ions.

• → free e-

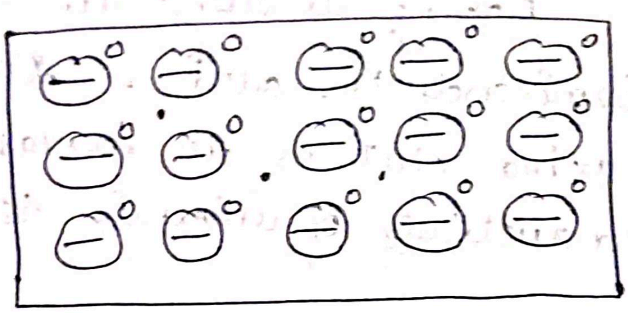
o → holes।

Majority carriers ⟶ electrons.
Minority carriers ⟶ holes.

P-Type Semiconductor – When a trivalent impurity (Acceptor) is added in pure semiconductor (Si or Ge), the resulting semiconductor is p-type. As trivalent atom (Boron, Aluminium, Gallium etc) have 3 valence e-. Therefore in p-type semiconductor, a 'B' [Acceptor atom – because it is ready to accept a free e- from a Semiconductor] is added to intrinsic semiconductor (Si or Ge), a 3 valence e- of 'B' form covalent bond with 3 valence e- of Si (neighbouring atom). 4th covalent bond however remains incomplete as a result vacancy (Hole) is created. Here trivalent impurity provide charge carriers for conduction.



P- Type Semiconductor



There are three particle in P- Type semiconductor

⊖ Acceptor ions.

o ← holes

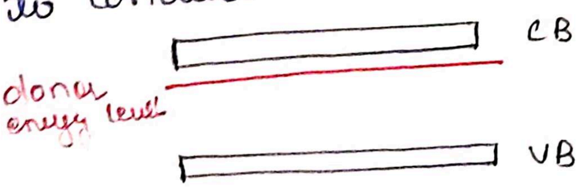
• ← electrons.

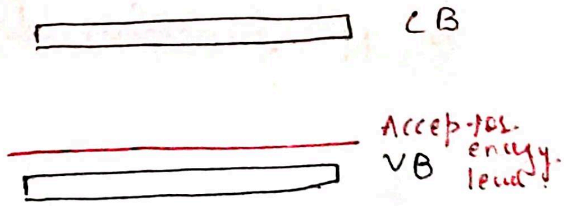
Majority carriers → holes

Minority carriess → electrons.

Ques Differentiate between N-type & p-type Semiconductor.

N- Type Semiconductor	P- Type Semiconductor
1. Pentavalent impurities such as (P, As, Sb) are added.	1. Trivalent impurities such as (B, Al, Ga) are added.
2. Impurities are called Donor atom.	2. Impurities are called Acceptor atom.
3. Majority carrier are electron. Minority carrier are holes.	3. Majority carrier are holes. Minority carrier are electrons
4. The donor energy level is close to Conduction Band.	4. The acceptor energy level is close to Valence Band.





Ques What do you mean by doping? (AKTU QUESTION)

Doping is the process of adding impurities to intrinsic semiconductor. Trivalent and pentavalent atoms are used for doping.

When trivalent impurities are added then it becomes p type semiconductor. When pentavalent impurities are added then it becomes n type semiconductor.

Need of Doping — Doping is done to increase the conductivity of Semiconductor devices. Doping creates extra holes or extra electrons to increase the flow of currents. so conductivity of intrinsic semiconductor increases.

Type of current in Semiconductor : There are two type of current in semiconductors (a) drift current (b) diffusion current.

1. Drift Current :- Drift current is due to flow of charge carriers under the influence of Electric field.

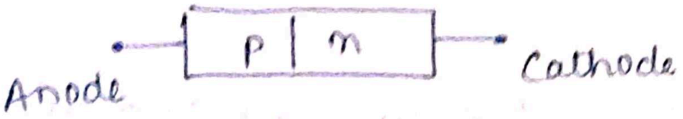
2. Diffusion current :- Diffusion current is due to movement of charge carriers from higher concentration to lower concentration (because of concentration gradient).

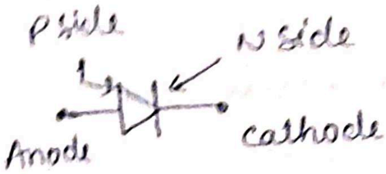
Lecture - 02

P–N junction Diode —

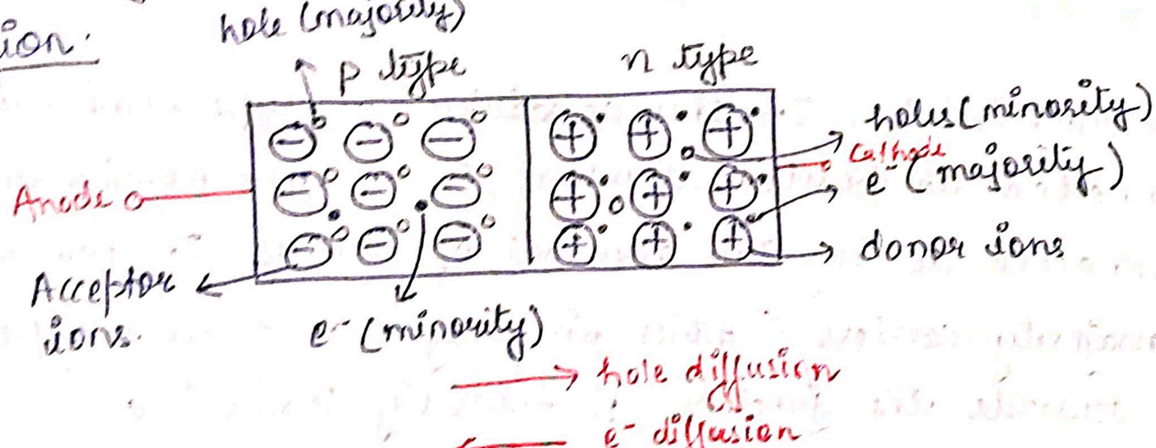
Ques Define depletion layer in a diode [AKTU QUESTION]

When a p-type semiconductor material is suitably joined to a n-type semiconductor, the contact surface is called p-n junction [Semiconductor Diode].

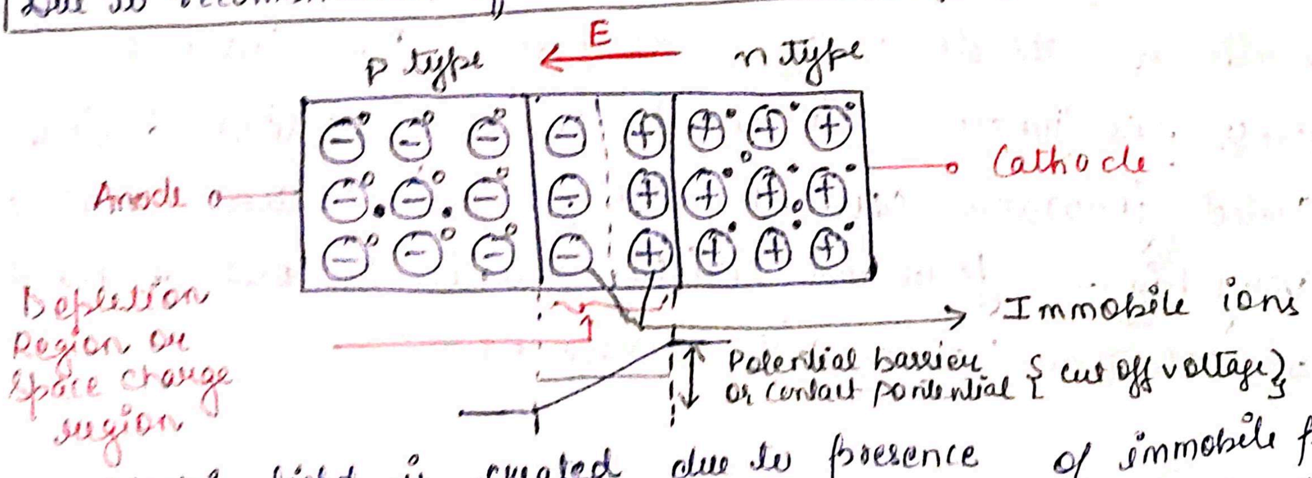




When a p-n junction is formed then hole starts to move from p to n & electron starts to move from n to p due to concentration gradient. This is called diffusion process. An electric field is generated at the junction which stops the further movement of electrons & holes. So, a layer of immobile ions is formed at the junction. This layer is called depletion layer or space charge region.



Due to recombination of hole & electron only immobile ion are left



A Electric field is created due to presence of immobile positive & negative ions on opposite side of junction is known as Barrier

potential or junction potential or cut in voltage / Knee Voltage
Due to presence of depletion region, the charge carriers (e^- & holes) can't cross the junction anymore & the current flowing through an unbiased p-n junction is zero.

NOTE: Explain the knee voltage. What is the knee voltage for Ge & Si?

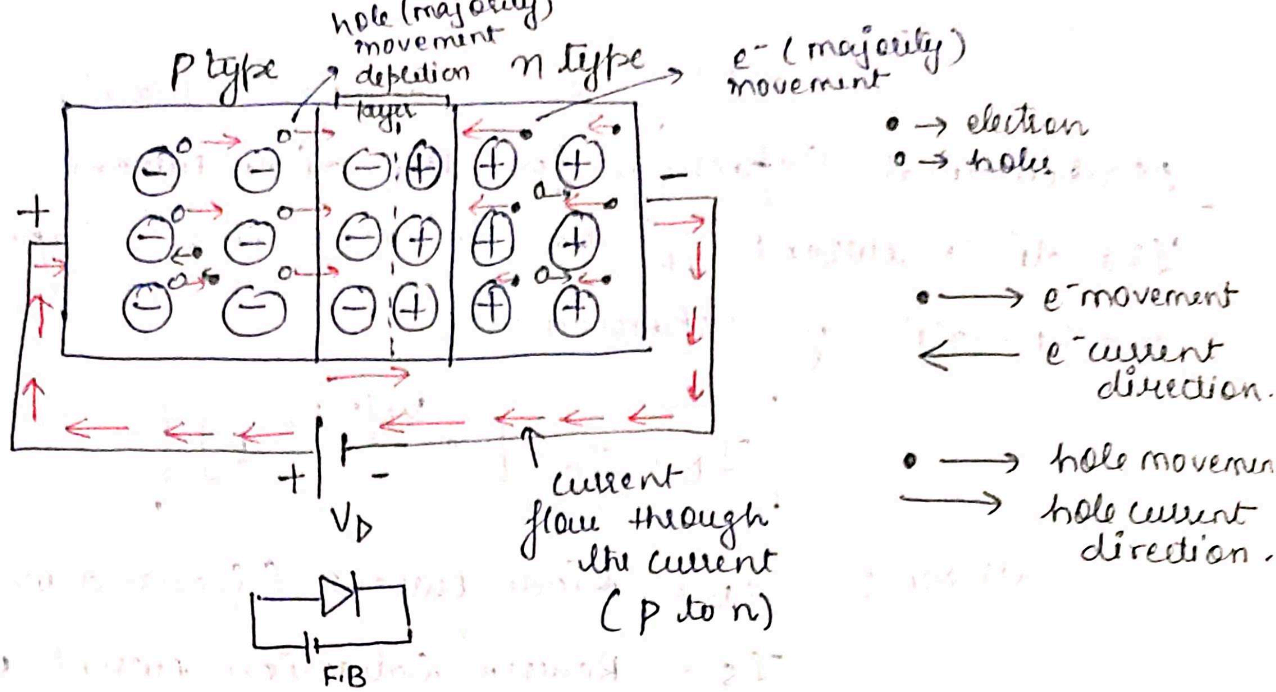
A minimum positive voltage is required to start conduction in a forward biased diode. This minimum positive voltage is called Knee voltage or cut off voltage (V_γ).

for Ge, $V_\gamma = 0.3$ Volt.
Si $V_\gamma = 0.7$ Volt.

Connecting a p-n junction to an external dc voltage source is called Biasing

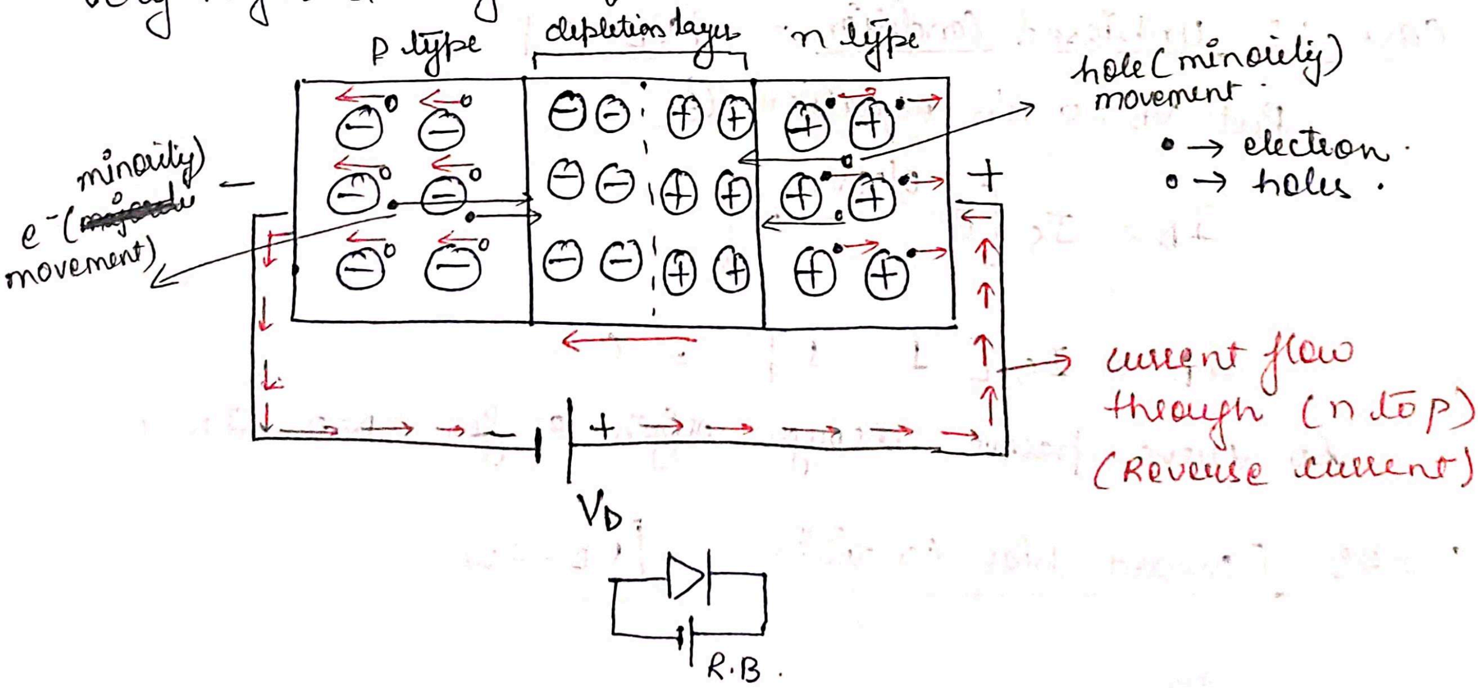
Imp. Ques. Explain the working of p-n junction under forward bias & reverse bias condition [AKTU QUESTION].

Forward Bias :- In this condition, p-type semiconductor is connected to positive terminal & n-type semiconductor is connected to negative terminal of battery. In forward bias majority carriers (holes in p type & e^- in n type) moves towards the junction & minority carries (e^- in p type & hole in n type) move away from the junction. So width of depletion layer decreases. The current across the junction is due to majority carriers & it is called forward current. So forward current will be very high, forward resistance will be low & height of potential barrier will decrease.



<u>Reverse Bias</u> — In this condition p-type semiconductor is connected to negative & n type semiconductor is connected to positive terminal of battery. So majority carrier move away from the junction (holes in p type & e^- in n-type) & minority carriers (e^- in p type & hole in n type) move towards the junction. So, width of depletion layer increases. The current across the junction is due to <u>minority carriers</u> & it is called <u>reverse saturation current or leakage current</u>.

So, current will be very low, reverse resistance will be very high & height of potential barrier will increase.



Lecture - 03

Shockley Diode Current Equation

Mathematical Expression for the diode current -

The diode current "I_D" has an exponential shape. It is mathematically expressed as :-

$$\boxed{I_D = I_S \left[e^{V_D/\eta V_T} - 1 \right]}$$

Where : I_D = Diode current (forward or reverse)

I_S = Reverse Saturation current or leakage current.

V_D = Diode voltage (voltage across diode)

η = Ideality factor for Ge $\eta = 1$
Si $\eta = 2$

$V_T = \frac{T}{11,600}$ (volt equivalent of Temperature) (T should be in Kelvin)
at room temp. $V_T = 26 mV$.

V. Imp

Ques Draw & Explain the V-I characteristics of p-n junction diode. [AKTU QUESTION]

V-I characteristics of a p-n junction diode is a graph of voltage across diode vs the current flowing through it.

Diode current equation : $\boxed{I_D = I_S \left[e^{V_D/\eta V_T} - 1 \right]}$ --- (1)

Case 1: Unbiased Condition - $\boxed{V_D = 0}$

Put $V_D = 0$ in equation (1).

$$I_D = I_S \left[e^{0/\eta V_T} - 1 \right]$$

$$I_D = I_S [1 - 1] = 0$$

So curve passes through origin as for $V_D = 0$, $I_D = 0$.

Case 2: Forward bias condition - $\boxed{V_D = +ve}$

Put V_D +ve in equation ①

$$I_D = I_S [e^{+V_D/\eta V_T} - 1]$$

But $e^{V_D/\eta V_T} >> 1$

Therefore equation reduces to $\boxed{I_D \approx I_S \, e^{(V_D/\eta V_T)}}$

Hence Forward Characteristics is of exponential nature (1st quadrant)

Case 3 : Reverse Bias Condition . $\boxed{V_D = -ve}$

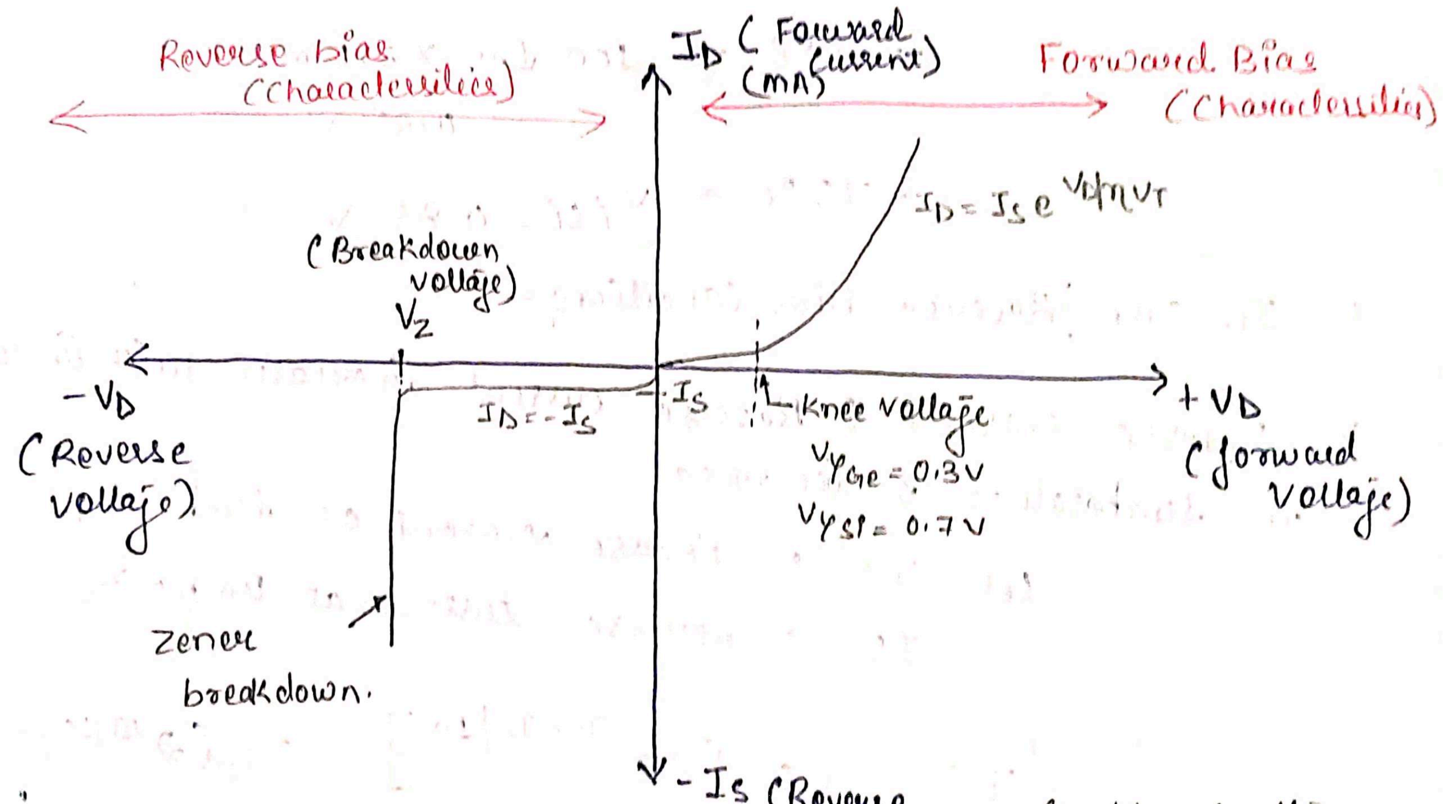
Put V_D -ve in equation ①

$$I_D = I_S [e^{-V_D/\eta V_T} - 1] = I_S \left[\frac{1}{e^{V_D/\eta V_T}} - 1\right]$$

But $\frac{1}{e^{V_D/\eta V_T}} << 1$

So equation reduces to $\boxed{I_D \simeq -I_S}$

Hence Reverse characteristics is represented by a straight line (3rd quadrant).



V-I Characteristics of Semiconductor Diode { Graph of voltage across diode vs the current flowing through it }

Is Si	: nA
Is Ge	: μA

V. Imp

~~Ques~~ Explain the effect of temperature on the V-I Characteristics of p-n junction diode [AKTU QUESTION]

The diode current $I_D = I_S\,[\,e^{V_D/\eta V_T} - 1\,]$

Two parameters I_S & V_T in the expression for diode current are temperature dependent.

Effect of temperature - ⓐ In case of forward biased region the characteristics of Si diode shift to the left at a rate of 2.5 mV/°C rise in temperature, & vice versa.

Let at 25°C $\rightarrow V_\gamma$ Si = 0.7 V.

125°C $\rightarrow$ 100 ↑es × 2.5 mV
= 0.25 V

125°C $\rightarrow V_\gamma$ Si = 0.25 V

-75°C $\rightarrow$ 100 ↓es × 2.5 mV
= 0.25 V

-75°C $\rightarrow V_\gamma$ Si = 0.85 V

ⓑ In case Reverse bias condition -

⇒ Reverse current : Reverse current increases with increase in temperature & vice versa.

Let I_{S_1} : Reverse current at temp. T_1
I_{S_2} : Reverse current at temp. T_2

$$\boxed{I_{S_2} = I_{S_1}\left[2^{T_2 - T_1/10}\right] = I_{S_1}\left(2^{\Delta T/10}\right)}$$

Generally reverse current doubles for every 10°C rise in temperature -

Let at 25°C → 10nA

125°C → 100 ↑es

$$I_{S_2} = I_{S_1}\, 2^{100/10}$$

$$= 10 \times 10^{-9} \times 2^{10}$$

$$= 10240\, nA$$

or 10.24 μA

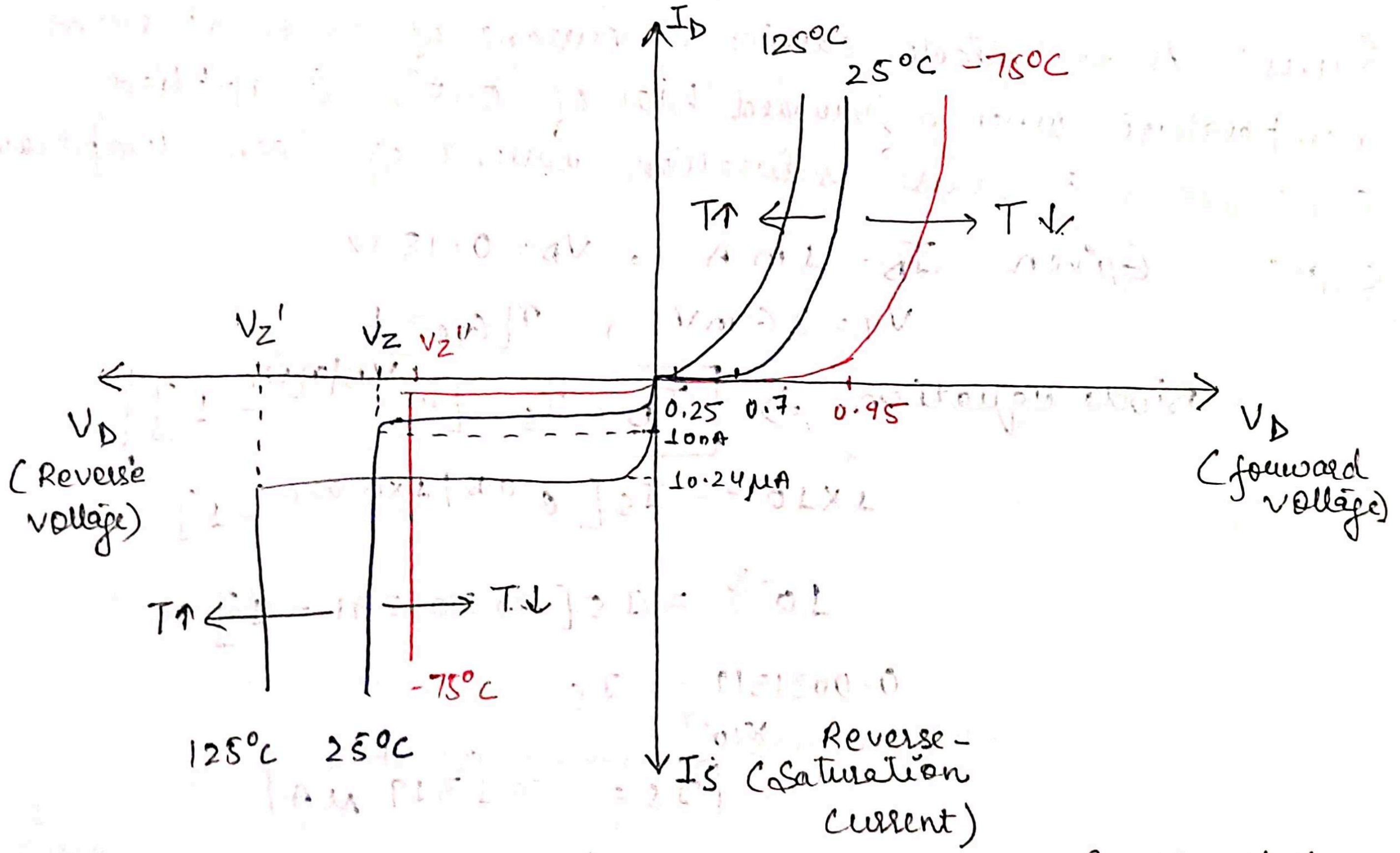
$-75°C$ → 100 ↓es

$$I_{S_2} = I_{S_1}\, 2^{-100/10}$$

$$= 10 \times 2^{-10}\, nA$$

$$= 0.00976\, nA$$

⇒ Breakdown Voltage (V_Z): Breakdown voltage increases with increase in temperature & vice versa.



NOTE: long Question on V-I characteristics of P-n junction diode. And explain effect of temperature on V-I characteristics.

Lecture-04

Question On diode equation

Ques^n: The reverse saturation current of Si P-n junction diode is 10 μA at 300 K. Determine the forward bias voltage to be applied to obtain diode current of 100 mA.

Sol^n: Given $I_S = 10\mu A$ $\quad \eta_{Si} = 2 \quad V_T = 26\,mVolt$

$I_D = 100\,mA$

Diode equation $\Rightarrow$ $\boxed{I_D = I_S\left[e^{V_D/\eta V_T} - 1\right]}$

$$100\times10^{-3} = 10\times10^{-6}\left[e^{V_D/2\times26\times10^{-3}} - 1\right]$$

$$10000 = e^{V_D/0.052} - 1$$

$$10001 = e^{V_D/0.052}$$

taking natural log (ln) on both sides.

$$\ln(10001) = V_D/0.052$$

$$9.210\times0.052 = V_D$$

$$\boxed{V_D = 0.4789\text{ volt}}$$

Ques: A Ge diode carries a current of 1 mA at room temperature when a forward bias of 0.15 V is applied. Estimate the reverse saturation current at room temperature.

Sol^n: Given $I_D = 1\,mA$, $V_D = 0.15\,V$

$V_T = 26\,mV$, $\eta_{Ge} = 1$

Diode equation $\Rightarrow$ $\boxed{I_D = I_S\left[e^{V_D/\eta V_T} - 1\right]}$

$$1\times10^{-3} = I_S\left[e^{0.15/1\times0.026} - 1\right]$$

$$10^{-3} = I_S[320.291 - 1]$$

$$0.0031319\times10^{-3} = I_S$$

$$\boxed{I_S = 3.1319\,\mu A}$$

Ques^n A Si diode has a saturation current of 5 nA at 25°C what is the saturation current at 100°C.

Solⁿ: Reverse saturation current equation

Given: $I_{S_1} = 5nA$
$T_1 = 25°C$
$T_2 = 100°C$

$$I_{S_2} = I_{S_1}\left[2^{T_2 - T_1/10}\right]$$

$$I_{S_2} = 5\times10^{-9}\left[2^{100-25/10}\right]$$

$$I_{S_2} = 5\times10^{-9}\left[2^{75/10}\right]$$

$$I_{S_2} = 2^{7.5}\times5\times10^{-9}$$

$$\boxed{I_{S_2} = 905.0966\ nA}$$

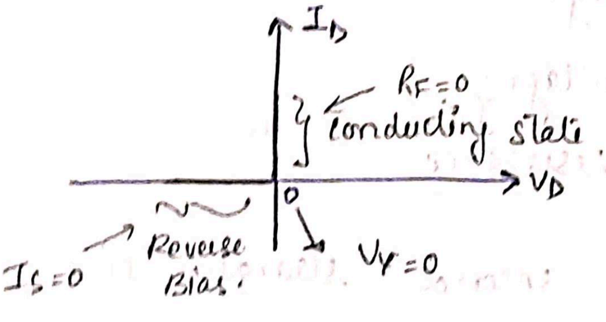
Ques: Explain all the equivalent/approximation circuits of a diode. [AKTU QUESTION]

Diode is a non linear device because its input/output characteristics is nonlinear. The analysis of a nonlinear circuit is not a straight forward as the analysis of a linear circuit.

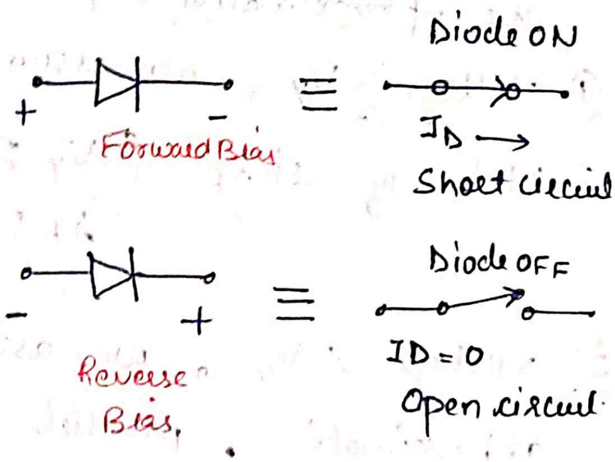
Equivalent linear Equivalent circuits –

1. An Ideal diode (First Approximation):

V-I Characteristics



Equivalent circuits



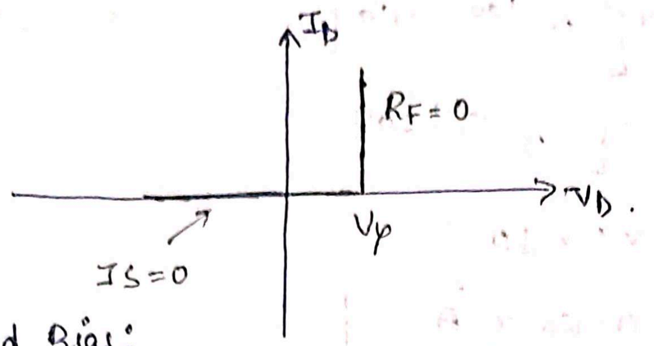
Ideal diode can be used as a perfect switch.

If the diode is Forward bias it acts as close switch, $R_F = 0$ (forward resistance = 0), $V_F = 0$.

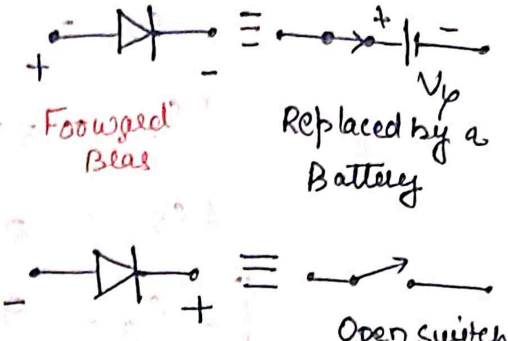
For Reverse bias, diode acts as open switch, $I_S = 0$ reverse current is zero as diode resistance is infinite.

2. Simplified equivalent Circuit – [Second Approximation]

V-I Characteristics



Equivalent Circuits



Forward Bias:

Since diode forward resistance is low. so it can be neglected i.e $R_F = 0$. Diode is replaced by battery (V_γ : cut off voltage of diode).

Reverse Bias : Acts as a open switch. ($I_S = 0$)

3. Piecewise linear Equivalent circuits :- In this circuit diode non-linear characteristics is replaced by a straight line.

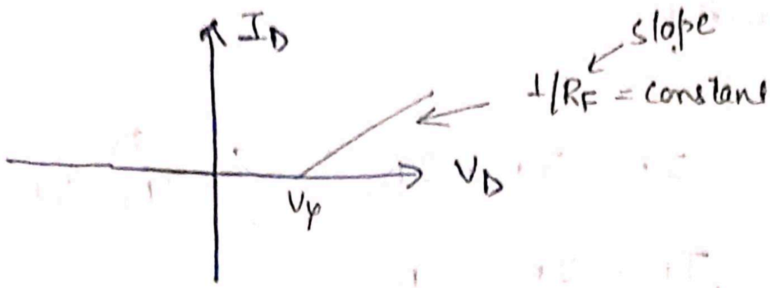
Two Approximation – [Forward Bias]

① voltage $\geq V_\gamma$, we assume a straight vertical line with a slope of $1/r_F$. { V_γ : cut off voltage}
r_F : forward resistance.

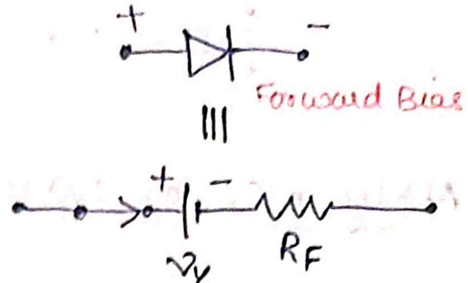
② voltage $< V_\gamma$, we assume the second straight line approximation, parallel to the V_D (X axis) at zero current level.

Reverse Bias : Acts as a open switch ($I_S = 0$)

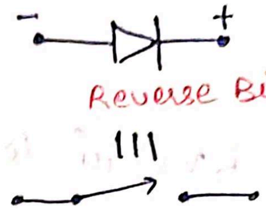
V-I Characteristics



Equivalent Circuit



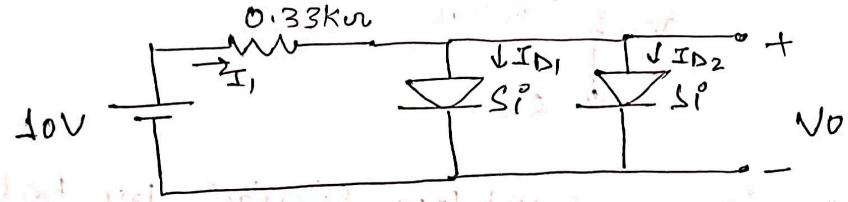
replaced by battery of V_γ & resistance (R_F).



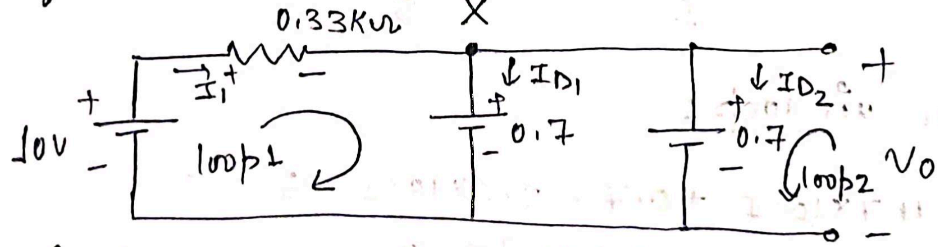
Open switch.

Lecture - 05 Problems based on series & parallel circuit of diode

Ques^n 1 Determine V_o, I_1, I_{D1} & I_{D2} for the parallel diode configuration shown in figure below.



Soln: When Si diode is forward bias then it is replaced by a short circuit or a battery of 0.7 V (knee voltage of Si).
Here Both the Si diodes are forward bias so replaced by a battery of 0.7V



Apply KVL in loop 1 :-

$$-10 + 0.33\times10^{3} I_1 + 0.7 = 0$$
$$0.33\times10^{3} I_1 = 9.3$$

$$I_1 = \frac{9.3}{0.33 \times 10^{-3}}$$

$$\boxed{I_1 = 28.181\, mA}$$

Apply KCL at Node X $\quad I_1 = I_{D_1} + I_{D_2} \quad \{ \text{as } I_{D_1} = I_{D_2} \}$

$$\frac{I_1}{2} = I_{D_1} = I_{D_2}$$

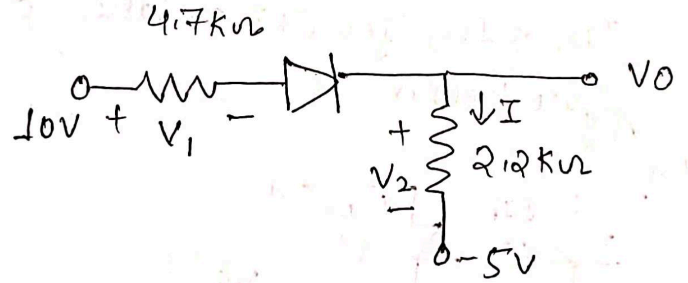
$$\boxed{I_{D_1} = I_{D_2} = \frac{28.181}{2} = 14.09\, mA}$$

Apply KVL in loop 2 -

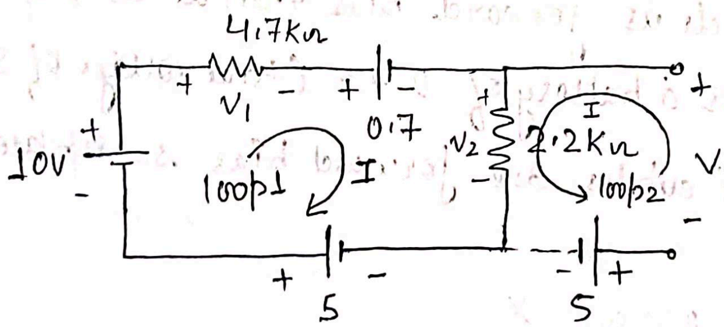
$$-V_O + 0.7 = 0$$

$$\boxed{V_O = 0.7\, V}$$

Ques Determine I, V_1, V_2 & V_O for the following circuit.



Redraw the circuit, and replace Si diode by battery of 0.7V



Apply KVL in loop 1 -

$$-10 + 4.7 \times 10^3 I + 0.7 + 2.2 \times 10^3 I - 5 = 0$$

$$-14.3 + 6.9 \times 10^3 I = 0$$

$$I = 14.3 / 6.9 \times 10^3 = 2.0724 \times 10^{-3}$$

$$\boxed{I = 2.0724\, mA}$$

$V_1 = 4.7 \times 10^3 \times 2.0724 \times 10^{-3}$ $[V = IR]$

$\boxed{V_1 = 9.73\,V}$

$V_2 = 2.2 \times 10^3 \times 2.0724 \times 10^{-3}$

$\boxed{V_2 = 4.55\,V}$

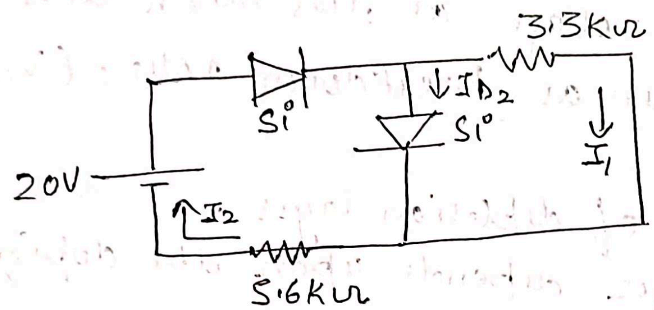
Apply KVL in loop 2 -

$-V_o + 2.2 \times 10^3 \times 2.0724 \times 10^{-3} - 5 = 0$

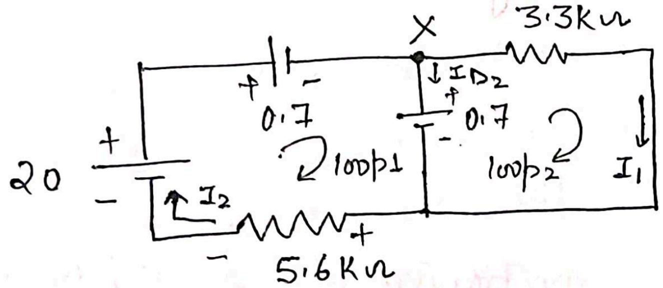
$V_o = 4.55 - 5$

$\boxed{V_o = -0.45\,V}$ {-ve sign show that Vo polarity is different from applied one.}

Ques Determine I_1, I_2 & I_{D_2} for the following circuit -



Both the diodes are forward bias, so replaced by battery of 0.7 V



Apply KVL in loop 1

$-20 + 0.7 + 0.7 + 5.6 \times 10^3 (I_2) = 0$

$5.6 \times 10^3 (I_2) = 18.6$

$I_2 = \frac{18.6}{5.6 \times 10^3}$ $\boxed{I_2 = 3.321\,mA}$

Apply KVL in loop 2

$-0.7 + 3.3 \times 10^3 I_1 = 0$ $I_1 = 0.7 / 3.3 \times 10^3$

$\boxed{I_1 = 0.212\,mA}$

Apply KCL at Node X

$$I_2 = I_{D1} + I_1$$

$$I_{D1} = I_2 - I_1$$

$$= (3.32 - 0.212) \times 10^{-3}$$

$$\boxed{I_{D1} = 3.102 \text{ mA}}$$

Lecture - 06 Breakdown Mechanism

Breakdown mechanism occur in reverse biased diode. If applied reverse voltage is continously increased a condition come at which current increases at a very rapid rate. The maximum reverse voltage at ~~this~~ which this condition is achieved is known as breakdown voltage (V_Z).

→ It depends on width of depletion layer.
→ Width of depletion layer depends upon the doping level.

The following two process cause junction breakdown due to increase in reverse bias voltage.

(a) Zener Breakdown

(b) Avalanche Breakdown.

Ques Describe Breakdown mechanism of diode [AKTU QUESTION]

If the reverse bias applied to p-n junction is increased a point will reach when the junction breakdown & reverse current rises sharply. This specific value of the reverse bias voltage is called breakdown voltage (V_Z).

The following two process (zener & Avalanche) causes junction breakdown.

(i) Zener Breakdown :- It occur in highly doped diode. Due to heavy doping of p & n side of diode, the depletion region is narrow in the reverse biased condition. As all the reverse voltage 'V' appears across the depletion region. Therefore Electric field is very intense across the depletion region [Causes High Electric field in depletion region]:

This High electric field can pull some of the valence electron into conduction band by breaking covalent bonds. These electrons then becomes free e^-. & will constitute a large reverse current. This is called Zener breakdown.

Zener breakdown occurs for voltage less than 6V.
Temperature coefficient for zener breakdown is negative (means raising in temperature will cause smaller breakdown voltage).

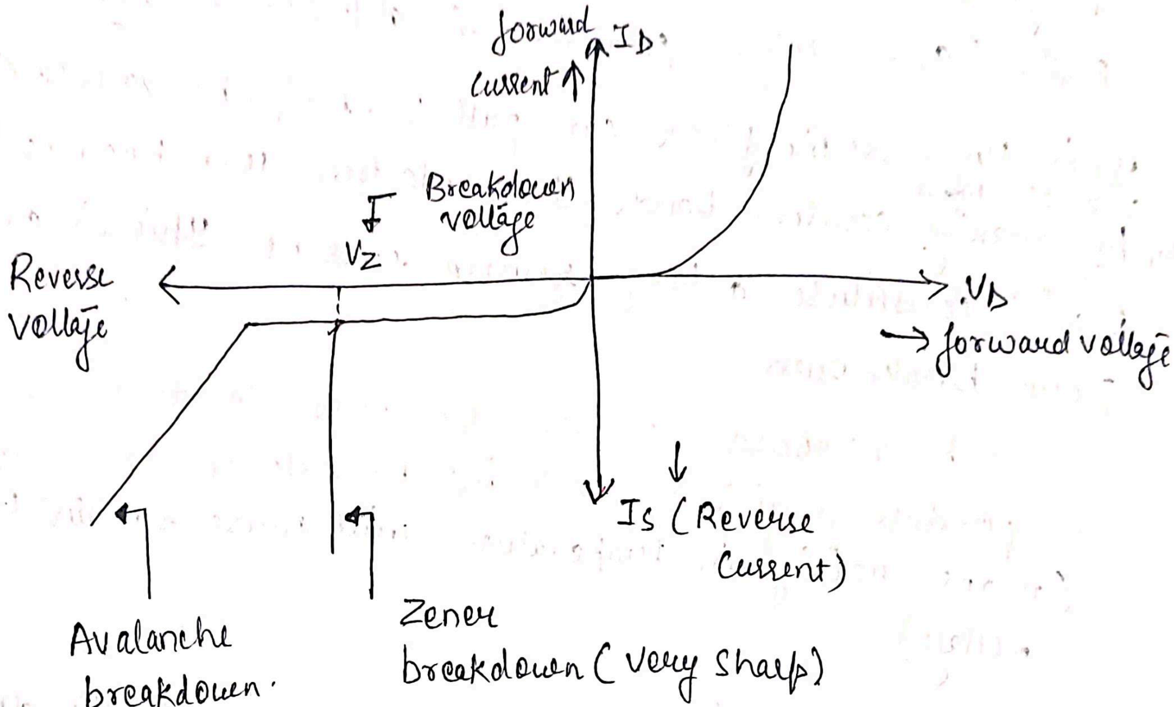
(ii) Avalanche Breakdown - It occur in lightly doped diode. In this width of depletion region is wide. So electric field & force is low. Therefore can't break covalent bond.

But as the reverse bias voltage is increased (large), the kinetic energy of minority carriers increase. While travelling these minority carriers will collide with the stationary atoms & present in depletion layer & impart some of the kinetic energy to the valence e^-. These valence e^- will break their covalent band and jump into conduction band to become free e^-.

Now these newly generated free electrons get accelerated. They will knock some more valence e^- by means of collision. This phenomenon is called as Carrier Multiplication or Avalanche breakdown.

Avalanche break down occur at voltage greater than 6 Volt
Temperature coefficient is positive (Raising the temperature will cause larger breakdown voltage).

V – I Characteristics –



Ques Differentiate between Avalanche & Zener breakdown

Zener Breakdown	Avalanche Breakdown
1. Occur in highly doped diode	1. Occur in lighly doped diode.
2. Due to very high Electric field, valence e⁻ are pulled into Conduction Band.	2. Valence e⁻ are pushed into Conduction Band due to energy imparted by Collision of accelerated minority carriers.
3. Tunneling effect occur.	3. Ionization effect occur.
4. Occurs less than 6V.	4. occur greater than 6V.
5. V-I characteristics is very sharp.	5. V-I characteristics is not as sharp as zener diode.
6. Covalent band breaks directly	6. Covalent bonds breaks indirectly.
7. Temperature coefficient is negative.	7. Temperature coefficient is positive.

APPLICATION of P-N Junction Diode

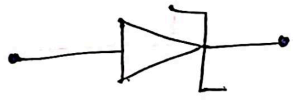
Some applications of p-n junction diode are as follows -

1. Rectifier circuits.
2. Clipping & clamping circuits.
3. voltage multipliers.
4. Log & antilog amplifiers using OPAMP.

ZENER DIODE :

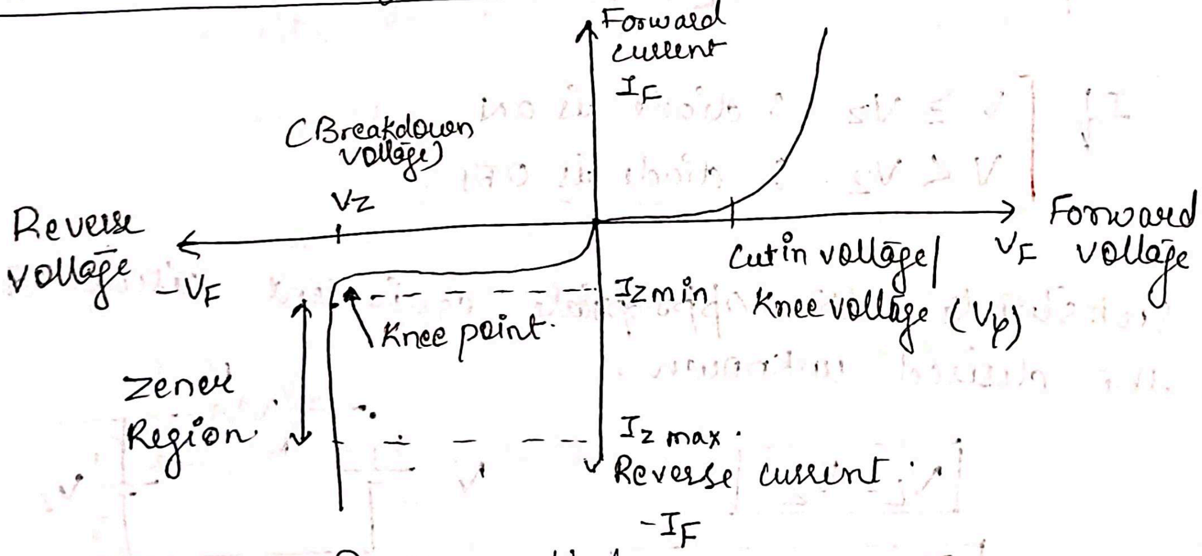
Zener diode is a type of diode that allow current to flow not only from its anode to its cathode, but also in the reverse direction, when the Zener voltage is reached.

Zener diode is a special type of p-n junction semiconductor diode which is used in Breakdown region. It is used for voltage regulation.

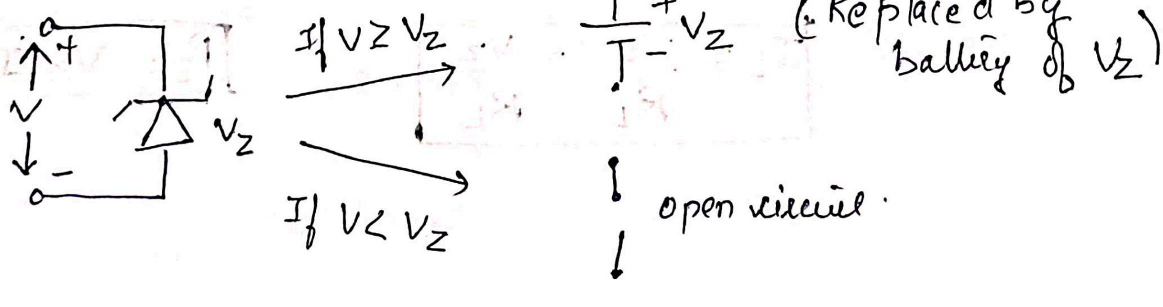


Symbol.

V-I characteristic of a Zener diode -



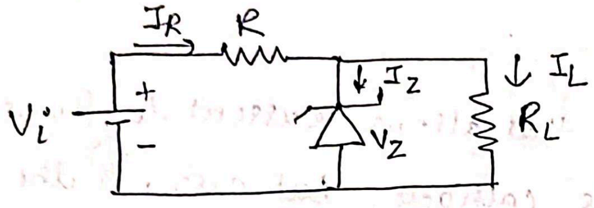
Equivalent circuit of Zener diode -



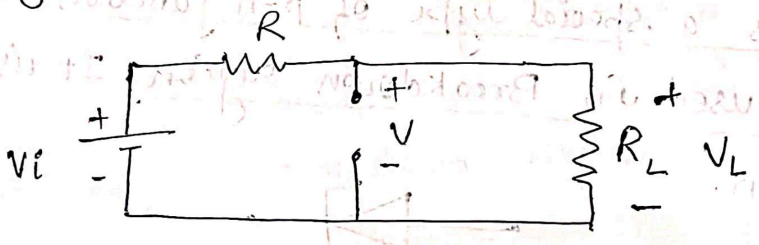
Zener diode as a Shunt voltage Regulator :

Voltage Regulator : A voltage regulator is a combination of elements designed to ensure that the output voltage of a supply remain constant.

(I) Fixed V_i & Fixed R_L :-



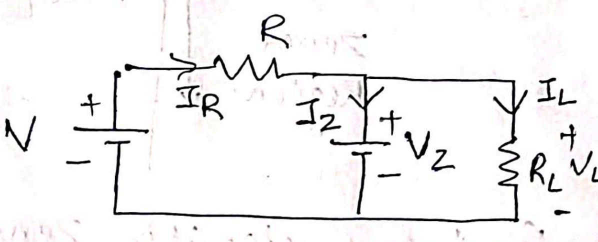
Determine the state of zener diode by removing it from the circuit & find the voltage across the open circuit.



$$\boxed{V = V_L = \frac{V_i R_L}{R + R_L}}$$ using voltage division law.

If $\boxed{\begin{array}{ll} V \geq V_Z & : \text{diode is ON} \\ V < V_Z & : \text{diode is OFF} \end{array}}$

Then substitute the appropriate equivalent circuit & solve for the desired unknown.



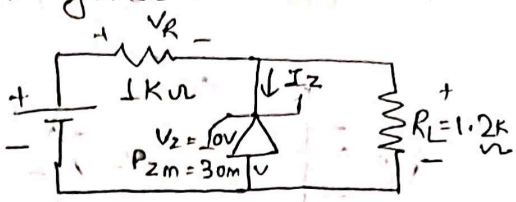
$$\boxed{V_L = V_Z}$$

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

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

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

Example: For the zener diode network. Find
(a) V_L, V_R, I_Z & P_Z
(b) Repeat part (a) with $R_L = 3\,k\Omega$



Given: $V_i = 16V$ $\quad R_L = 1.2 \times 10^3$ $\quad P_{zmax} = 30mW$
$R = 10^3 \Omega$ $\quad V_Z = 10V$

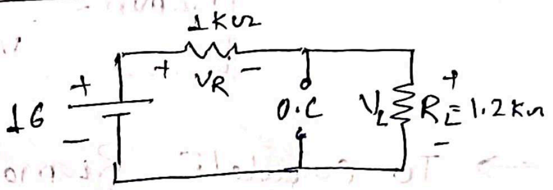
(a) First check whether diode is ON or OFF.

$$V = V_L = \frac{V_i R_L}{R_L + R} = \frac{16 \times 1.2 \times 10^3}{1.2 \times 10^3 + 10^3} = \frac{19.2}{2.2} = 8.72V$$

Given $V_Z = 10V$

$$\boxed{\begin{array}{ll} \text{If So } V \geq V_Z & \text{: Diode is ON} \\ V < V_Z & \text{: Diode is OFF.} \end{array}}$$

Here $\boxed{V = 8.72 < V_Z = 10 \text{ : Diode is OFF}}$



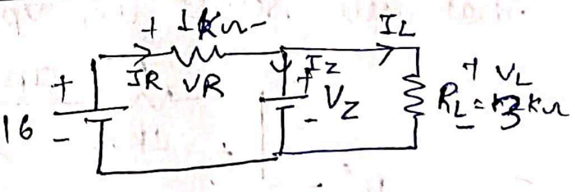
$V_R = V_i - V_L$
$= 16 - 8.72$
$\boxed{V_R = 7.27\,V}$

$\boxed{I_Z = 0}$ $\quad \boxed{P_Z = V_Z \times I_Z = 0\,W}$

(b) Check whether diode is ON or OFF with $R_L = 3k\Omega$

$$V = V_L = \frac{V_i R_L}{R + R_L} = \frac{16 \times 3 \times 10^3}{1 \times 10^3 + 3 \times 10^3} = 12\,V$$

Here $\boxed{V = 12V > V_Z = 10V \text{ : Diode is ON}}$



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

$V_R = V_i - V = 16 - 10 = 6V$

$\boxed{I_R = I_Z + I_L}$ $\quad \boxed{I_L = \frac{V_L}{R_L}} = \frac{10}{3 \times 10^3} = 3.33mA$

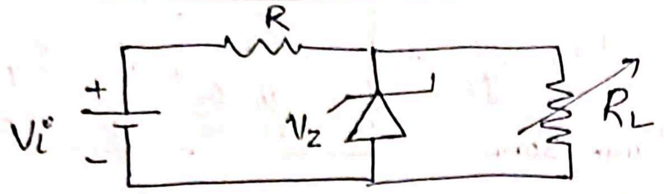
$I_Z = I_R - I_L$ $\quad \boxed{I_R = \frac{V_R}{R}} = \frac{6}{10^3} = 6mA$

$= 6 - 3.33 = 2.67mA$

$I_Z = 2.67mA$

$\boxed{P_Z = V_Z I_Z} = (10)(2.67 \times 10^{-3}) = 26.7\,mW$

II Fixed V_i & Variable R_L :-



We have to determine range of R_L -

→ To determine R_L min that will turn the Zener diode ON we put $\boxed{V_L = V_Z}$

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

$$\boxed{R_{L\,min} = \frac{R V_Z}{V_i - V_Z}} , \quad \boxed{I_{L\,max} = \frac{V_Z}{R_{L\,min}}}$$

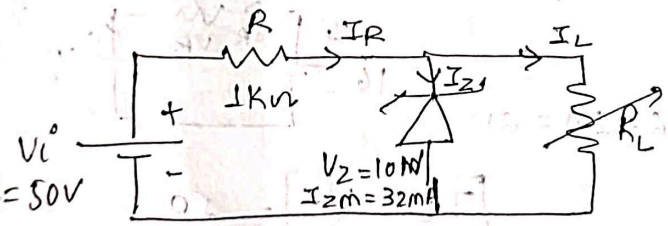
→ To calculate R_L max we have to calculate I_L min

$$\boxed{I_{L\,min} = I_R - I_{Z\,max}}$$

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

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

Ques^n: In the following figure determine the range of R_L & I_L that will result in V_{RL} being maintained at 10V.



Given: $V_i = 50V$
$R = 10^3 \Omega$
$V_Z = 10$
$I_{Z\,max} = 32mA$

for R_L min :

$$\boxed{V_L = V_Z = \frac{R_L V_i}{R + R_L}} = \frac{50 \times R_{L\,min}}{10^3 + R_{L\,min}} = 10$$

$$R_{L\,min} = \frac{10^3 \times 10}{50 - 10} = \frac{10 \times 10^3}{40} = 250\Omega$$

$$\boxed{I_{L\,max} = \frac{V_Z}{R_{L\,min}}} = \frac{10}{250} = 0.04 \text{ or } 40mA$$

$$\boxed{V_R = V_i - V_Z} = 50 - 10 = 40V$$

$$\boxed{I_R = \frac{V_R}{R}} = \frac{40}{1 \times 10^3} = 40mA$$

for R_{Lmax} :

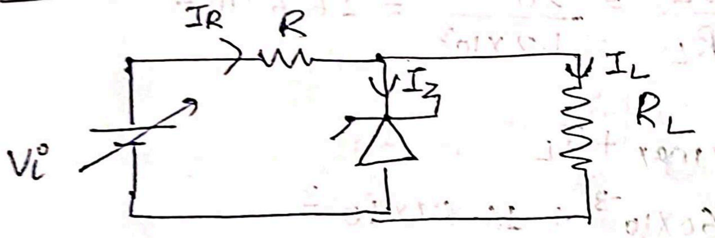
$$I_{Lmin} = I_R - I_{Zmax}$$ (Given $I_{Zmax} = 32mA$)

$$= (40 - 32) \times 10^{-3}$$

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

$$\boxed{R_{Lmax} = \frac{V_Z}{I_{Lmin}}} = \frac{10}{8 \times 10^{-3}} = 1.25 K\Omega$$

III Variable V_i & fixed R_L :



We have to determine range of V_i :-

The minimum voltage V_i that will turn ON the diode is calculated as -

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

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

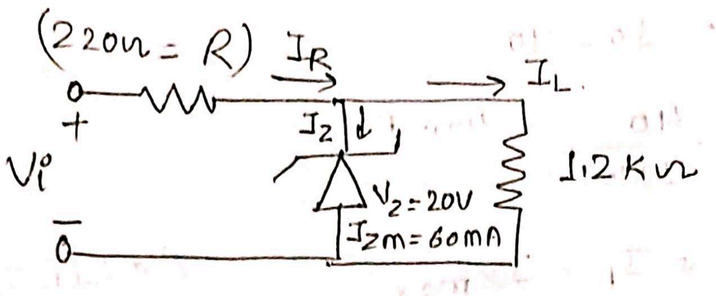
The maximum voltage V_{imax} is calculated as -

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

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

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

Ques^n find the range of values of V_i that will maintain the zener diode in ON state.



Given $R = 220$
$R_L = 1.2 \times 10^3$
$V_Z = 20V$
$I_{Zmax} = 60mA$

$$V_L = V_Z = \frac{R_L \cdot V_i}{R_L + R}$$

$$V_{i\,min} = \frac{(R_L + R)\, V_Z}{R_L} = \frac{(1.2 \times 10^3 + 220) \times 20}{1200}$$

$$\boxed{V_{i\,min} = 23.66\ V}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_Z}{R_L} = \frac{20}{1.2 \times 10^3} = 16.67mA$$

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

$$= 60 \times 10^{-3} + 16.67 \times 10^{-3}$$

$$\boxed{I_{R\,max} = 76.67\ mA}$$

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

$$= (76.67 \times 10^{-3}) \times 0.22 \times 10^3 + 20$$

$$\boxed{V_{i\,max} = 36.8674\ V}$$

Lecture-08 Rectifier -

A rectifier is a device that converts alternating voltage (current) to pulsating direct voltage (current) or Bipolar signal to unipolar signal.

Rectifiers are of two types :-

(a) Half Wave rectifier - a rectifier circuit that delivers power to load during only one half cycle of ac supply voltage.

OR

A type of rectifier that only allow half wave voltage to produce a unidirectional load current.

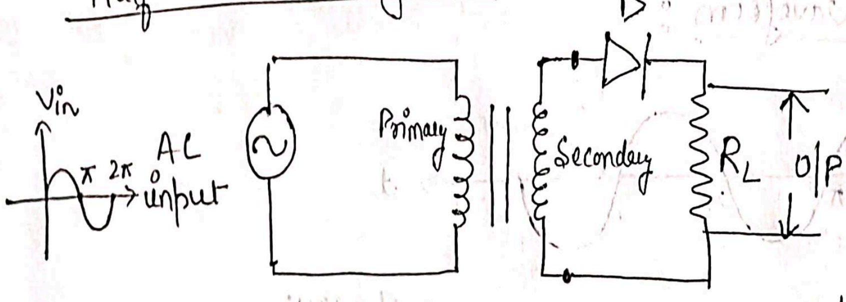
(b) Full wave rectifier - circuit which rectify both positive & negative half cycles of an input alternating waveform.

It can be further classify into two category:-
- centre tapped full wave rectifier
- full wave bridge rectifier.

V.Imp.

Ques: Draw & explain the working of half wave rectifier with input & output waveform. Also drive the expression for rectification efficiency. [AKTU QUESTION].

Half Wave rectifier -

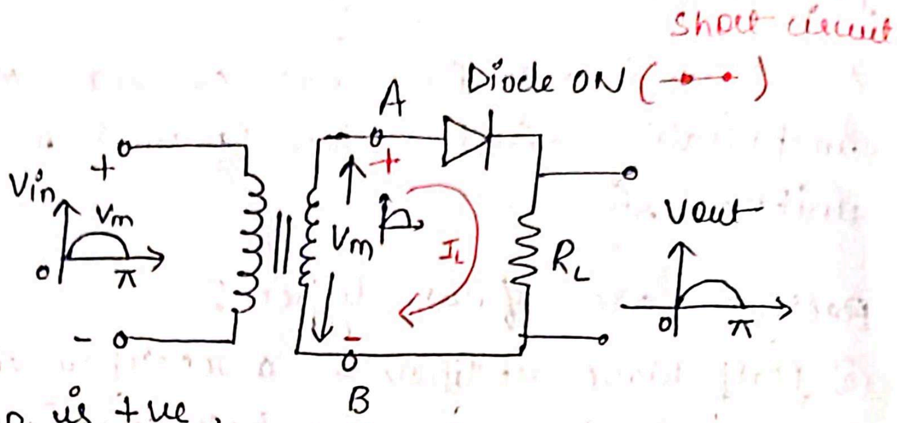


A half wave rectifier consists of a step down transformer, diode & load resistance. Input is applied across primary winding of transformer & output is taken out from load resistance R_L.

Working :-

Positive half cycle :

$(0 - \pi)$ of ac supply ;



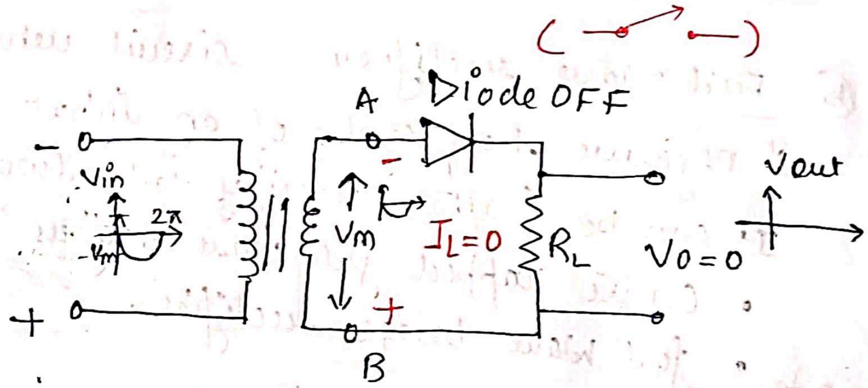
The secondary voltage V_{AB} is +ve ,

A → +ve B → -ve

makes diode forward bias , so diode acts as short circuit and current flows through R_L & a voltage is developed across it .

Negative half cycle :

$(\pi - 2\pi)$ of ac supply :

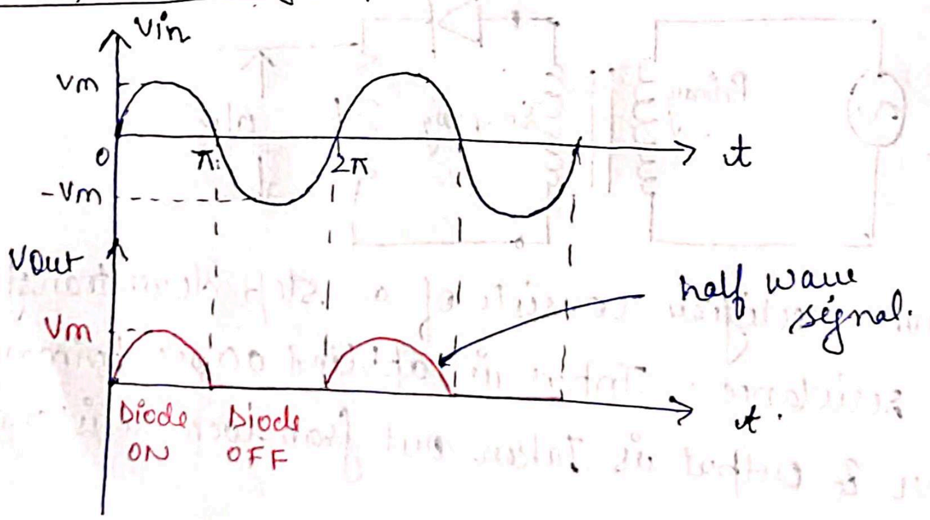


The secondary voltage V_{AB} is -ve

A → -ve B → +ve

makes diode reverse bias , so diode acts as open circuit & no current flows through R_L . Hence output voltage is zero

Input - Output waveform :



Expression for rectification efficiency or Power conversion efficiency for half wave rectifier -

Rectification efficiency is defined as the ratio of dc output power & ac input power.

$$\eta = \frac{\text{dc output power}}{\text{ac input power}} = \frac{P_o(dc)}{P_i(ac)} \quad \text{---} (1)$$

now, $P_o(dc) = I^2_{dc} \times R_L$

$P_i(ac) = I^2_{rms} \times (R_L + r_f)$ --- (2)

where R_L: load resistance

r_f: diode resistance

* Remember it:

for HWR:

$I_{dc} = I_m / \pi$

$I_{rms} = I_m / 2$ --- (3)

Put value of Idc & Irms in eq^n (2)

$$P_o(dc) = \left(\frac{I_m}{\pi}\right)^2 \times R_L \qquad P_i(ac) = \left(\frac{I_m}{2}\right)^2 (R_L + r_f)$$

Put values in eq^n (1)

$$\frac{P_o(dc)}{P_i(ac)} = \frac{\cancel{I_m^2} / \pi^2 \times R_L}{\cancel{I_m^2} / 4 \times (R_L + r_f)}$$

$$\boxed{\eta = \frac{4 \times R_L}{\pi^2 (R_L + r_f)}}$$

$\boxed{\text{if } r_f = 0}$ $\rightarrow$ $\eta_{max} = \frac{4 \cancel{R_L}}{\pi^2 (\cancel{R_L})} = \frac{4}{\pi^2}$

$\eta_{max} = 0.4052$

$\boxed{\eta_{max}\% = 40.6\%}$

{ so, efficiency of half wave rectifier is low. }

Expression for Ripple factor for Half wave Rectifier ?

Ripple factor: defined as the ratio of rms value of ac component to dc component.

The output of rectifier has ac component (ripple) & dc component both. Ripple factor measure, how much amount of ac component is present in the output.

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

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

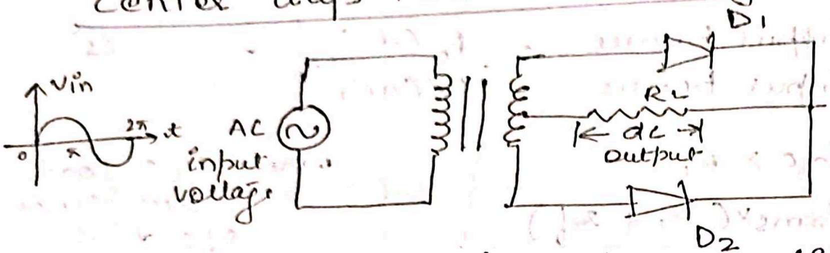
$$= \sqrt{\frac{(I_m/\pi)^2 - 1}{(I_m/2)^2 - 1}} \qquad \left[\begin{array}{l} I_{dc} = I_m/\pi \\ I_{rms} = I_m/2 \end{array}\right]$$

$$\gamma = \sqrt{(\pi/2)^2 - 1} = 1.21 \qquad \boxed{\gamma = 1.21}$$

So ripple factor of half wave rectifier is very high.

Ques Draw & explain the working principle of center tap full wave rectifier with input & output waveform. Also derive the expression for rectification efficiency. [AKTU QUESTION]

Center tap Full Wave Rectifier

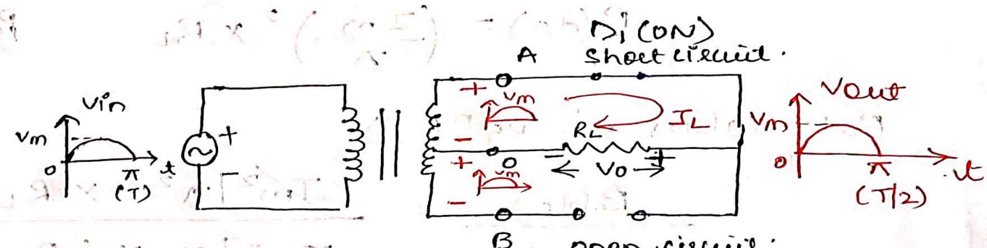


Centre tapped rectifier have a centre tapped step down transformer, two diodes D_1, D_2 & load resistance R_L. In centre-tapped transformer secondary winding is divided in two equal half.

Working

Positive half cycle :

(0 - π) of ac supply



The secondary voltage AO is +ve
voltage BO is -ve

V_{AO} +ve [A → +ve , O → -ve]

V_{BO} -ve [O → +ve , B → -ve]

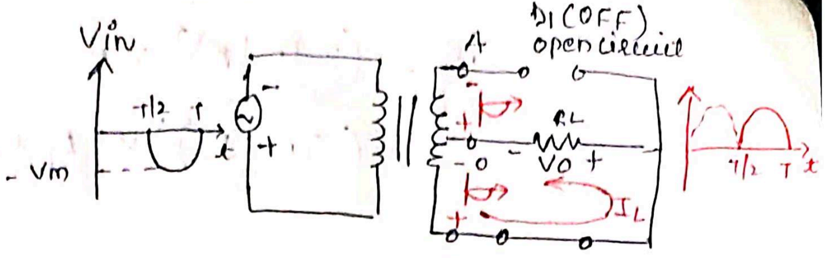
Diode D_1 is forward bias, acts as short circuit (ON) whereas

Diode D_2 is reverse bias, acts as open circuit (OFF)

so, current flows through the upper half of secondary winding.

Negative half Cycle -

($\pi - 2\pi$) of ac supply.



The secondary voltage AO → -ve
voltage BO → +ve

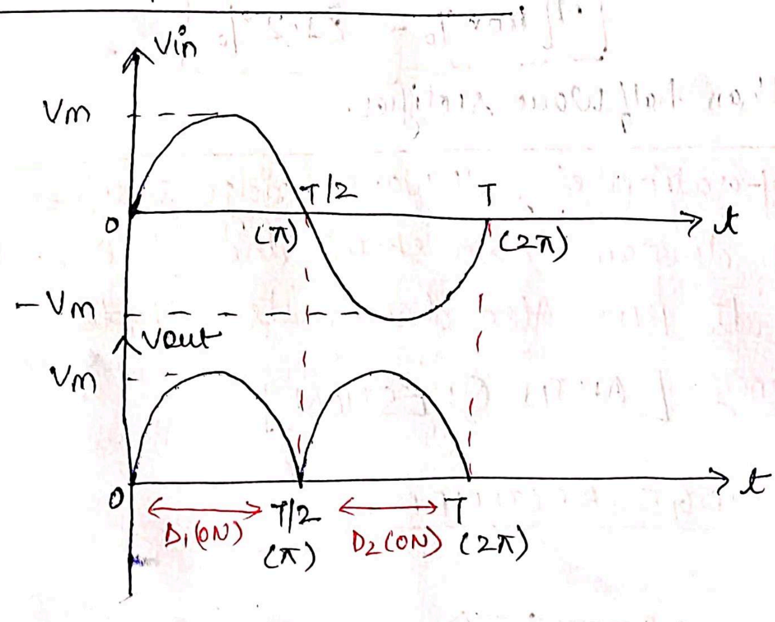
V_{AO} -ve [A → -ve , O → +ve]

V_{BO} +ve [B → +ve , O → -ve]

Diode D_1 is reverse bias, acts as open circuit (OFF) whereas
Diode D_2 is forward bias, acts as close circuit (ON)

so, current flows through the lower half of Secondary winding.

Input - Output waveform -



Expression for rectification efficiency -

$$\boxed{\eta = \frac{\text{dc output Power}}{\text{ac } \cancel{\text{output}} \text{ input Power}} = \frac{P_o(dc)}{P_i(ac)}} \quad ---- ①$$

now, $\boxed{\begin{aligned} P_o(dc) &= I_{dc}^2 \times R_L \\ P_i(ac) &= I_{rms}^2 \times (R_L + r_f) \end{aligned}}$ --- ②

for FWR

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

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

$$\eta = \frac{(2I_m/\pi)^2 \times R_L}{(I_m/\sqrt{2})^2 \times (R_L + r_f)}$$ Put eqⁿ(3), (2) in (1)

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

$$\boxed{\eta = \frac{8}{\pi^2}\frac{(R_L)}{(R_L + r_f)}}$$

if $r_f = 0$, $\eta_{max} = \frac{8}{\pi^2}\frac{\cancel{R_L}}{\cancel{R_L}}$

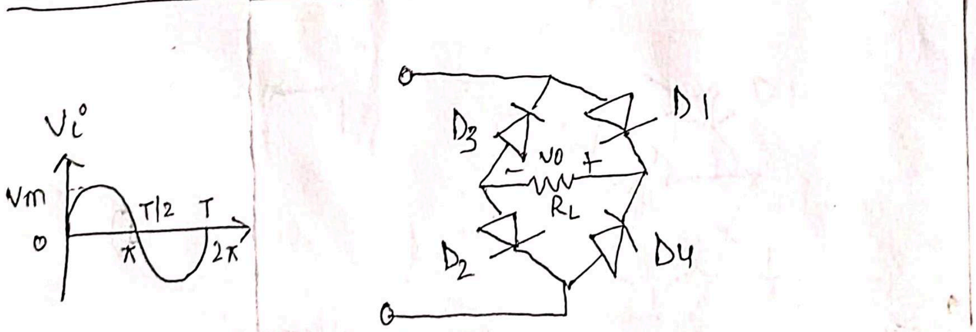
$$\eta_{max} = 8/\pi^2 = 0.812$$

$$\boxed{\eta_{max}\% = 81.2\%}$$

Efficiency is more than half wave rectifier.

V.Imp
~~Ques~~- Explain the operation of full wave bridge rectifier with the help of a circuit diagram. Also sketch the input & output waveforms. Define its PIV. Also derive its ripple factor & rectification efficiency. [AKTU QUESTION].

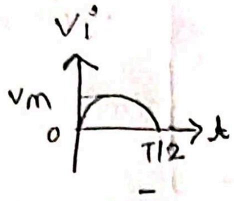
FULL WAVE BRIDGE RECTIFIER -

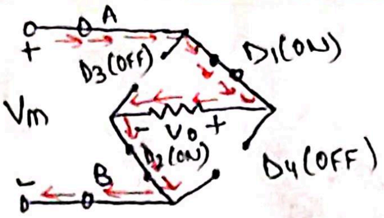


Bridge rectifier consists of 4 diode (D_1, D_2, D_3, D_4) & load resistance R_L, step down transformer.

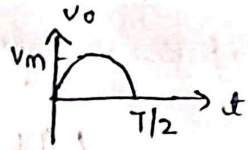
Working -

Positive Cycle :-
(0 - π)



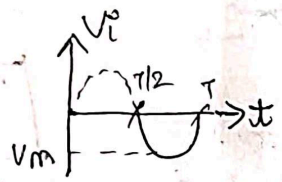


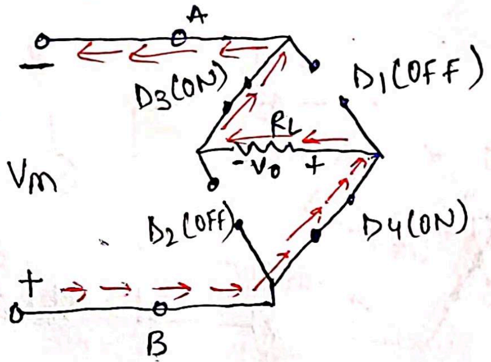
B

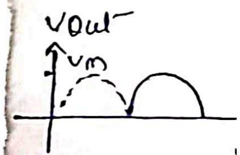


In +ve cycle : V_{AB} is +ve (A → +ve , B → -ve)
So diode D_1, D_2 are forward bias , so acts as short circuit (ON)
& diode D_3, D_4 are reverse bias, acts as open circuit (OFF)
Current flows through D_1, D_2 and give the output across load resistance.

Negative Cycle :-
(π - 2π)

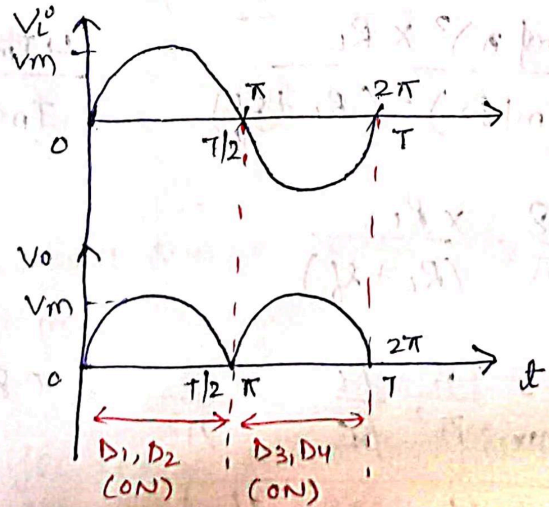






In -ve cycle : V_{AB} is -ve (A → -ve, B → +ve)
So diode D_1, D_2 are reverse bias, acts as open circuit (OFF) &
diode D_3, D_4 are forward bias, acts as short circuit (ON).
Current flows through D_3, D_4 & give the output across load resistance R_L.

Input - Output Waveform -



PIV: (Peak Inverse voltage):- It is maximum reverse voltage that can be applied across a diode without damaging it.

for Bridge rectifier $(PIV = V_m)$

Expression for ripple factor for centre tapped or bridge rectifier -

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

(Ratio of rms value of ac component to dc component).

Remember

For bridge Rectifier

$$\left[\begin{array}{l} I_{rms} = I_m/\sqrt{2} \\ I_{dc} = 2I_m/\pi \end{array}\right]$$

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

$$\gamma = \sqrt{\frac{\cancel{I_m^2}/2}{4\cancel{I_m^2}/\pi^2} - 1}$$

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

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

The output of rectifier has ac component (ripple) & dc component both. Ripple factor measure, how much amount of ac component is present in the output.

Expression for rectification efficiency for bridge Rectifier -

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

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

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

$$\eta = \frac{8}{\pi^2} \frac{\times R_L}{(R_L + r_f)}$$

$\boxed{\text{if } r_f = 0}$

$$\eta_{max} = \frac{8}{\pi^2} \frac{\cancel{R_L}}{\cancel{R_L}} = \frac{8}{\pi^2} = 0.812$$

$$\boxed{\eta_{max}\% = 81.2\%}$$

Compare Half Wave & Full wave rectifier

Parameters	Half Wave rectifier	Full wave: Centre tapped	Full wave: Bridge Rectifier
1. No. of diodes	1	2	4
2. Operation	Conducts during +ve cycle (half)	Conducts during both half cycles.	Conducts during both half cycles.
3. V_{dc}	V_m/π	$2V_m/\pi$	$2V_m/\pi$
Imp 4. I_{dc}	I_m/π	$2I_m/\pi$	$2I_m/\pi$
5. V_{rms}	$V_m/2$	$V_m/\sqrt{2}$	$V_m/\sqrt{2}$
Imp 6. I_{rms}	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
Imp 7. Efficiency	40.6%	81.2%	81.2%
Imp 8. PIV	V_m	$2V_m$	V_m
Imp 9. Ripple factor	1.21	0.48	0.48
10. Ripple frequency	$f_r = f_i$	$f_r = 2f_i$	$f_r = 2f_i$

Ques^n: What is PIV. Write the value of PIV for half wave & full wave rectifiers.

PIV: It the maximum reverse voltage that can be applied across a diode without damaging it.

for half wave rectifier, $PIV = V_m$
for centre tapped rectifier, $PIV = 2V_m$
for Bridge rectifier, $PIV = V_m$

Ques What is ripple frequency. Write the value of for half wave & full wave rectifiers.

Ripple frequency : It the frequency of output wave in a rectifier. It is also called output frequency.

for half wave rectifier $f_r = f_i$

for center tapped rectifier $f_r = 2f_i$

for Bridge rectifier $f_r = 2f_i$

Lecture - 09 – Different Parameters of Rectifiers

HALF WAVE RECTIFIER

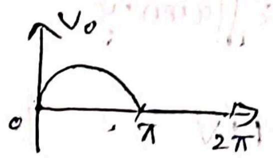
(i) DC or Average output (load) current I_{dc}: Let $\boxed{V = V_m \sin\theta}$

'V' voltage across secondary winding

$$I = \frac{V_m}{R_L + r_f} \sin\theta = I_m \sin\theta$$

$\left\{ \begin{array}{l} I_m = V_m/(R_L + r_f) \\ R_L : \text{load resistance} \\ r_f : \text{diode resistance} \end{array} \right\}$

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



$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\theta \, d\theta + \cancel{\int_{\pi}^{2\pi} I_m \sin\theta \, d\theta}^{\,0}\right]$$

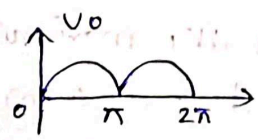
$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\theta \, d\theta\right] = \frac{1}{2\pi}\left[-I_m \cos\theta\right]_0^{\pi}$$

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

$$I_{dc} = -\frac{I_m}{2\pi}\left[-1 - 1\right] = I_m/\pi$$

$$\boxed{I_{dc} = I_m/\pi}$$

FULL WAVE RECTIFIER



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

$$= \frac{1}{\pi}(I_m)\left[\int_0^{\pi} \sin\theta \, d\theta\right] = \frac{I_m}{\pi}\left[-\cos\theta\right]_0^{\pi} = -\frac{I_m}{\pi}\left[\cos\pi - \cos 0\right] = \frac{2I_m}{\pi}$$

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

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

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

Half Wave Rectifier | **Full Wave Rectifier**

(2) DC or Average Output (load voltage) V_{dc} :

Half Wave Rectifier

$$V_{dc} = I_{dc} \times R_L$$

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

$$V_{dc} = \frac{V_m}{\pi(R_L + r_f)} \times R_L$$

If $r_f = 0$, $V_{dc} = \frac{V_m \times \cancel{R_L}}{\pi(\cancel{R_L})}$

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

If diode is not ideal,

$$\boxed{V_{dc} = \frac{V_m - V_\gamma}{\pi} = 0.318(V_m - V_\gamma)}$$

Full Wave Rectifier

$$V_{dc} = I_{dc} \times R_L$$

$$= \frac{2I_m}{\pi} \times R_L$$

$$V_{dc} = \frac{2V_m}{\pi(R_L + r_f)} \times R_L$$

If $r_f = 0$, $V_{dc} = \frac{2V_m \times \cancel{R_L}}{\pi(\cancel{R_L})}$

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

If diode is not ideal,

$$\boxed{V_{dc} = \frac{2(V_m - V_\gamma)}{\pi}}$$

(3) rms output (load) Current (I_{rms}) :

Half Wave Rectifier

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(I_m \sin\theta)^2 d\theta}$$

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

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

$$I_{rms} = \sqrt{\frac{I_m^2}{2\pi} \times \frac{1}{2}\left[\int_0^{\pi}(1 - \cos 2\theta)\, d\theta + \cancel{\int_{\pi}^{2\pi}(1 - \cos 2\theta) d\theta}^{\,0}\right]}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[\int_0^{\pi}(1 - \cos 2\theta)\, d\theta\right]}$$

Full Wave Rectifier

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi}(I_m \sin\theta)^2 d\theta}$$

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

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

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

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

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

$$I_{rms} = \sqrt{\frac{I_m^2}{4\pi}\left[(\theta)_0^{\pi} - \left(\frac{\sin 2\theta}{2}\right)_0^{\pi}\right]}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left[(\pi-0)-(0-0)\right]}$$

$$I_{rms} = \sqrt{\frac{I_m^2(\cancel{\pi})}{4\cancel{\pi}}} = \frac{I_m}{2}$$

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

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

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

(4) rms output voltage or load voltage (V_{rms}):-

$$V_{rms} = I_{rms} \times R_L$$

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

$$V_{rms} = \frac{V_m}{2(R_L + r_f)} \times R_L$$

$\boxed{\text{if } r_f = 0,}$ $V_{rms} = \frac{V_m \times \cancel{R_L}}{2\cancel{R_L}}$

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

$$V_{rms} = I_{rms} \times R_L$$

$$= \frac{I_m}{\sqrt{2}} \times R_L$$

$$V_{rms} = \frac{V_m}{\sqrt{2}(R_L + r_f)} \times R_L$$

$\boxed{\text{if } r_f = 0,}$ $V_{rms} = \frac{V_m \times \cancel{R_L}}{\sqrt{2}(\cancel{R_L})}$

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

~~Ques No - Expression for half wave rectifier of ripple factor~~

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

Advantages of Bridge Rectifier - 1. The need for centre-taped transformer is eliminated.

2. PIV is half (1/2) compared to centre tapped.
3. Used where large amount of power required.
4. Rectifier efficiency is high.

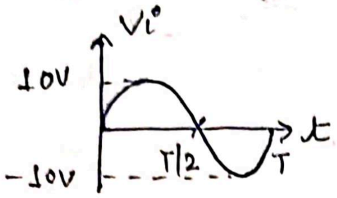
Disadvantage - 1. It requires 4 diode.

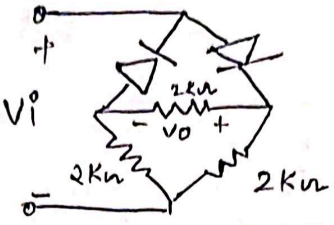
2. The use of two extra diodes cause a additional voltage drop thereby reduce the output voltage.

Lecture - 10

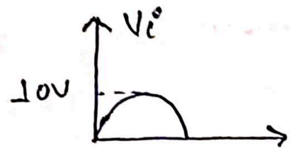
Ques^n 1: Determine the output waveform for the following figure & calculate the o/p dc level and required PIV of each diode.

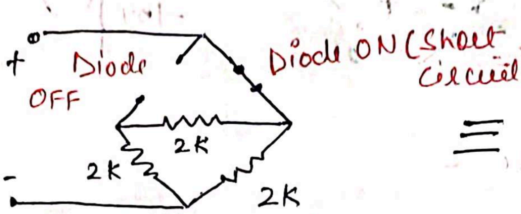
[AKTU numericals].



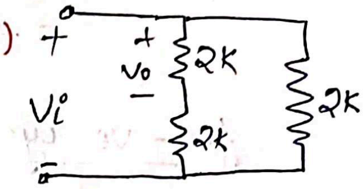


Sol^n: +ve cycle :



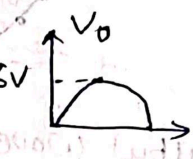


$\equiv$

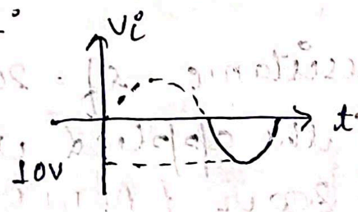


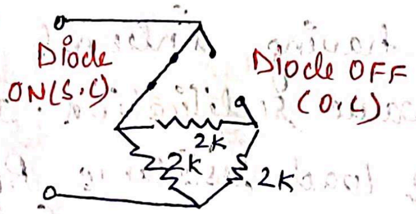
$$V_o = \frac{V_i \times 2\times10^3}{2\times10^3 + 2\times10^3} = \frac{V_i \times \cancel{2\times10^3}}{\cancel{4\times10^3}\ 2}$$

$$\boxed{V_o = \frac{V_i}{2}} \qquad V_o = \cancel{10}/\cancel{2} = 5V$$

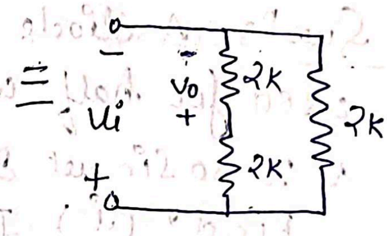


-ve cycle:



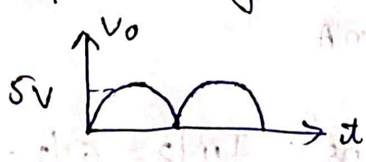


$\equiv$



$$V_o = \frac{V_i \times 2\times10^3}{2\times10^3 + 2\times10^3} = \frac{V_i}{2} \qquad \boxed{V_o = 5V}$$

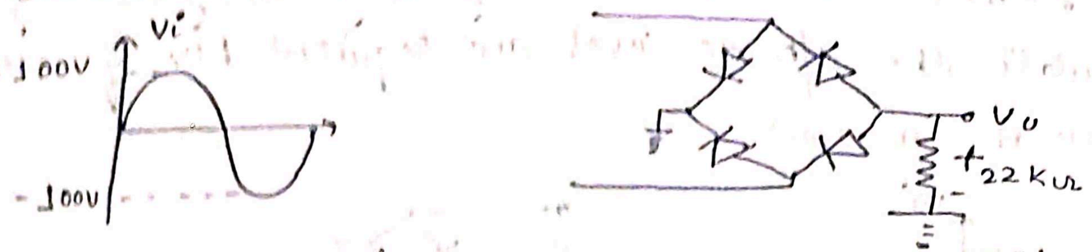
So, o/p wave form -



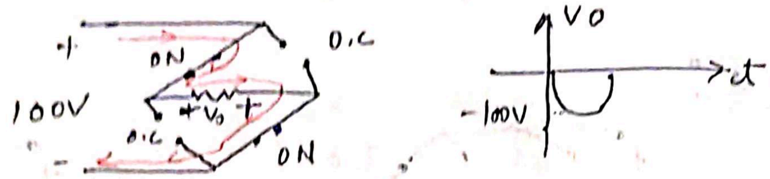
$$V_{dc} = \frac{2V_m}{\pi} = 0.636\,V_m$$
$$= 0.636 \times 5$$
$$= 3.18\ V$$

$\boxed{PIV = 5V}$

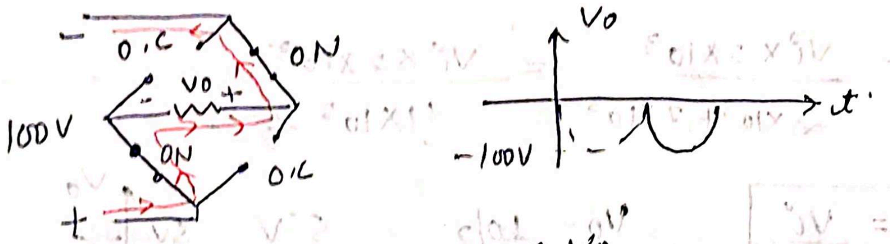
Quesⁿ2 Determine V_o & required PIV rating of each diode. All diodes are ideal



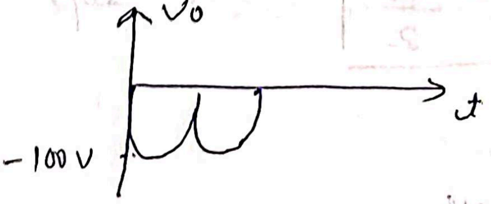
Solⁿ: for +ve cycle :-



for -ve cycle -



Output waveform :-



Required PIV = 100V

Quesⁿ3 A diode having internal resistance $r_f = 20\Omega$ is used for half wave rectification. If the applied voltage $V \approx 50 \sin \omega t$ & load resistance $R_L = 800\Omega$ [AKTU QUESTION].
Find? (i) I_m, I_{dc}, I_{rms} (ii) ac Power input
(iii) dc power output (iv) dc output voltage.
(v) efficiency of rectification.

(i) $I_m = \dfrac{V_m}{R_L + r_f} = \dfrac{50}{800+20} = \dfrac{50}{820} = 61\,mA$

$I_{dc} = I_m/\pi = 61/\pi = 19.4\,mA$, $I_{rms} = I_m/2 = 61/2 = 30.5\,mA$

(ii) $P_{i(ac)} = (I_{rms})^2 (R_L + r_f) = \left(\dfrac{30.5}{1000}\right)^2 (800+20) = 0.763\,W$

$P_{o(dc)} = I_{dc}^2 R_L = \left(\dfrac{19.4}{1000}\right)^2 \times 800 = 0.301\,W$

(iii) dc output voltage $= I_{dc} \times R_L = (19.4 \times 10^{-3})(800) = 15.52\,V$

(iv) $\eta = \frac{0.301}{0.763} \times 100 = 39.5\%$

Lecture-11 : CLAMPER

Clamper is an electronic circuits that changes the DC level of a signal to the desired level without changing the shape of the applied signal as well as peak to peak value of input signal is unchanged.

Clamper circuit moves the whole signal up or down to set either to +ve or -ve peak of signal at the desired level.

Clamper is circuit made of diode, capacitor & a large value of resistance.

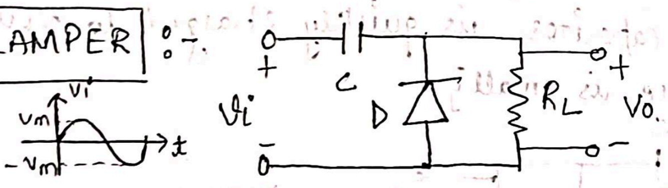
Clamper circuits are of three types -

→ Positive Clamper

→ Negative Clamper

→ Biased Clamper

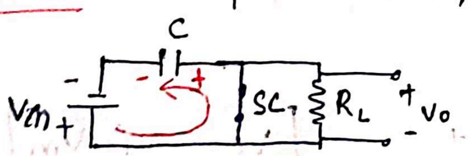
$\boxed{\text{POSITIVE CLAMPER}}$:-



When the clamper circuit shifts ac signal in upward direction then clamper is called positive clamper.

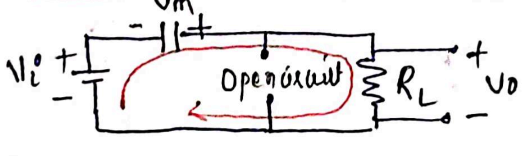
[NOTE: Always start ~~the with~~ cycle in which diode is ON]

Case 1: -ve cycle - In -ve cycle diode is forward bias & acts as short circuit. So capacitor is quickly charged to voltage (V_m) {as diode resistance is small}

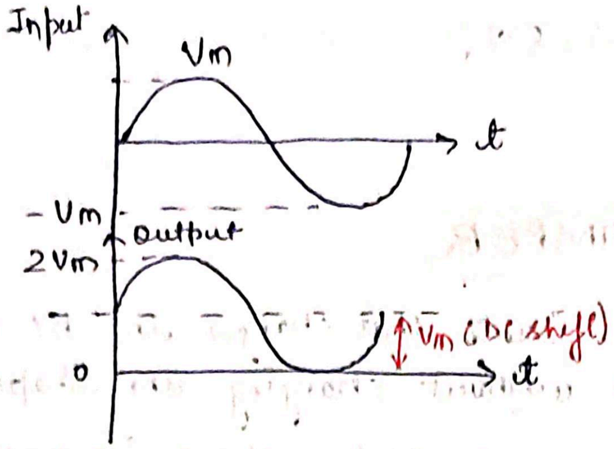


$\boxed{V_C = V_m}$

Case 2: +ve cycle & -ve cycle (subsequent) - due to large RC time constant, the capacitor doesn't lose much charge. So for rest of the operation Diode is reverse bias & acts as open circuit (for both cycle)



$\boxed{V_0 = V_i + V_m}$ → Positive DC shift.



$$\boxed{V_o = V_i + V_m}$$

+ve $\rightarrow V_i = V_m$

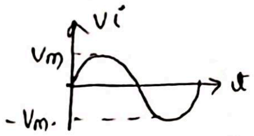
$V_o = 2V_m$

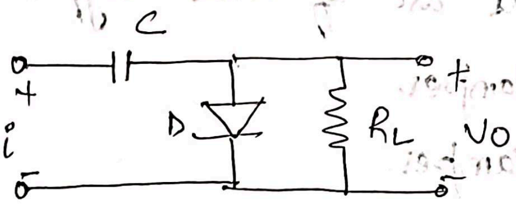
-ve $\rightarrow V_i = -V_m$

$V_o = 0$

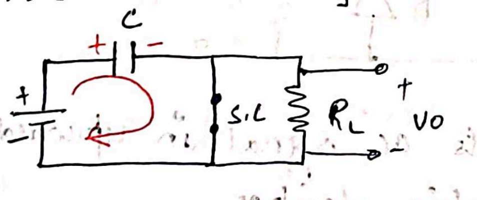
	V_i	V_o
-ve	V_m	$2V_m$
+ve	$-V_m$	0

Negative Clamper :- when the clamper circuit shifts the ac signal in downward direction, then clamper is known as negative clamper.



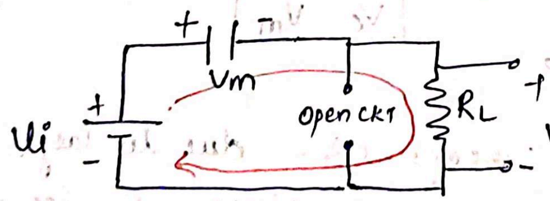


Case1: +ve cycle In +ve cycle diode is forward bias & acts as a short circuit. so capacitor is quickly charged to voltage (V_m) {as diode resistance is small}.



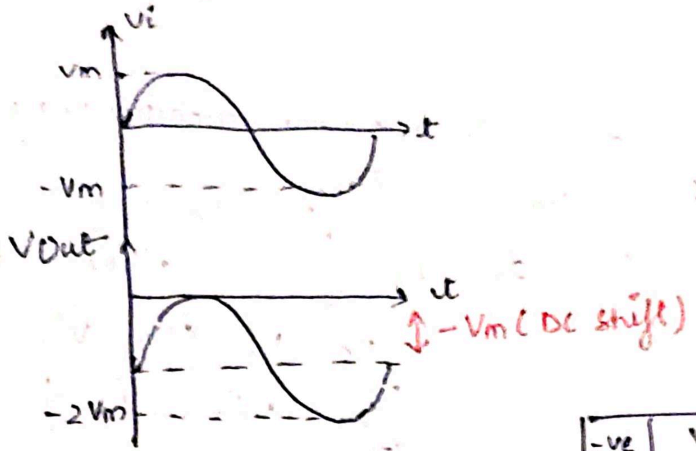
$$\boxed{V_c = V_m}$$

Case 2: -ve cycle & +ve cycle (subsequent) :- due to large RC time constant, the capacitor doesn't loose much charge. so for rest of operation diode is reverse biased & acts as open circuit.



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

negative DC shift



* $\boxed{V_o = V_i - V_m}$

+ve cycle $V_i = V_m$

$\boxed{V_o = V_m - V_m = 0}$

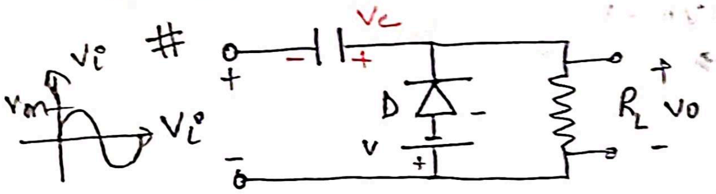
-ve cycle $V_i = -V_m$

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

	V_i	V_o
-ve	V_m	0
+ve	$-V_m$	$-2V_m$

$\boxed{\text{BIASED CLAMPER}}$:- If dc supply is also present in the clamper circuit then such type of clamper is called biased clamper -

@ Positive bias clamper :-



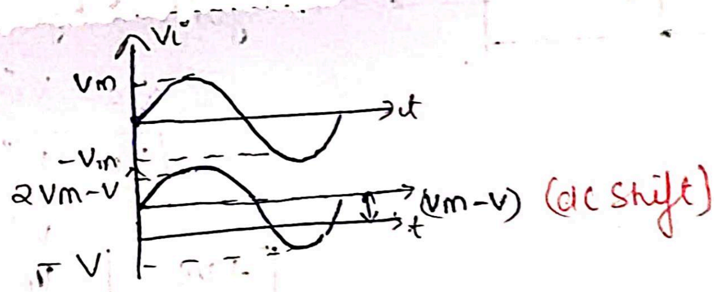
during -ve cycle capacitor charged to Vc

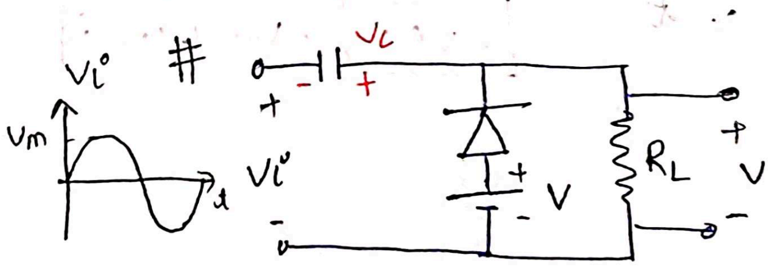
$V_c = (V_m - V)$

For other cycles - diode is OFF (Reverse bias) . So

$\boxed{V_o = V_i + V_m - V}$

	V_i	V_o
+ve	V_m	$2V_m - V$
-ve	$-V_m$	$-V$





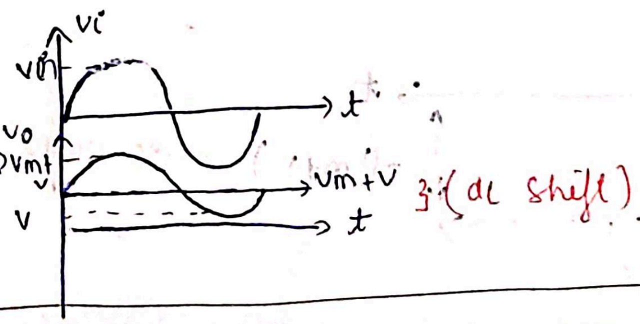
during -ve cycle capacitor charged to Vc.

$V_c = (V_m + V)$

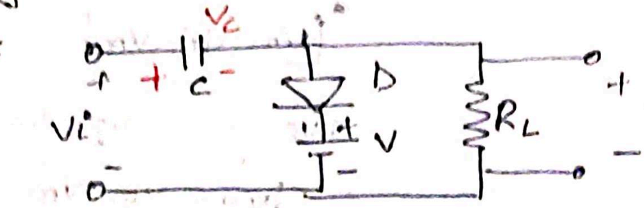
For other cycle - diode is (OFF

$\boxed{V_o = V_i + V_m + V}$

	V_i	V_o
+ve	V_m	$2V_m + V$
- ve	$-V_m$	V



(b) Negative biased clamper -



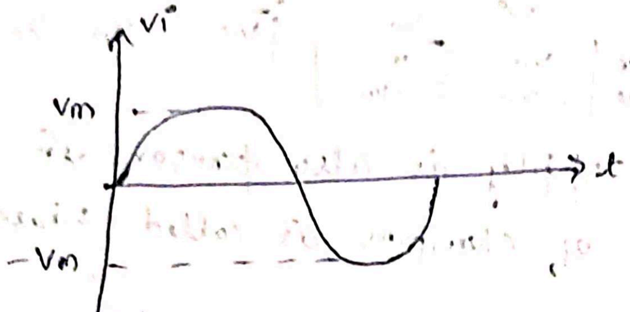
In +ve cycle, capacitor charges to $\boxed{V_c = V_m - V}$

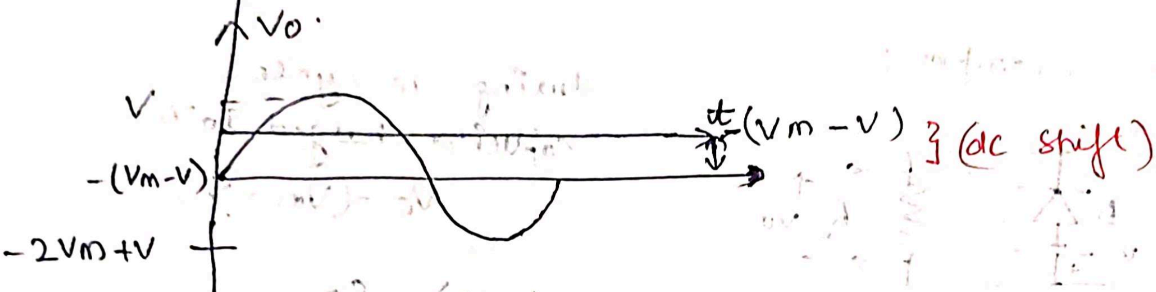
For other cycles — diode is OFF

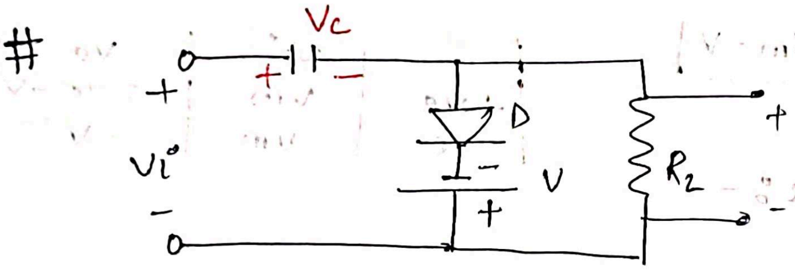
$V_o = V_i - (V_m - V)$

$\boxed{V_o = V_i - V_m + V}$

	V_i	V_o
+ve	V_m	V
-ve	$-V_m$	$-2V_m + V$







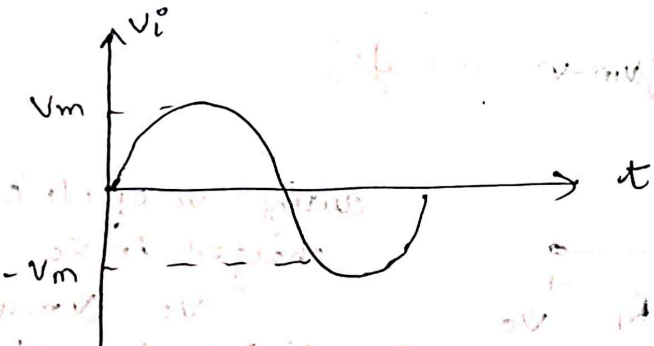
In +ve cycle, capacitor charges to $\boxed{V_c = V_m + V}$

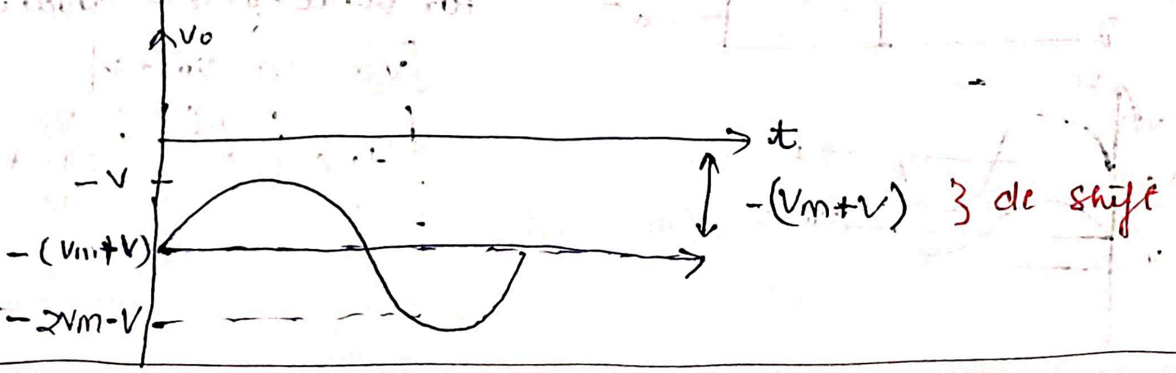
for other cycles - diode is OFF

$V_o = V_i - (V_m + V)$

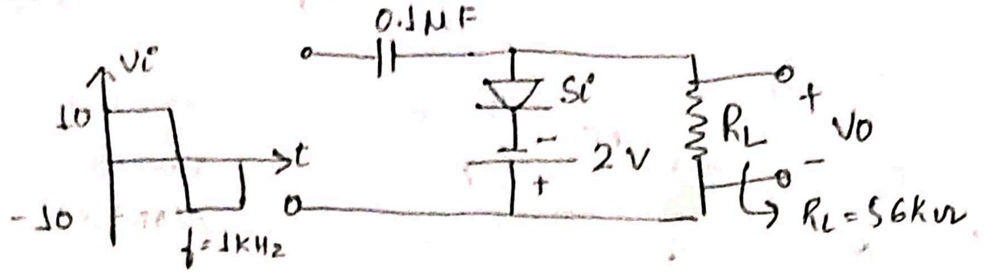
$\boxed{V_o = V_i - V_m - V}$

	V_i	V_o
+ve	V_m	$-V$
-ve	$-V_m$	$-2V_m - V$



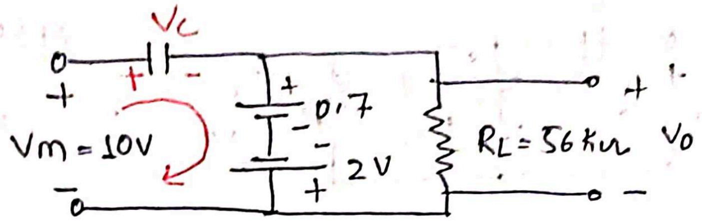


Ques: ~~Draw~~ Determine V_o for the circuit shown in. [AKTU QUESTION]



Negative Bias Clamper

Case 1: +ve cycle - The diode is forward bias (replaced by a battery of 0.7 V) & capacitor start charging quickly.

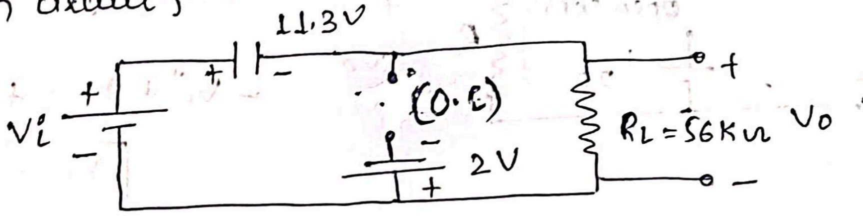


Apply KVL in circuit -

$$-10 + V_C + 0.7 - 2 = 0$$

$$\boxed{V_C = 11.3 \text{ Volt}}$$

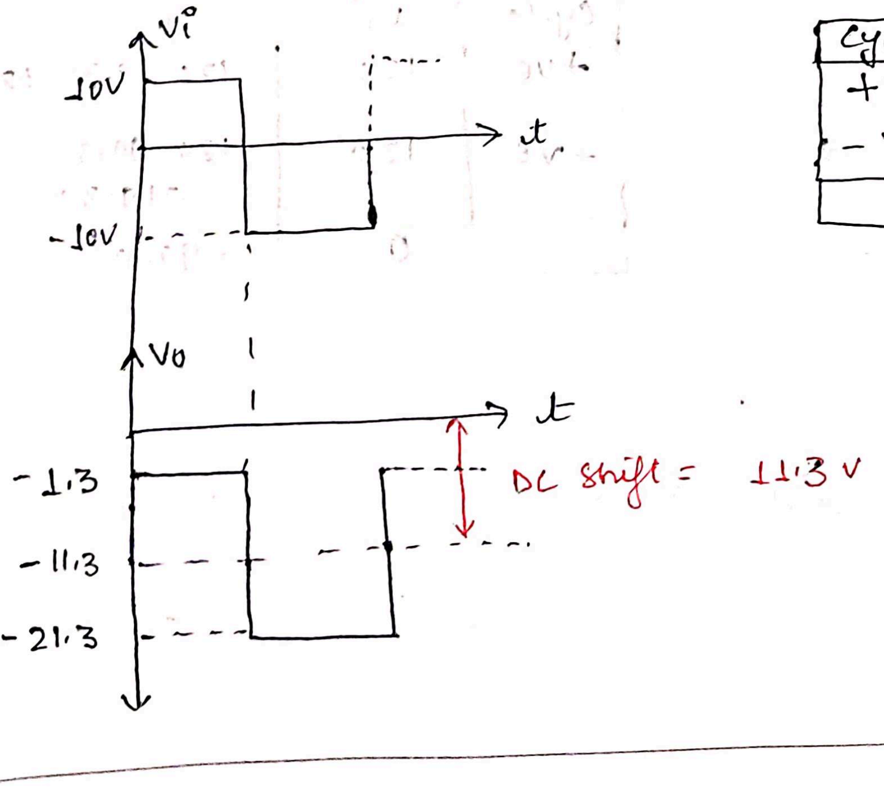
Case 2: for other cycle, capacitor is fully charged & doesn't lose charge due to RC constant is high. & diode is Reverse Bias (open circuit) -



Apply KVL

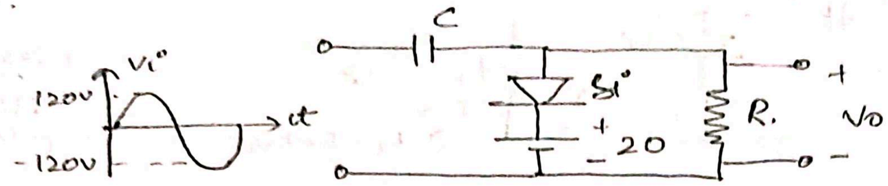
$$-V_i + 11.3 + V_o = 0$$

$$\boxed{V_o = V_i - 11.3}$$



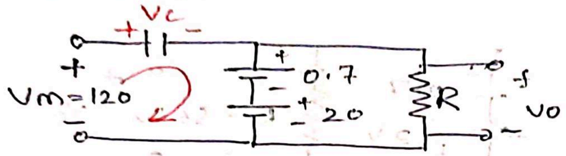
Cycle	V_i	V_o
+ve	10	10 - 11.3 = -1.3
-ve	-10	-10 - 11.3 = -21.3
	0	-11.3

Ques^n Sketch the output for given clamper circuit with shown input. [AKTU QUESTION]



Negative biased Clamper.

Case 1: +ve cycle - The diode is forward bias (replaced by a battery of 0.7 V) & capacitor starts charging quickly.



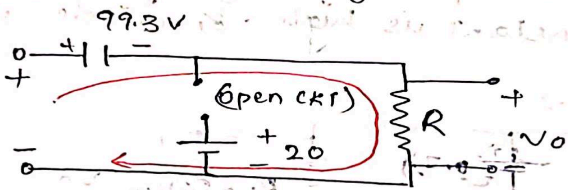
Apply KVL -

$$-120 + V_C + 0.7 + 20 = 0$$

$$V_C = 120 - 20.7$$

$$\boxed{V_C = 99.3V}$$

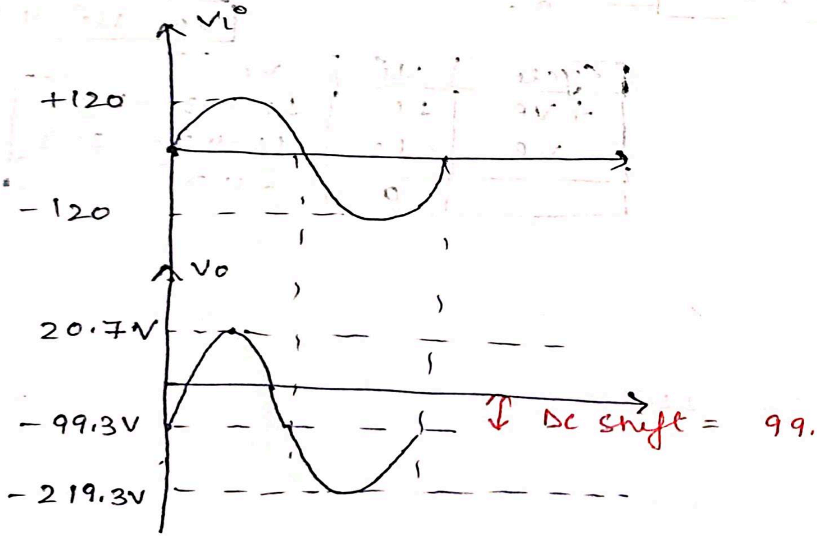
Case 2: Other cycle - Diode is reverse bias as capacitor is fully charged and doesn't lose charge because of high RC constant.



Apply KVL

$$-V_i + 99.3 + V_o = 0$$

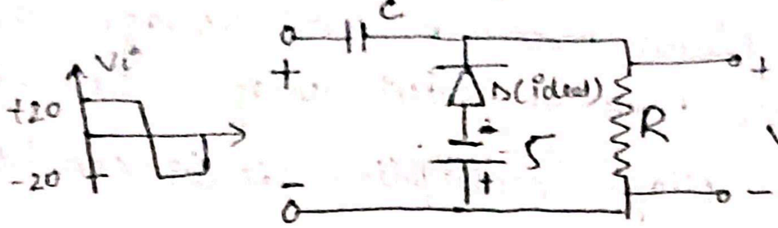
$$\boxed{V_o = V_i - 99.3}$$



DC shift = 99.3 V

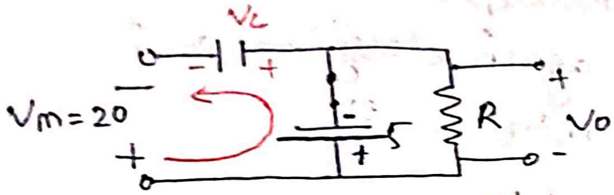
Cycle	Vi	Vo.
+ve	120	120-99.3= +20.7
-ve	-120	-120-99.3 = -219.3 V
	0	-99.3V

Ques- Draw the output waveform for the circuit of - [AKTU QUESTION]



Positive biased Clamper

Case 1: $-ve$ cycle: Diode is ~~reverse~~ forward bias acts as short circuit Capacitor starts charging.

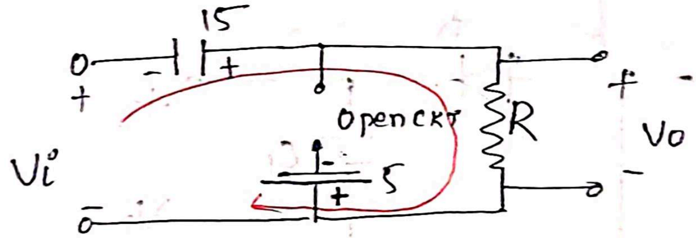


Apply KVL

$$-20+5-V_c=0$$

$$\boxed{V_c = 15V}$$

Case 2: Other cycles: ~~that~~ Capacitor charged fully, so diode is reverse bias (open circuit).

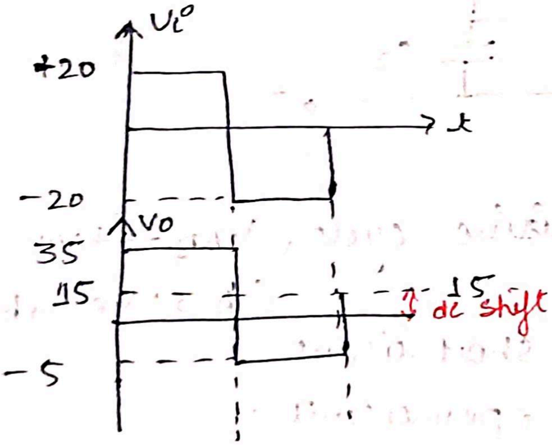


Apply KVL

$$-V_i - 15 + V_o = 0$$

$$\boxed{V_o = V_i + 15}$$

Cycle	Vi	Vo
+ve	20	20+15=35
−ve	−20	−20+15=−5
	0	15

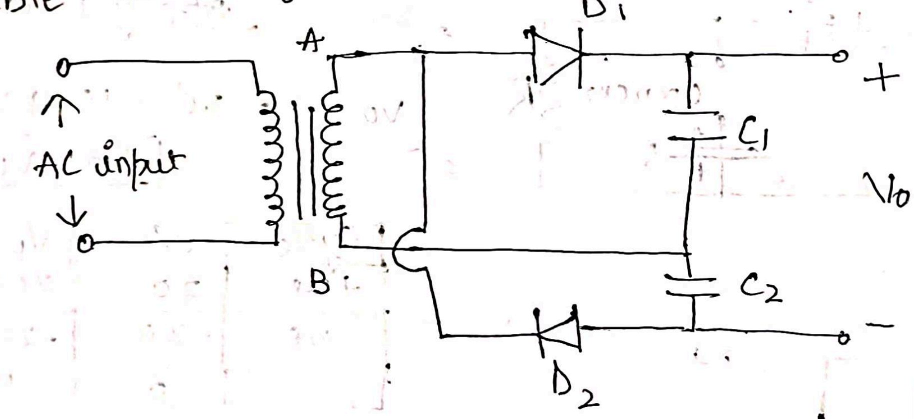


Lecture - 12 Voltage Multiplier Circuit

Voltage multiplier circuit produce a dc voltage that is some multiple of the peak ac input voltage. On the basis of multiplying factor voltage multiplier circuit can be classified as :-
(i) voltage doubler
(ii) voltage trippler
(iii) voltage Quadrupler.

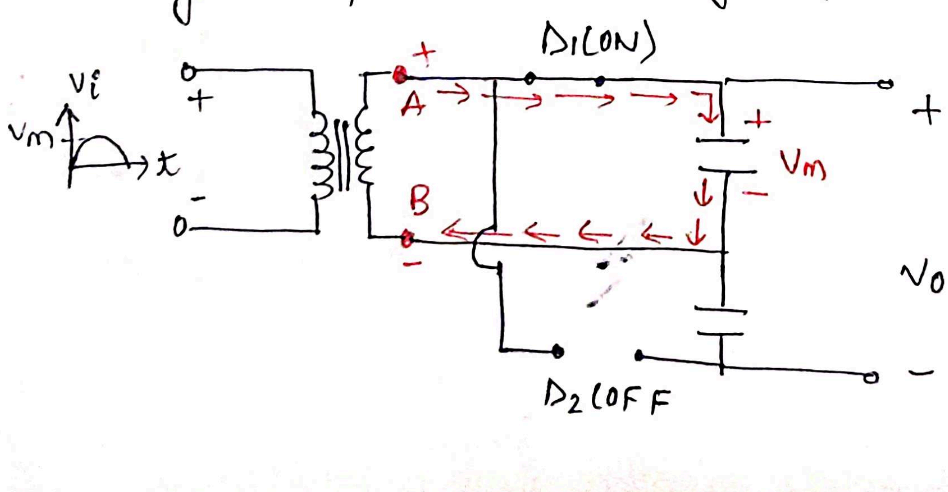
Now voltage doubler is again classified as :-
(a) Half wave voltage doubler.
(b) Full wave voltage doubler.

Ques^n Explain the working of full wave voltage double circuit?



Working - (1) +ve cycle - In positive cycle, $V_{AB} \rightarrow +ve$ ($A \rightarrow +ve$, $B \rightarrow -ve$)

so, D_1 is Forward bias acts as short circuit.
D_2 is reverse bias acts as open circuit.
Therefore capacitor C_1 charges upto to V_m.



(2) -ve cycle - In negative cycle, $V_{AB} \rightarrow -ve$.
($A \rightarrow -ve$, $B \rightarrow +ve$)

So, D_1 is reverse bias acts as short circuit.
D_2, is forward bias acts as open circuit.

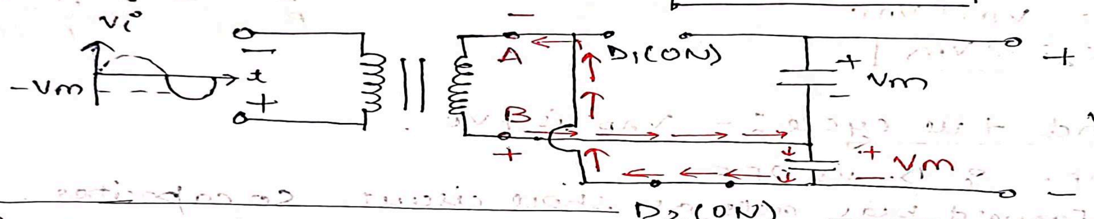
Therefore capacitor C_2 charges upto its V_m

Thus at end of -ve cycle, the voltage across each capacitor is V_m.

Output voltage (V_o) = sum of capacitor voltages V_{C1} & V_{C2}

$= V_m + V_m$

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

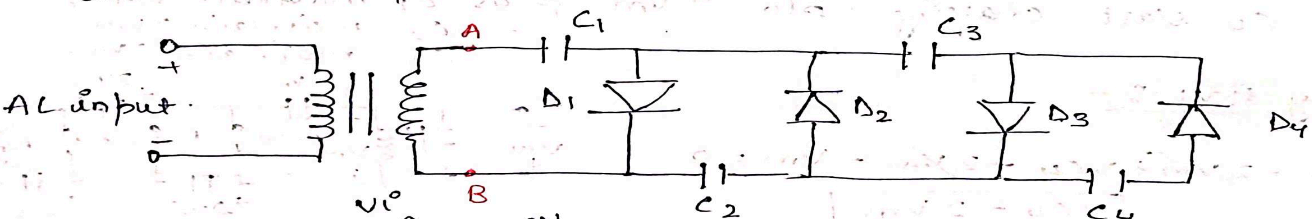


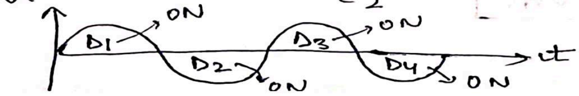
Ques^n. Explain the multiplier circuit (Half wave double, Tripler, Quadrupler) [AKTU QUESTION]

This circuit diagram is a general voltage multiplier circuit. It can perform function of voltage doubler, tripler & quadrupler. So for doubler, two diode & two capacitor are needed.

for tripler, 3 diode & 3 capacitor

If we need "n.Vm" at output we have to use n-diode & n capacitor.

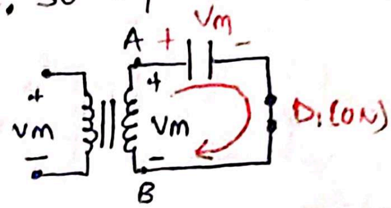




Working :- ① For first +ve cycle :- V_{AB} is +ve , ($A \to +ve$, $B \to -ve$)

D_1 is Forward bias acts as short circuit, so capacitor C_1 charges up to 'V_m'

$\boxed{V_{C_1} = V_m}$



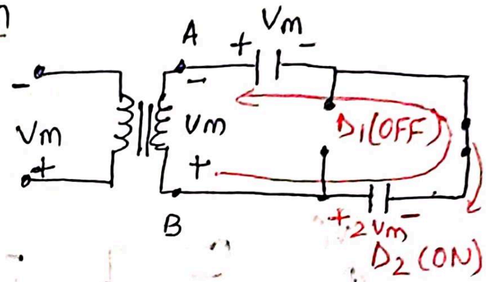
② for first -ve cycle :- V_{AB} is -ve , ($A \to -ve$; $B \to +ve$)

D_2 is Forward bias acts as short circuit. So capacitor C_2 start charging upto to $2V_m$ as C_1 maintain its charge V_m.

Apply KVL : $-V_m + V_{C_2} - V_m = 0$

$V_{C_2} = V_m + V_m$

$\boxed{V_{C_2} = 2V_m}$



③ for Second +ve cycle :- V_{AB} is +ve .

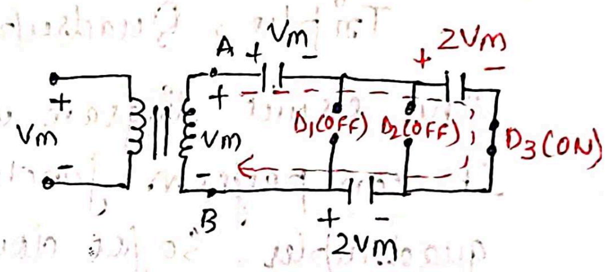
D_1 is OFF & D_2 is OFF .

D_3 is Forward bias acts as short circuit. So capacitor C_3 start charging upto $2V_m$. { as C_1 maintain V_m, C_2 maintain $2V_m$ }

Apply KVL :-

$-\cancel{V_m} + \cancel{V_m} + V_{C_3} - 2V_m = 0$

$\boxed{V_{C_3} = 2V_m}$



④ for second -ve cycle :- V_{AB} -ve

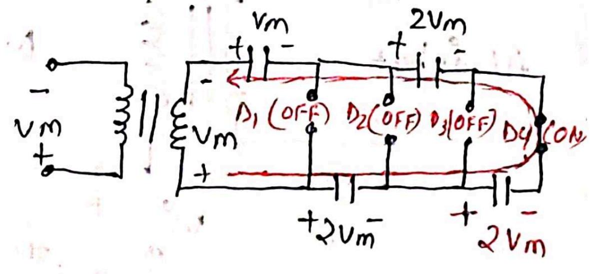
D_1 is OFF , D_2 is OFF , D_3 is OFF .

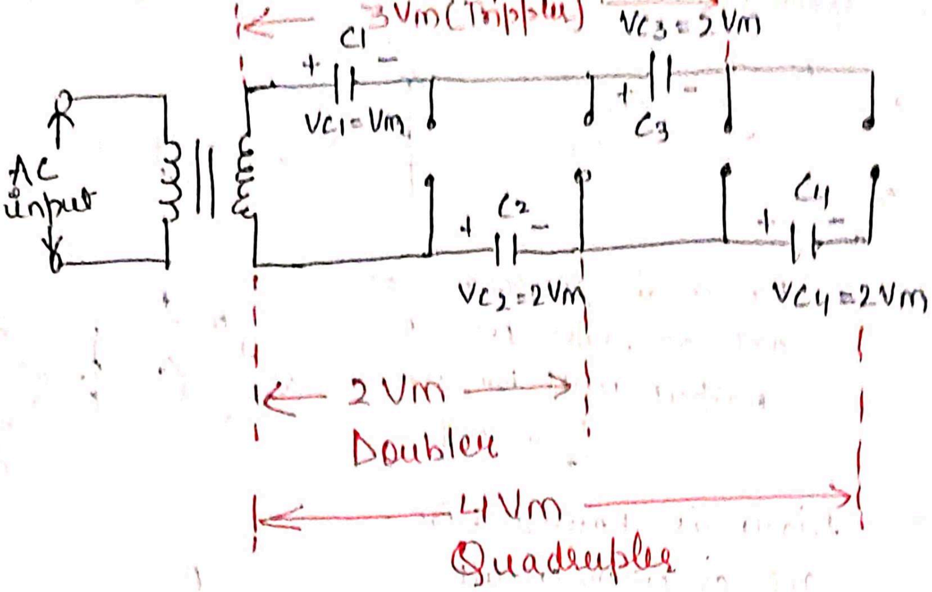
D_4 is Forward bias acts as short circuit . So capacitor C_4 start charging upto $2V_m$. { as C_1 maintain V_m, C_2 maintain $2V_m$, C_3 maintain $2V_m$ }

Apply KVL :-

$-V_m + 2\cancel{V_m} + V_{C_4} - 2\cancel{V_m} - V_m = 0$

$\boxed{V_{C_4} = 2V_m}$





Lecture - 13

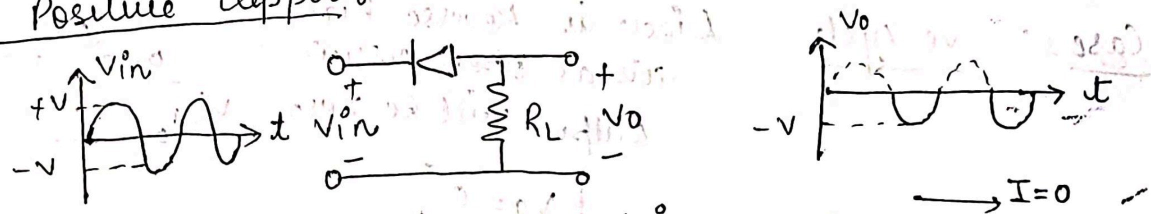
Clippers

Clippers are circuit made of diode, resistance & dc supply. Clippers can remove or clipp off some portion of input ac signal without distorting remaining part of the signal.

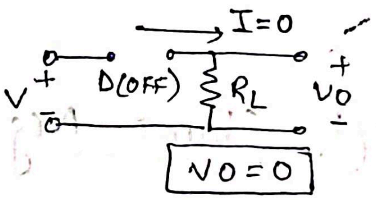
Types of clipper circuit :- (1) Positive clipper
(2) Negative clipper
(3) Biased clipper

POSITIVE CLIPPER : A positive clipper removes the positive half cycle of the input ac voltage.

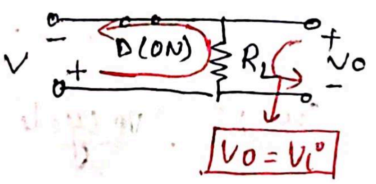
(a) Series Positive clipper :-



Case 1 : +ve cycle : Diode is reverse bias acts as open CKT o/p voltage is zero.

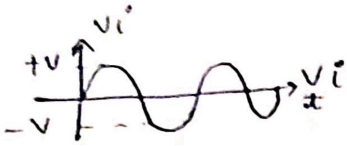


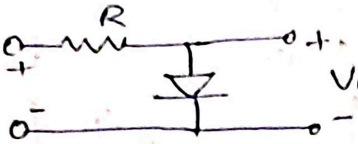
Case 2 : -ve cycle : Diode is forward bias acts as short CKT.

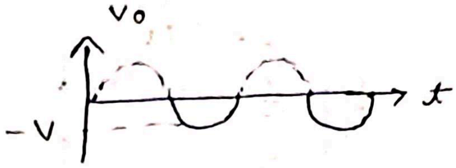


$\boxed{V_O = V_i}$

(b) Shunt positive clipper :-

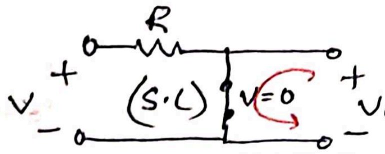






Case 1 : +ve cycle - Diode is forward bias.
acts as short circuit.
output will be zero

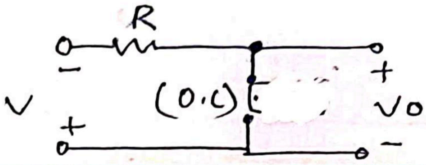
$\boxed{V_O = 0}$



$\boxed{V_O = 0}$

Case 2 : -ve cycle - Diode is Reverse bias.
acts as open circuit.
Output will be vi

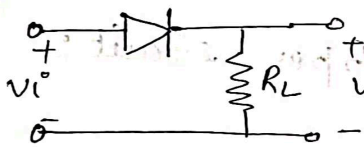
$\boxed{V_O = V_i}$

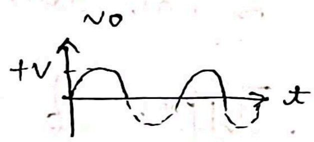


NEGATIVE CLIPPER :-

A negative clipper remove the negative half cycle of input ac voltage.

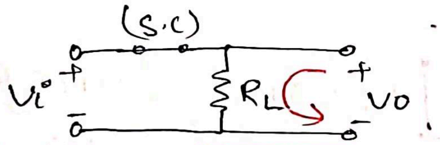
(a) Series Negative Clipper :-





Case 1 : +ve cycle - Diode is Forward bias
acts as short circuit.
output will be vi

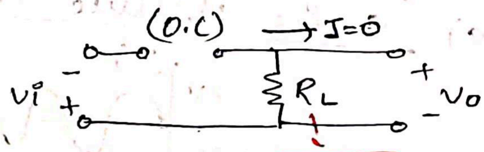
$\boxed{V_O = V_i}$



$\boxed{V_O = V_i}$

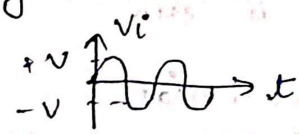
Case 2 : -ve cycle - Diode is Reverse bias
acts as open circuit
Output will be zero

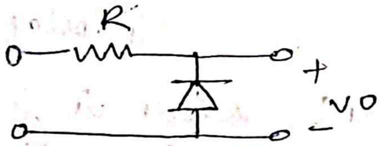
$\boxed{V_O = 0}$

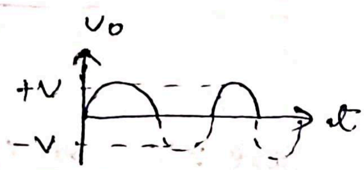


$\boxed{V_O = 0}$

(b) Shunt Negative Clipper :-

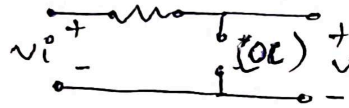






Case 1 : +ve cycle - Diode is reverse bias
so acts as open circuit

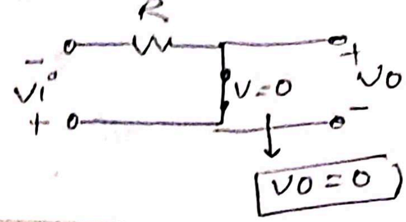
$V_O = V_i$



$\boxed{V_O = V_i}$

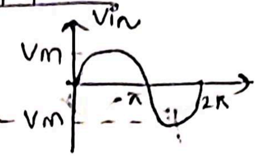
Case 2 : – ve cycle – Diode is forward bias so acts as close circuit.

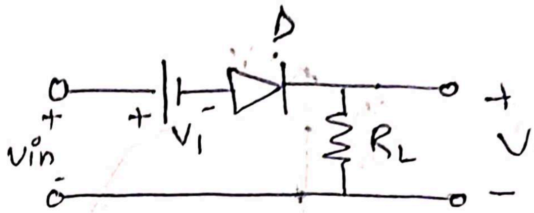
$\boxed{V_o = 0}$



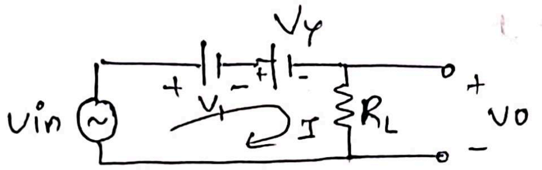
BIASED CLIPPER :– Biased clipper is used to clip off or remove a small portion of positive cycle or negative cycle or both. This is achieved by adding a battery in series with diode.

(a) Series Negative Biased Clipper –





If $V_{in} - V_1 > V_\gamma$ or $V_{in} > V_1 + V_\gamma$, then diode is ON (F.B) & replace by V_γ.



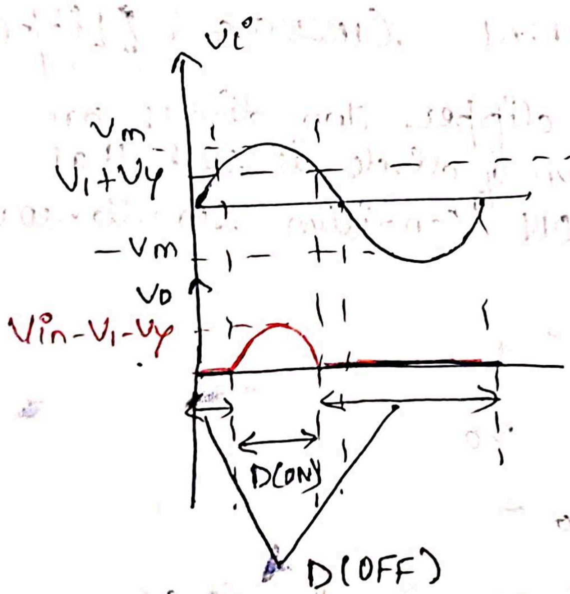
$-V_{in} + V_1 + V_\gamma + I \times R_L = 0$

$I R_L = V_{in} - V_1 - V_\gamma$

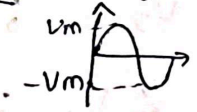
$\boxed{V_o = V_{in} - V_1 - V_\gamma}$

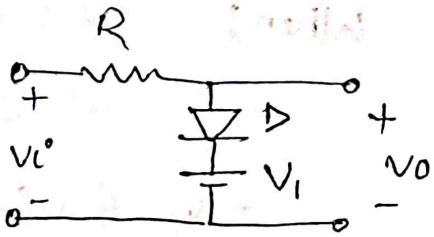
If $V_{in} - V_1 \leq V_\gamma$: then diode is OFF (R.B) acts as open circuit.

$\boxed{V_o = 0}$

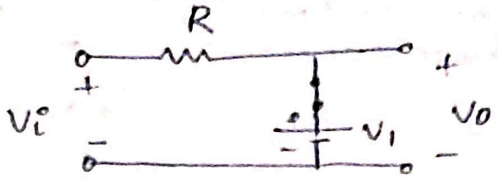


(b) Shunt Positive Biased Clipper –



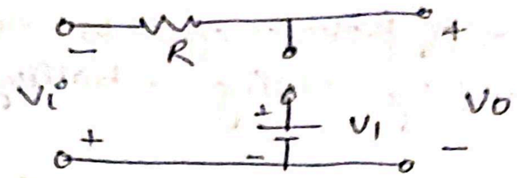


If $V_{in} > V_1$: diode is ON (Forward Bias) acts as short circuit.

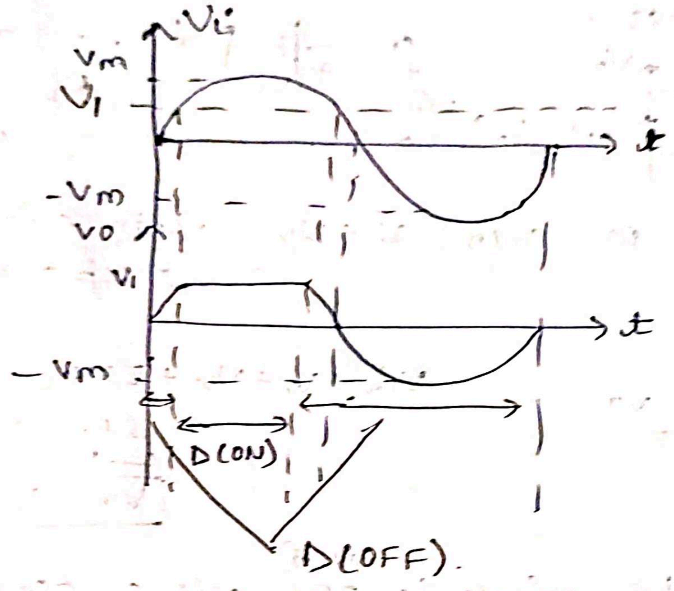


$\boxed{V_o = V_1}$

If $V_{in} < V_1$: diode is reverse bias (OFF) acts as open circuit.

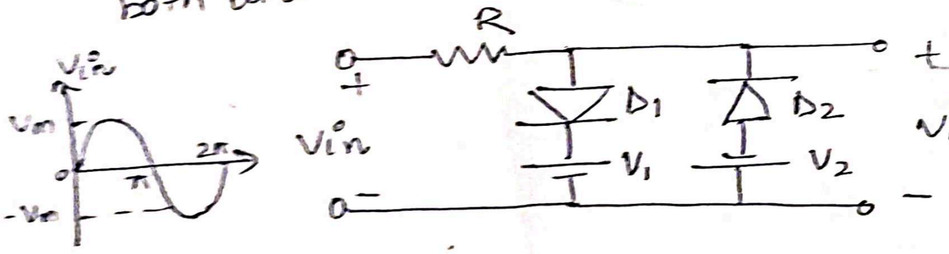


$\boxed{V_o = V_i}$



TWO WAYS OR COMBINATIONAL ~~CIRCUITS~~ Clipper :

In two way or combinational clipper two diodes are in parallel branch. The orientation of diode is such that both the diodes can not be in ON condition simultaneously.

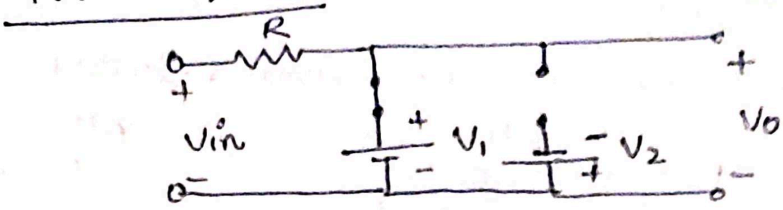


When: $V_{in} > V_1$; D_1 is ON & D_2 is OFF

$V_{in} < -V_2$; D_1 is OFF & D_1 is ON

$-V_2 \leq V_{in} \leq V_1$; Both diodes are OFF

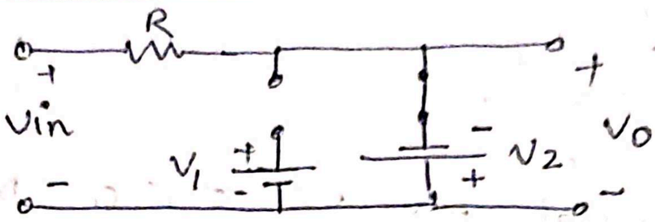
For $V_{in} > V_1$



$D_1 \to$ F.B acts as short CKT
$D_2 \to$ R.B acts as open CKT

$\boxed{V_o = V_1}$

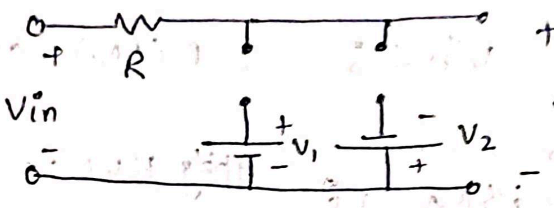
For $V_{in} < -V_2$



$D_1 \to$ R.B acts as open circuit
$D_2 \to$ F.B acts as short CKT

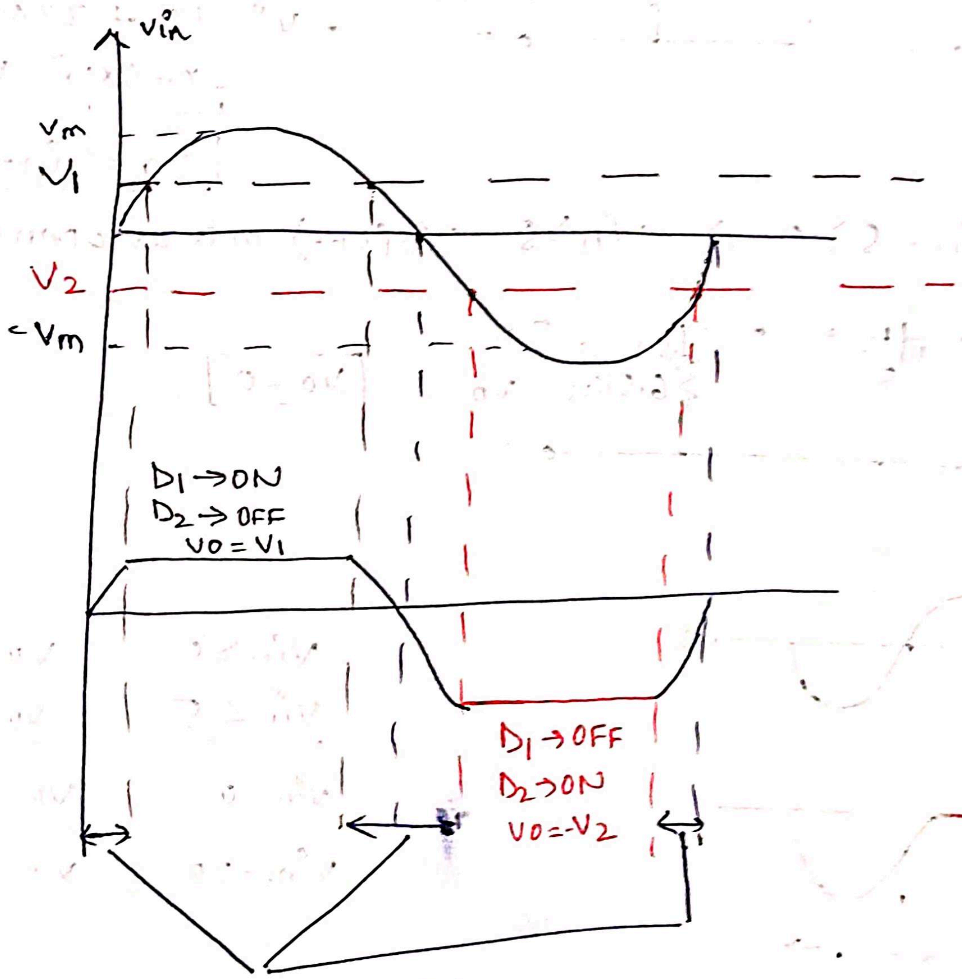
$\boxed{V_o = -V_2}$

For $-V_2 \leq V_{in} \leq V_1$



$D_1 \to$ R.B acts as O.C
$D_2 \to$ R.B acts as O.C

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



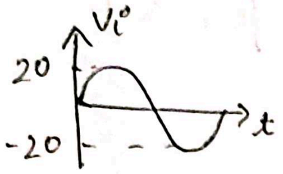
$D_1 \to$ OFF
$D_2 \to$ OFF

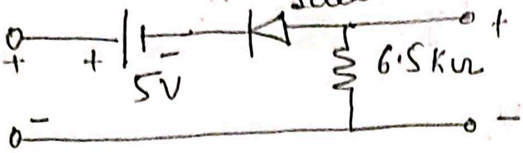
$\boxed{V_o = V_i}$

Clipper Numericals :-

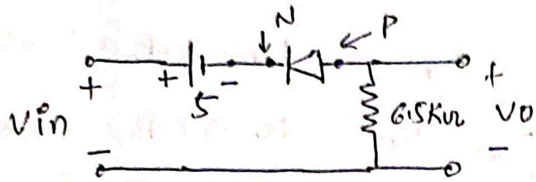
Q. Determine & sketch V_o for the given network.

(AKTU QUESTION)





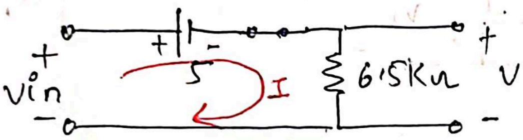
Series Positive Biased Clipper



As diode is ideal $\rightarrow$ $V_{in} - 5 < 0$ Diode is F.B (ON)

$V_{in} - 5 \geq 0$ Diode is R.B (OFF)

Case 1: $V_{in} - 5 < 0 \Rightarrow V_{in} < 5$; D(ON) acts as short CKT



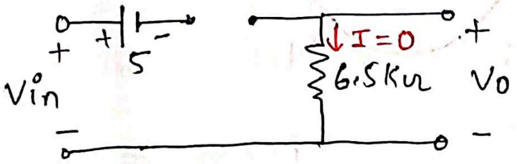
Apply KVL –

$-V_{in} + 5 + I \times 6.5 \times 10^3 = 0$

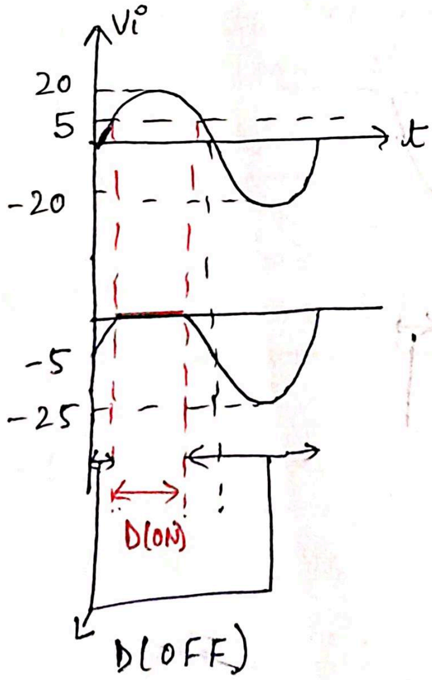
$\underbrace{I \times 6.5 \times 10^3}_{} = V_{in} - 5$

$\boxed{V_o = V_{in} - 5}$

Case 2: $V_{in} - 5 > 0 \Rightarrow V_{in} > 5$; D(OFF) acts as open CKT.

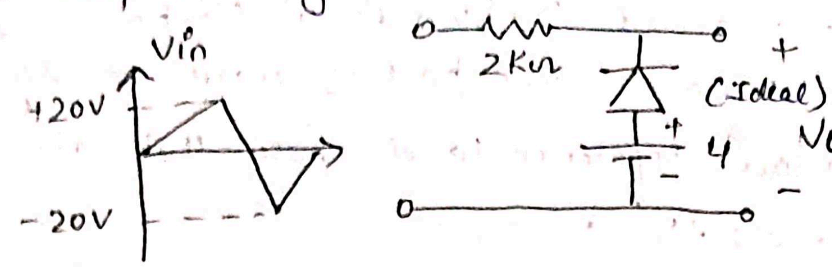


$\boxed{V_o = 0}$



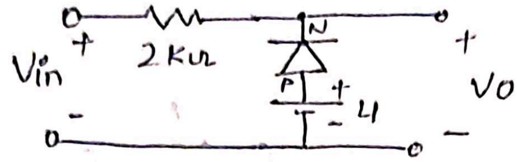
$V_{in} > 5$	$V_o = 0$
$V_{in} < 5$	$V_o = V_{in} - 5$
$V_{in} = 0$	$V_o = -5$
$V_{in} = -20$	$V_o = -20 - 5 = -25$

Ques^n Draw the output waveform - [AKTU QUESTION].



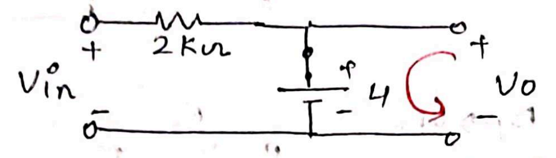
Shunt Negative Biased Clipper

Let diode given in CKT is ideal -



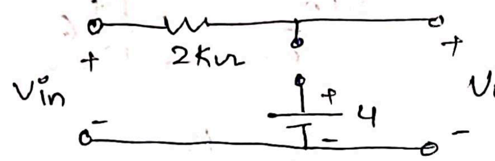
Vin < 4 : Diode ON
Vin ≥ 4 : Diode OFF

Case 1: Vin < 4 ; Diode is F.B acts as short CKT

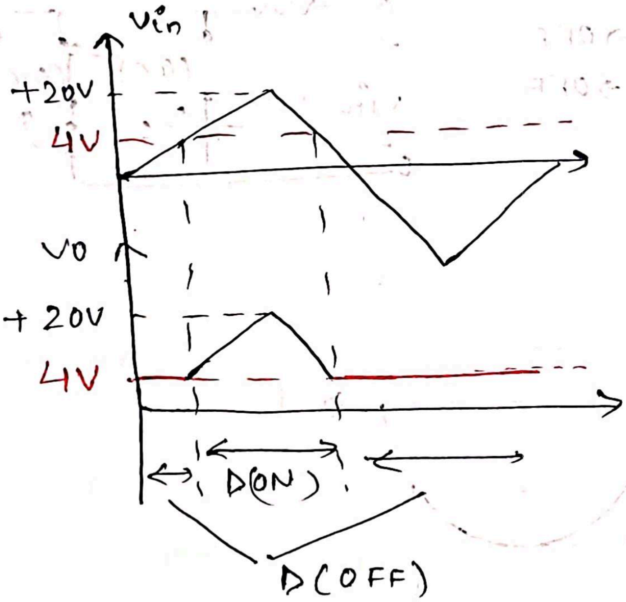


$\boxed{Vo = 4}$

Case 2: Vin ≥ 4 ; Diode is R.B acts as open CKT.

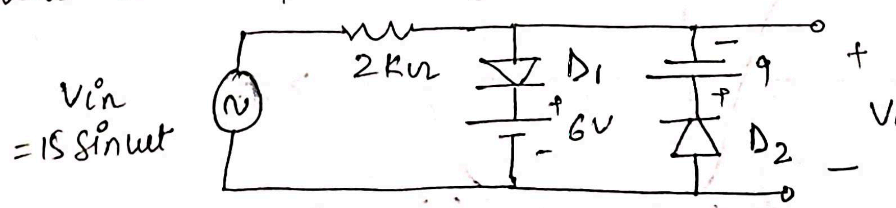


$\boxed{Vo = Vin}$



Vin < 4 $\boxed{Vo = 4V}$
Vin ≥ 4 $\boxed{Vo = Vin}$

Ques^n Explain the function of the circuit shown in figure & draw the output waveform - [AKTU QUESTION].



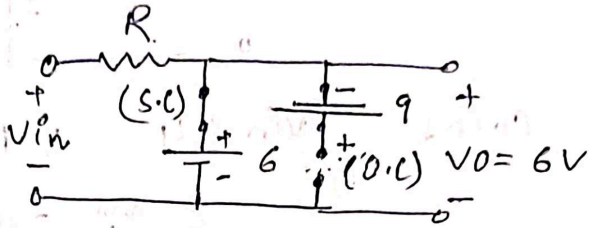
The circuit shown above is a two way clipper circuit which is also called combinational clipper.

As a clipper remove some part of input ac signal above or below a certain reference level, here this circuit has two reference levels $+V_1$ & $-V_2$.

The CKT removes the part of i/p ac signal greater than V_1 & less than $-V_2$ b/w the levels the ac signals remains unchanged.

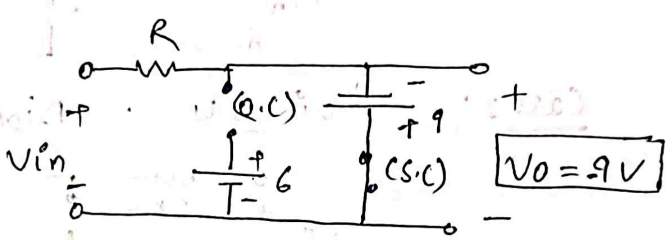
For $V_{in} > 6V (V_1)$ $D_1 \to ON$, $D_2 \to OFF$

$\boxed{V_0 = +6V}$



For $V_{in} < -9 (V_2)$ $D_1 \to OFF$, $D_2 \to ON$

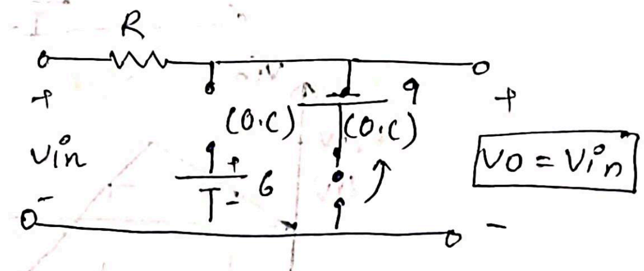
$\boxed{V_0 = -9V}$

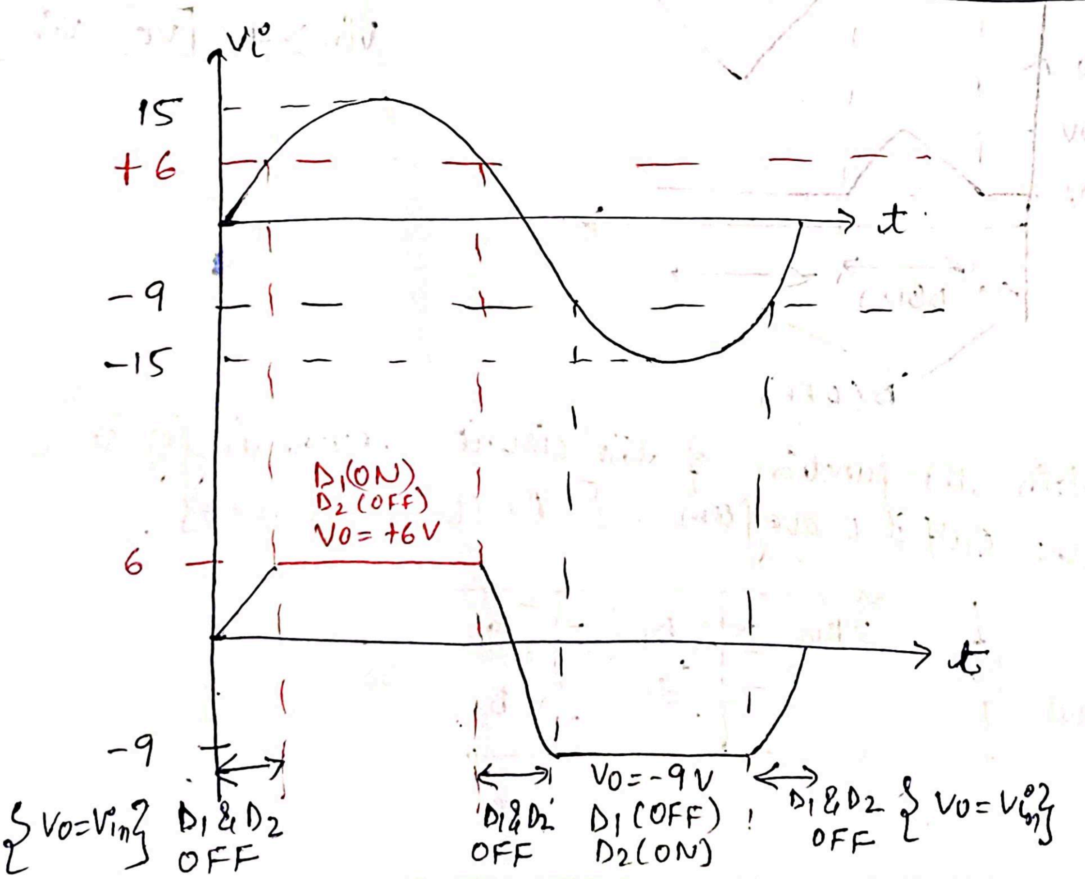


For $-9 \le V_{in} \le 6$

$D_1 \to OFF$
$D_2 \to OFF$

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





Lecture-14 — Special Purpose diode

- ↳ varactor diode
- ↳ LED
- ↳ Photo diode
- ↳ Tunnel diode.

Ques^n Write short notes on :- [AKTU QUESTION].

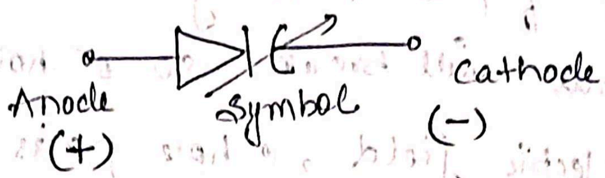
(i) Varactor diode

(ii) Photo diode

(i) Varactor diode :- Also known as (Varicap) {Variable Capacitor}

It is a special purpose diode which can be used as variable capacitor in microwave CKT.

Symbol :



Working: 1. It is used in reverse bias condition.

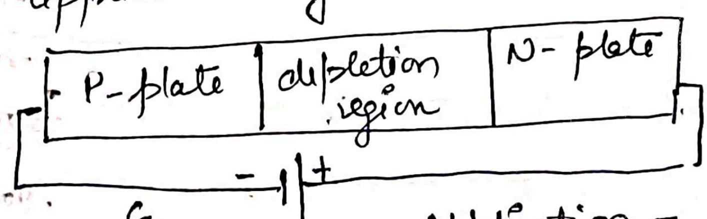
2. In reverse bias, P region & N region acts like plate of capacitor, while the depletion region acts like dielectric. So there exist a capacitance,

Space charge capacitance
or
depletion region capacitance.

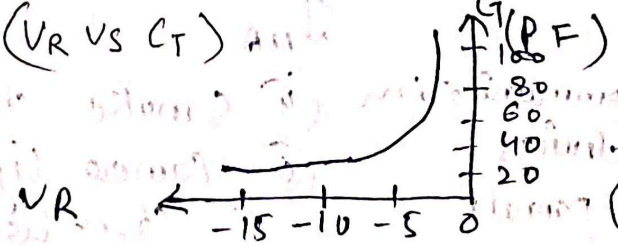
$$\boxed{C_T = \frac{\varepsilon A}{W}}$$

where ε : permittivity of semiconductor
A : Area of cross section.
W : width of depletion region.

3. As reverse bias applied to diode increase, the width of depletion region (W) increases. So C_T decreases & vice versa. Therefore capacitance can be controlled by applied voltage.



Graph : (V_R vs C_T)



Application −

1. FM modulator
2. Tunning circuit
3. TV recievers.
4. Radio Reciever.

(ii) Photo diode :- A photo diode is a semiconductor p-n junction device that converts light to an electric current.

Symbol

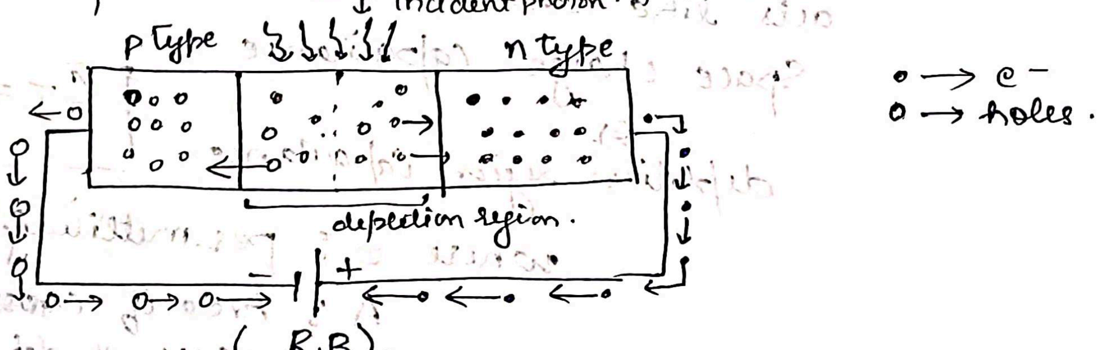
Works in reverse bias condition

Working : 1. When a light or photon is used to illuminate p-n junction than photon hits the immobile ions present in the depletion region.

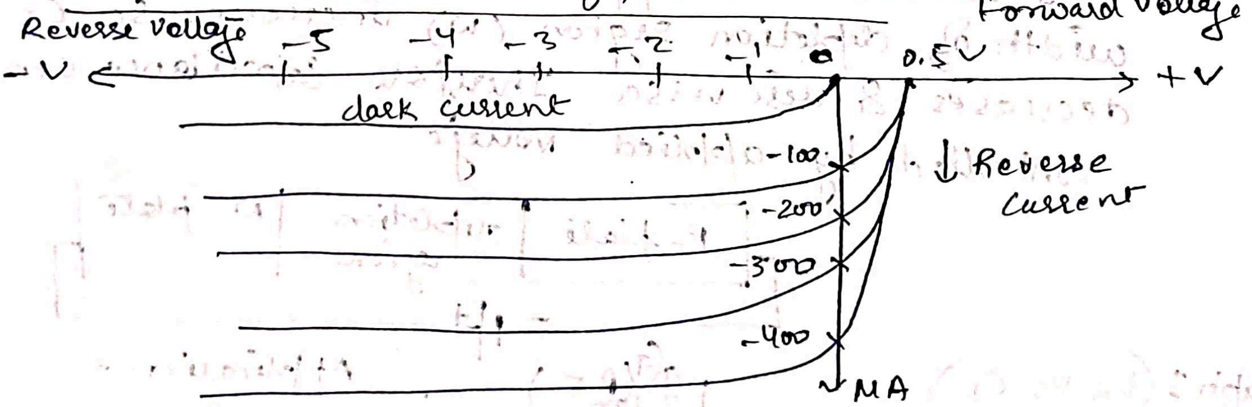
2. If energy of photon is greater than 1.1 ev than covalent bonds will break. So e^- hole pair are generated.

3. Due to electric field, e^- hole pairs move away from the junction. Hence hole moves to anode & cathode e^- moves towards cathode to produce photo current.

This entire process is known as photo electric effect.



V-I characteristics of photo diode :-

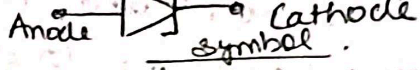


Application : (1) Optical communication
(2) Medical devices
(3) Solar cell pannels
(4) Smoke detectors.
(5) Camera light meters & Street lights.

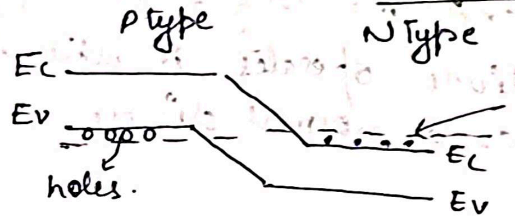
Ques Explain working & characteristics of Tunnel diodes & LED with the help of real diagram. [AKTU QUESTION]

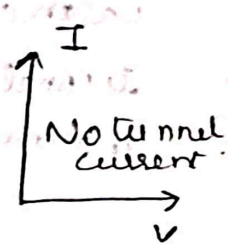
(1) Tunnel diode – A tunnel diode is a heavily doped p-n junction diode. The doping of tunnel diode is 1000 times greater than simple diode. So depletion layer is very narrow & is of the order of 10 nm.

In tunnel diode electric current is caused by 'Tunneling' or 'Tunneling effect'.



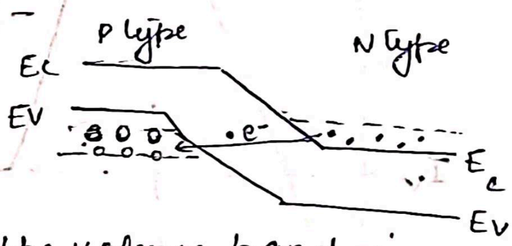
Working: (1) Unbaised tunnel diode:

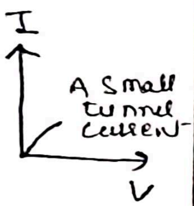




due to high doping the conduction band of n-type overlaps with valence band of p-type materials. Because of this overlapping the conduction band e⁻ & valence band holes are at the same energy level.

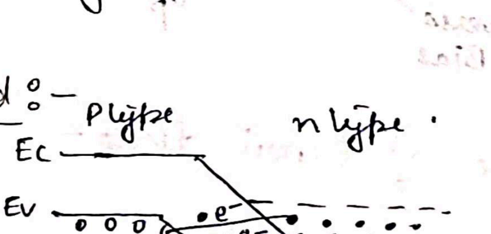
(2) Small voltage is applied :-

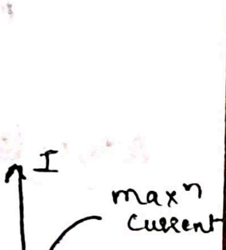




due to small voltage is applied, then a small no. of e⁻ in the conduction band of n region will tunnel to the empty states of the valence band in p region. This will create a small forward bias tunnel current.

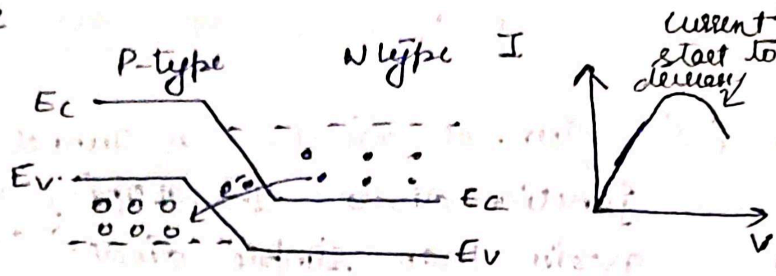
(3) Applied voltage is slightly increased :-



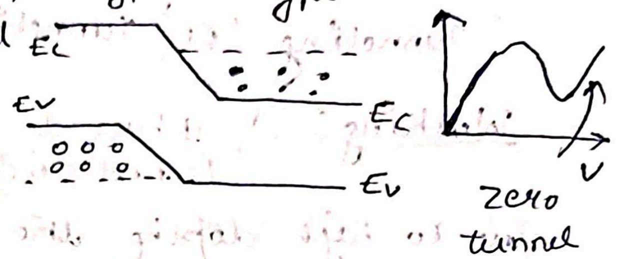


when voltage applied is slightly increased, the energy level of n-side conduction band becomes exactly to energy level of p-side valence band. As a result, maximum current flows.

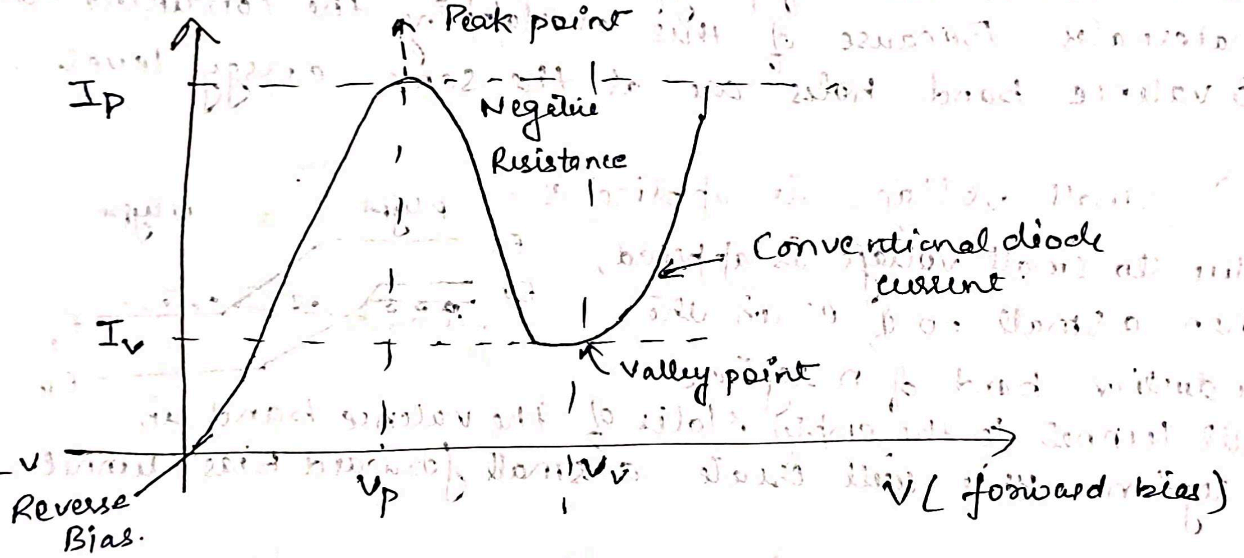
(4) Applied voltage is further increased :- A slight misalign of the conduction band & valence band take place. So current starts to decrease.



(5) Applied voltage is largely increased :- At this point the conduction band & valance band no longer overlap, and tunnel diode operates in the same manner as a normal diode.



V-I characteristics of tunnel diodes



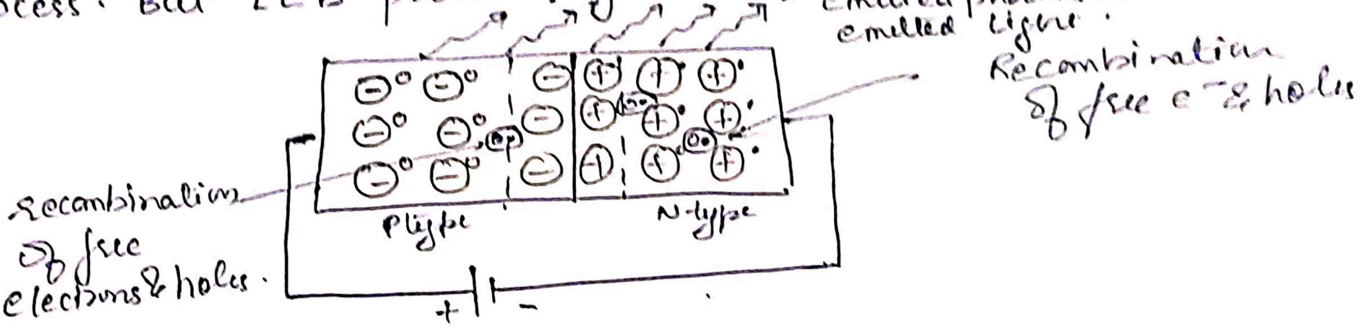
Advantage of tunnel diode - 1. long life
2. High speed operation
3. low noise
4. low power consumption.

Disadvantage :- 1. They are not fabricated in large no.
2. Being a two terminal device, the input & output are not isolated from one another.

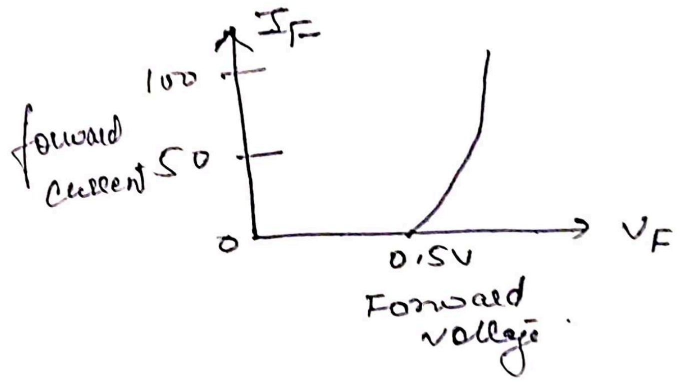
Applications :- 1. Are used as logic memory storage devices.
2. Tunnel diode are used in relaxation oscillator ckt.
3. used as an ultra high speed switch.
4. used in FM recievers.

(iii) **LED:** Light emitting diode (LED) is a photo electronic device which converts electrical energy into light energy. Materials like Gallium, Phosphorus & Arsenic are used for the manufacturing of LED.

working:- when LED is forward biased then hole in p-type & electron in n-type starts to cross the junction & recombine with each other. Simple diode (Ge, Si) produce heat in recombination process. But LED produce light in recombination.



V-I Characteristics -



Applications:

1. used in digital clocks
2. used in calculators
3. used in mobile, TV displays.
4. used in seven segment displays.

S.No	material	colour
1.	GaN	Blue (5V)
2.	GaN	white (4V)
3.	Ga As P	Red (1.8V)
4.	Ga As P	orange (2V)
5.	Ga P	Green.