mood-book

UNIT - 1

→ **Introduction :-** A device made up of Semiconductor material and whose operation is based on controlled flow of electrons is called Electronic device.

Eg:- Diode, BJT, MOSFET, FET

⇒ **Energy level :-** It is defined as the energy of an electron

Eg:- If the electron having energy 'E' it is said to be in energy level E. It is measured in electron volt.

$$1eV = 1.6 \times 10^{-19} J.$$

→ 1eV is defined as the energy gained by an electron when it travels through a potential difference of 1V.

* e^{-} always travels from low potential to high potential.

ENERGY LEVEL SPLITTING :- consider a Si atom whose atomic number is 14.

$$Si — 1s^2 2s^2 2p^6 3s^2 3p^2$$

It has 4 valence electrons. consider 'N' Si atoms, which are far away from each other when those atoms are brought closer.

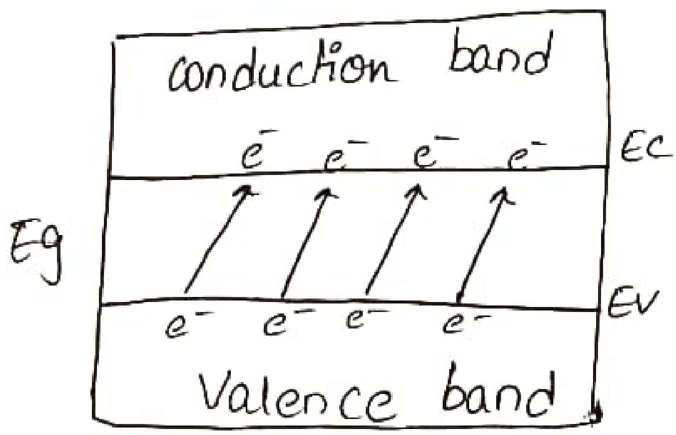
to each other interatomic action takes place i.e, Nucleus of one atom will attract the valence $e^{\ominus}$ of near by atom and valence electrons of two atoms will start repelling each other. when these atoms are brought closer to each other interatomic action takes place i.e, Nucleus of one atom will attract the valence e $e^{\ominus}$ of near by atom and valence electrons of two atoms will start repelling each other. Due to this a group of N atoms will convert into an electronic system which must follow Pauli's exclusion principle. ie, no two $e^{\ominus}$'s in an electronic system will have Same energy level.

Hence, 3s level will split into '2N' levels and 3p will split into '6N' levels, so that each valence electron occupies a distinct energy level.

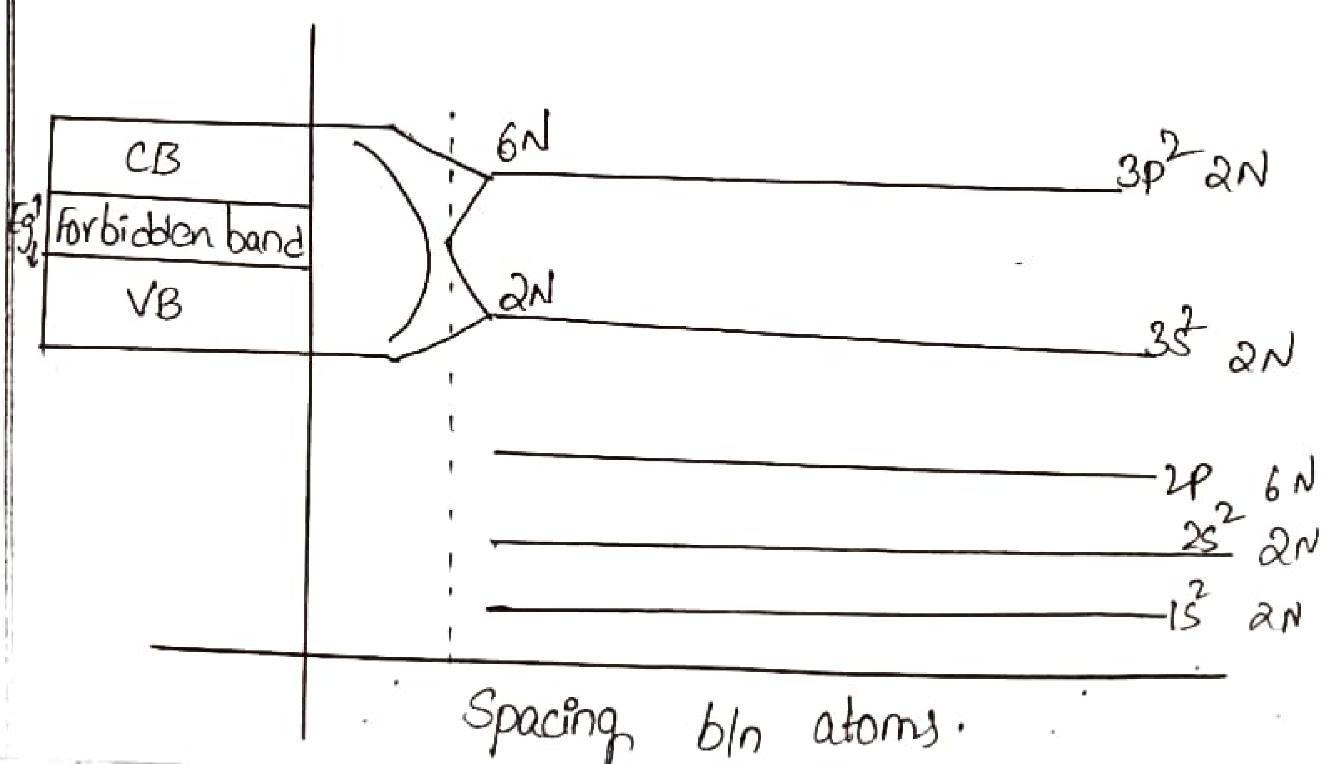
When interatomic spacing is further decreased, then 2N of level of 3s band, 6N levels of

3p band will merge into single band of into single band of 8N levels.

At lattice spacing a_0 [std distance b/w two atoms in a crystal], the signal band of 8N level will split into 2 bands, upper band has 4N levels called conduction band & lower band as Valence band.



$$E_g = E_c - E_v$$



At 0 kelvin electrons will prefer to be present in the lowest energy level. i.e, in the valence band. Therefore the valence band is completely filled with 4N. electrons and conduction band remains completely empty.

* Valence Band :- It is the Band of energy levels which is closer to the nucleus.

An electron present in Valence band is called as a bound electron because it can not move freely when external electric field is applied.

In the diagram E_v is the top level of the valence band.

* conduction Band :- It is the band of energy level which is far away from nucleus. An electron present in conduction band is free electron or conduction electron. because it can move freely when external electric field is applied.

Here E_c is the bottom level of conduction band

* **Forbidden Band** :- It is the band of Energy level where the probability of finding the electron is zero. It is also called disallowed energy level.

Here E_g is forbidden gap.

$$E_g = E_c - E_v$$

Based on the value of E_g, materials are divided in to 3 types.

1. **Insulator** :- Any material having large energy gap.

$E_g \geq 5eV$ Due to large E_g electrons can not be excited from VB to C.B.

→ Insulators have filled V.B and empty C.B.

Eg:- Diamond, SiO_2, glass

2. **Semiconductor** :- These are materials with a smaller energy gap. i.e, $E_g \approx 1eV$

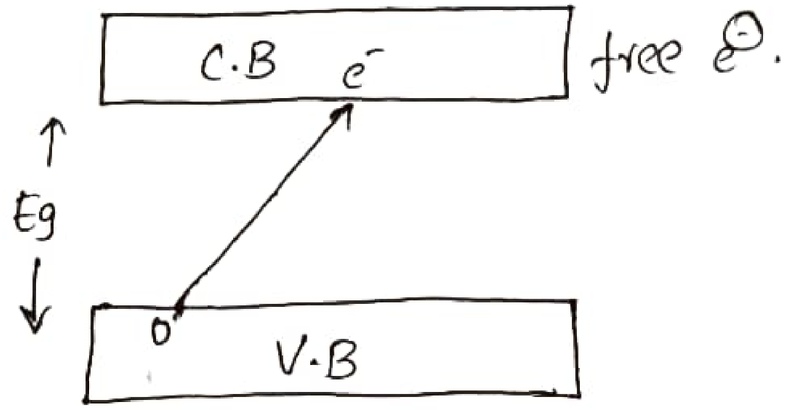
Eg:- Silicon, Germanium, Graphite (Brittle Nature)

Energy gap decreases with increase in temp.

At 0K the semiconductor behave as insulator.

If temperature is increased valence electron recieve thermal energy in the form of heat. If the temp is further increased the valence electrons accquire energy which is greater than equal to Eg. Then it moves into conductio Band.

The electron moves into C.B and becomes free electron. A vaccancy or an empty energy level will appear in the V.B which is called as Hole.



Hence conductivity of Semiconductor increases with increase in temperature and conductivity is zero at 0 K.

TYPES OF SEMICONDUCTORS :-

Semi Conductor
- Intrensic (pure s.c) — Low conductivity
- Externsic (Dopped s.c)

1. Intrensic Semiconductor :- semiconductors belonging to IV group of perodic table, and are tetravalent [valence e^- are 4].

1. Carbon
   - Isotope → Diamond (Insulator)
   - → Graphite (semi conductor) Brittle

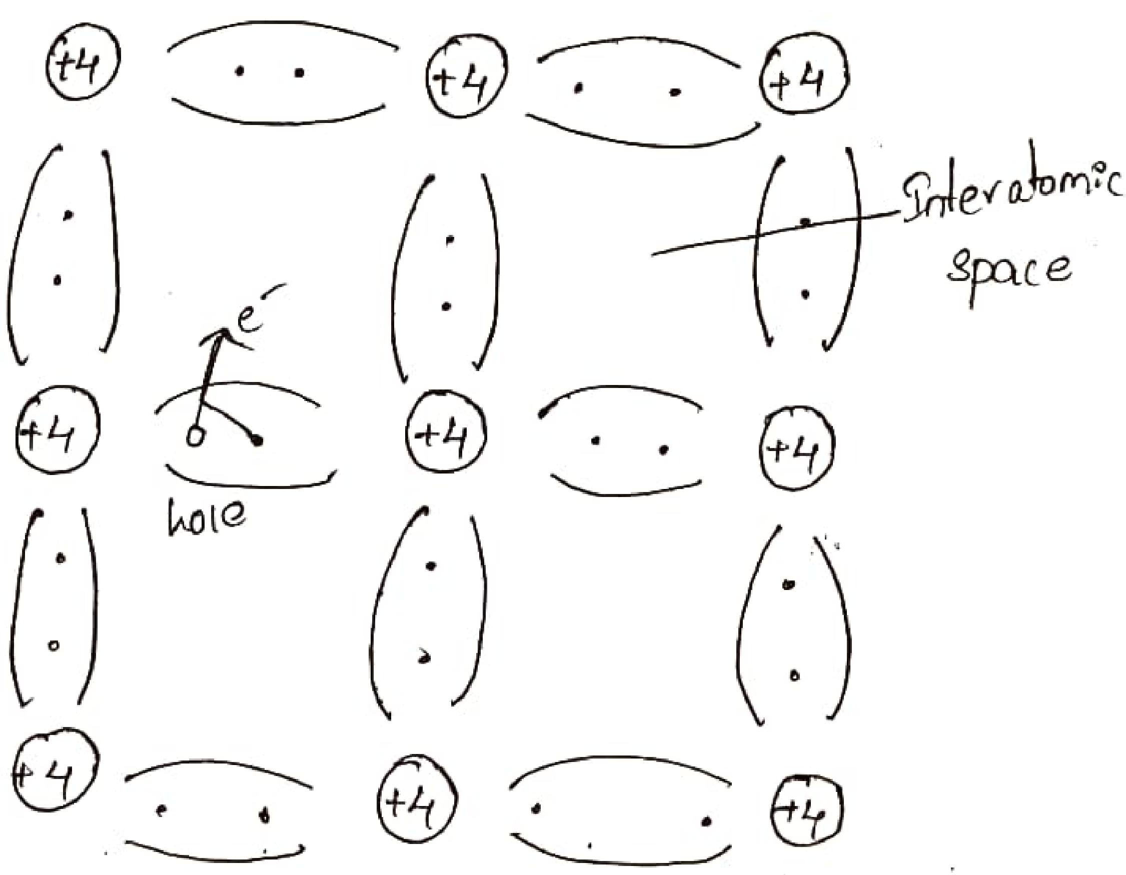
2. Silicon
3. Germanium

} – widely available

Tin, lead } s.c.

→ In a s.c crystal each atom forms 4 covalent Bonds to become stable. At 0 K all the valence electrons are present inside the covalent Bond is called bound electrons. Hence, at 0K conduction can not occur and S.C behaves as a insulator. when temp is increased due to heating effect electrons gets thermal energy greater than equal to Eg and it breaks out of covalent bond into free space or inter atomic space and becomes free electron.

* Incomplete covalent bond will act as Holes.
* The flow of free electrons produces current.



Extrensic Semiconductor :-

Doping:- The process of adding impurities to the pure semiconductor.

→ Doping is done to improve conductivity of S.C.

→ To fabricate different electronic devices.

Doping is done by performing.

(i) Impurity diffusion method [High Temp].

(ii) Ion Implantation method [Low Temp].

↳ Here we hit the S.C with impurities with high velocity.

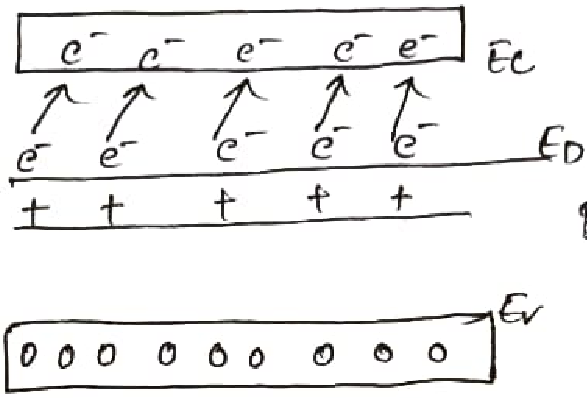
⇒ **N-Type Semiconductor** :-

It is formed by adding group-5 elements or pentavalent impurities to a pure semiconductu

Nitrogen :- Doesn't donate electrons

Phosphorous :- present in gaseous form

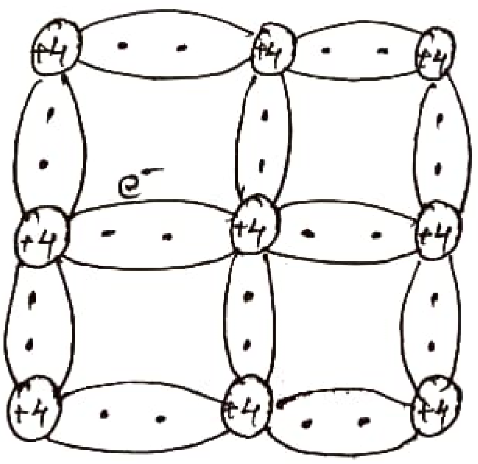
→ Addition of pentavalent impurities results in filled (E_D) energy slightly below the C.B edge.



Band diagram

→ Free electrons present in E_D (Donor energy level) will move to conduction band because of thermal energy, Hence free electron concentration increase.

→ A few of those electrons recombine with holes and hole concentration decreases.



→ In crystal structure the added impurity displaces a semiconductor atom and forms four covalent bond it donates the fifth valence electron to the semi-conductor crystal which becomes a free electron

free electrons :- majority charge carriers

Holes :- minority charge carriers

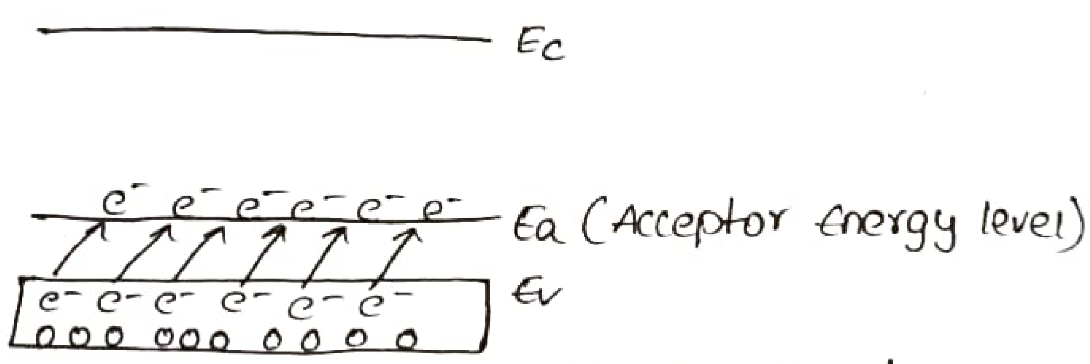
→ pentavalent impurity is called donar impurity because it donates electron and converts into positive ion.

P-type semiconductor:-

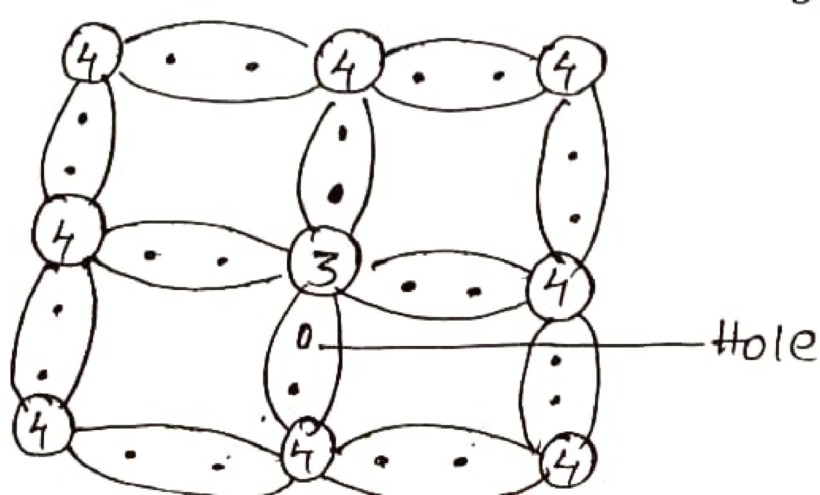
→ It is formed by adding group-3 elements or tri-valent impurities to a pure semiconductor.

Boran - B_2H_6 [present in gaseous state]

→ Addition of trivalent impurities result in empty energy level (Ea) slightly above the V-B edge.



→ At 0K, there will be no e⁻s in acceptor energy level. So 'Ea' is empty energy level.



→ When thermal energy is given then the $e^{\ominus}$'s will excite to E_a level leaving holes in the Valence bond.

Hence holes concentration increases.

→ A few $e^{\ominus}$'s will recombine with holes and $e^{\ominus}$'s concentration decreases.

→ When a trivalent impurity is added to pure intrensic semiconductor, the it displaces the semiconductor atom and 3 covalent bonds are formed and a hole in the left. On supplying thermal energy this hole accept free electron.

→ In P-type semiconductor Holes are majority and free $e^{\ominus}$ are minority carriers.

→ Trivalent impurity is called acceptor impurity because it accepts electrons.

Un-biased P-n Junction :

The layer which separates p-type and n-type material called PN Junction.

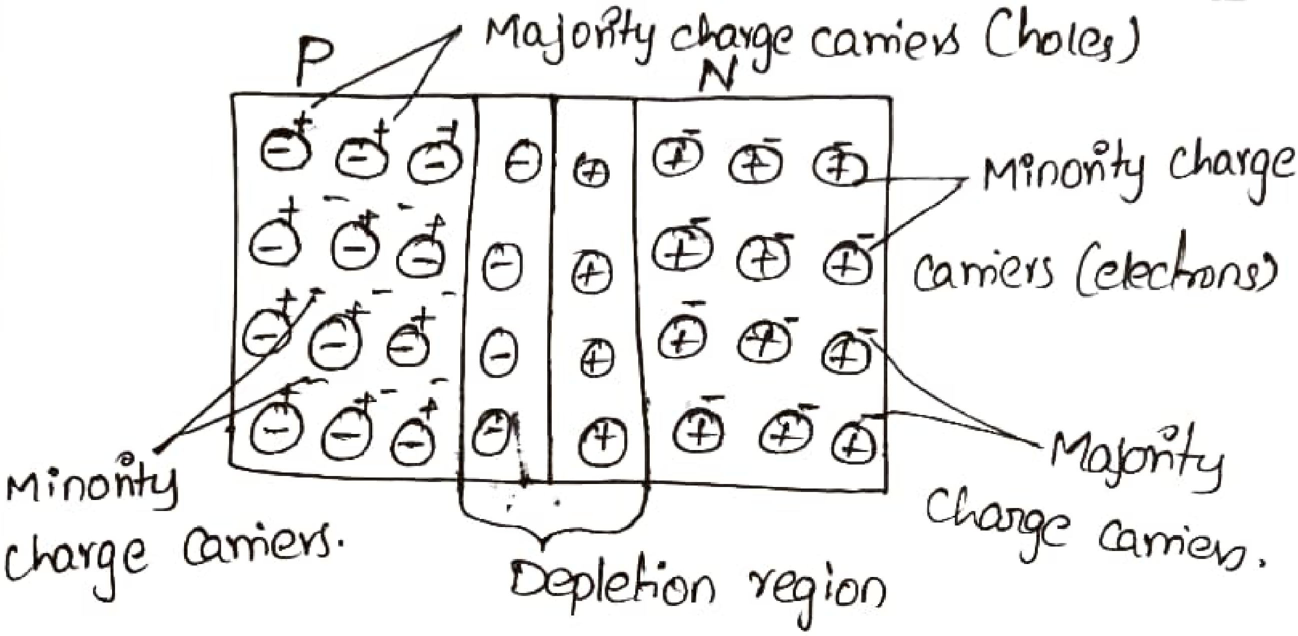
→ The n-type material has electrons as majority charge carriers and holes as minority carriers.

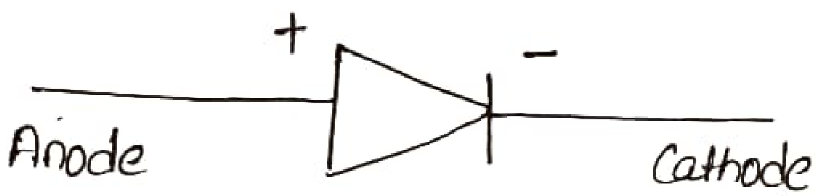
→ The p-type material has holes as majority charge carriers and electrons as minority carriers.

→ Due to the above distribution of charge carriers a "potential gradient" is formed. As a result the charge carriers i.e electrons flow from n to p and holes from p to n.

→ The flow of current called diffusion current. As the junction is unbiased the charge carriers do not have sufficient energy to flow from n to p and p to n material. Hence only few charge carriers cross the Junction.

→ Due to the above process few electrons and holes will combine with each other and form a neutral region. The neutral region is called "depletion region" (or) space charge region (or) depletion layer.





As the charge carriers do not have sufficient energy to cross depletion region. There fore the charge carriers accumulate on either side of the Junction and form a potential known as "potential barrier" (ev).

→ Hence in a unbiased P.N Junction there is no conduction

Biased P-N Junction:-

Diode:- A diode or P-N Junction is a Semiconductor device which conducts current only in one direction.

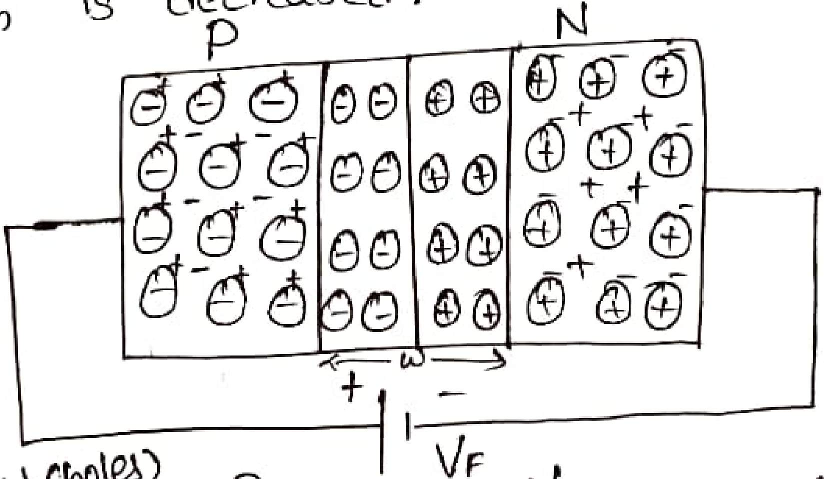
A diode is operated in 2 modes:

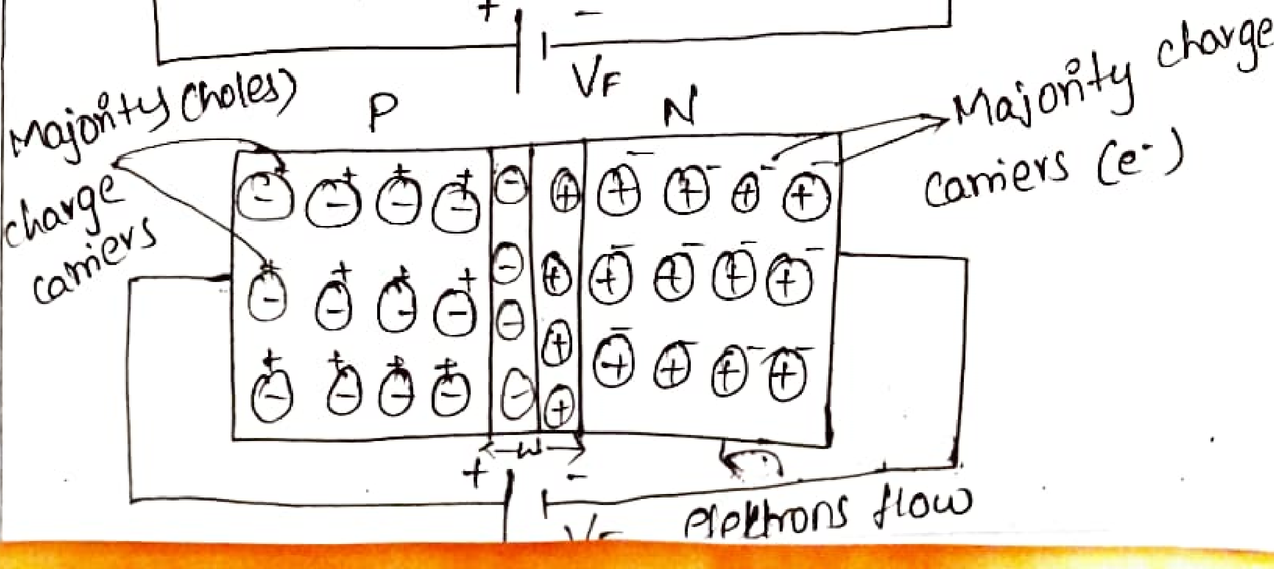
1. Forward bias
2. Reverse bias.

Forward bias :-

when the p-type material is connected to positive terminal and n-type material is connected to negative terminal then the diode is said to be in forward bias.

→ The positive terminal repels the holes and negative terminal repels the electrons as a result both the charge carriers moves towards the junction there by the depletion region width is decreased.





→ Initially with increase in forward voltage there is no current observed upto certain voltage called cut in voltage or threshold voltage.

→ The forward voltage at which the forward current starts flowing is called cut-in voltage (V_γ) or threshold voltage.

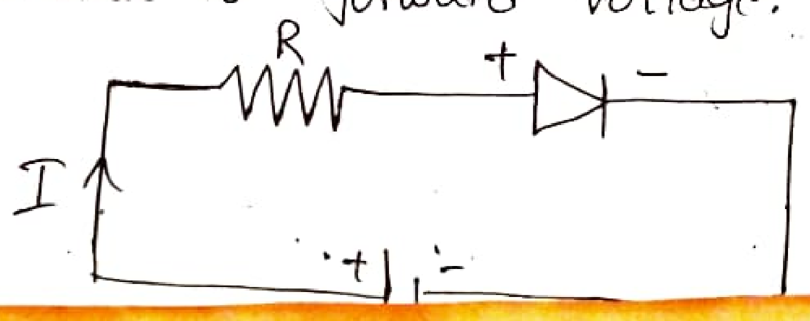
→ with further increase in forward voltage beyond 'V_γ' the forward current increases exponentially.

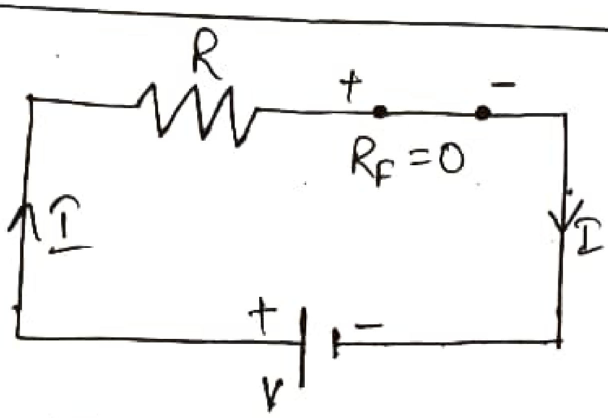
→ under forward bias diode conducts current therefore it acts as closed switch.

→ under forward bias an ideal diode offers "zero" resistance and practically it offers very low resistance (10 Ω to 300 Ω).

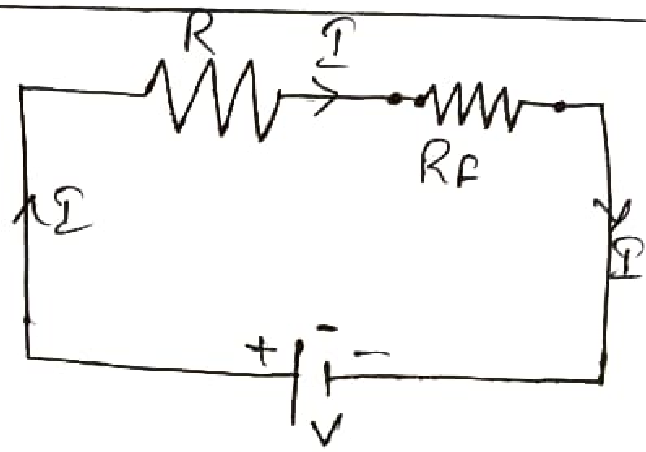
→ with increase in forward voltage. The depletion region decreases there by forward resistance also decreases.

→ Hence the forward resistance is inversly proportional to forward voltage.





Ideal diode



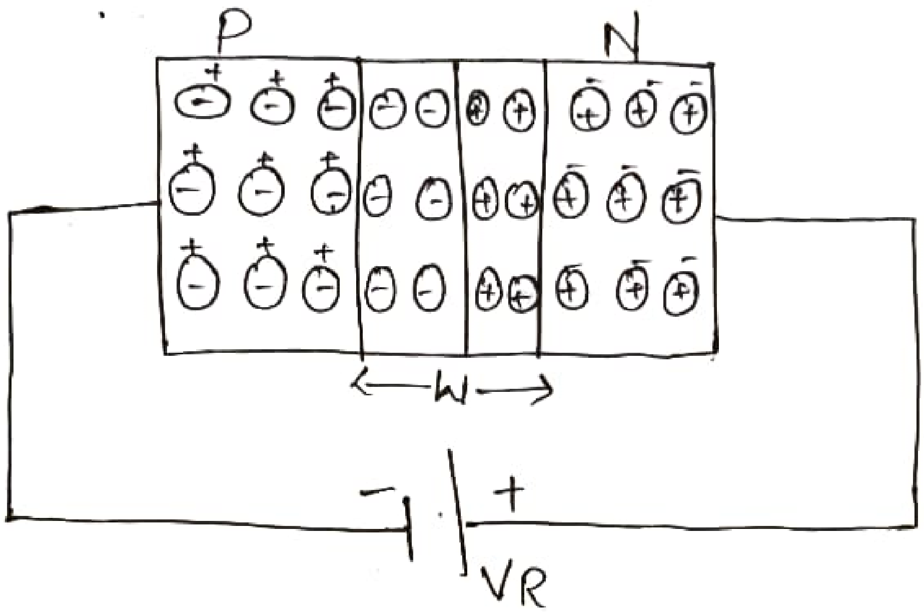
practical diode.

Reverse bias :-

when p-type material is connected to negative terminal and n-type material is connected to positive terminal then the diode is said to be in "reverse bias".

→ the positive terminal attracts the electrons and negative terminal attracts the holes. as a result both the charge carriers move away from the junction.

→ Due to the above action depletion region width increases and there are no charge carriers crossing the junction.



→ with increase in reverse voltage there is a small leakage (or) reverse saturation current of negligible value upto certain reverse voltage called breakdown voltage.

→ With increase in reverse voltage beyond break down voltage the minority current (or) leakage current increases with increase in reverse voltage

→ It is not ~~advisable~~ advisable to operate a diode beyond break down voltage if operated diode gets damaged.

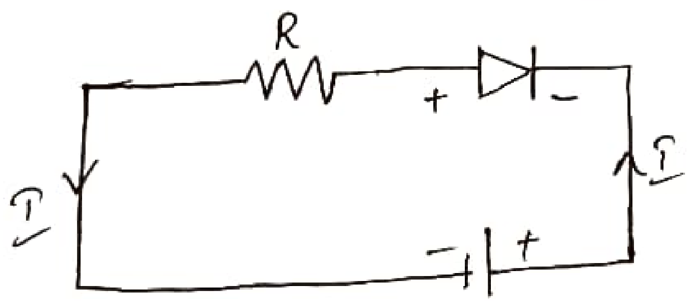
→ A diode under reverse bias acts as open switch

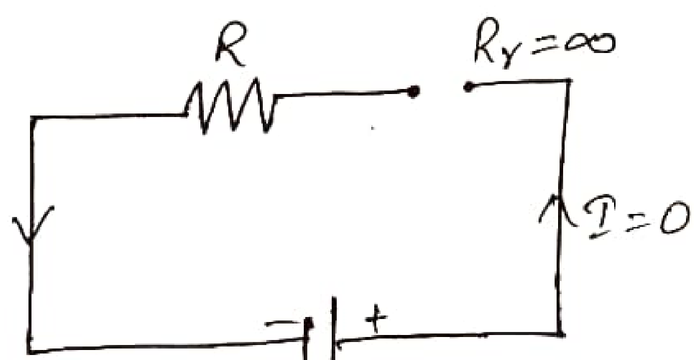
→ Hence under reverse bias a diode doesnot conduct current.

→ Ideally under reverse bias diode offers infinite resistance, practically it offers very high resistance

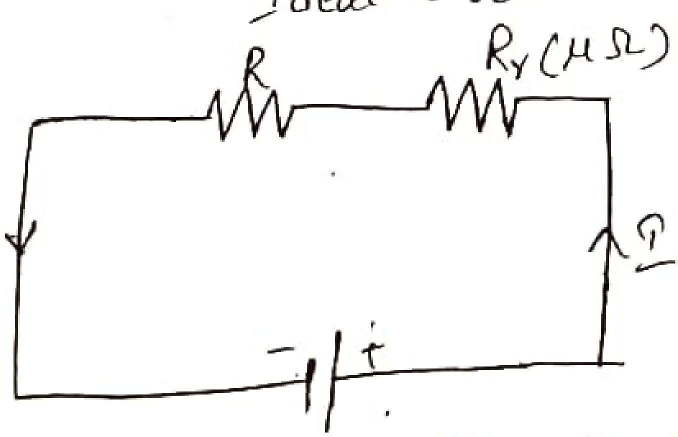
→ With increase in reverse voltage the depletion region width increases hence reverse resistance increases.

→ Therefore reverse resistance is directly proportional to reverse voltage.



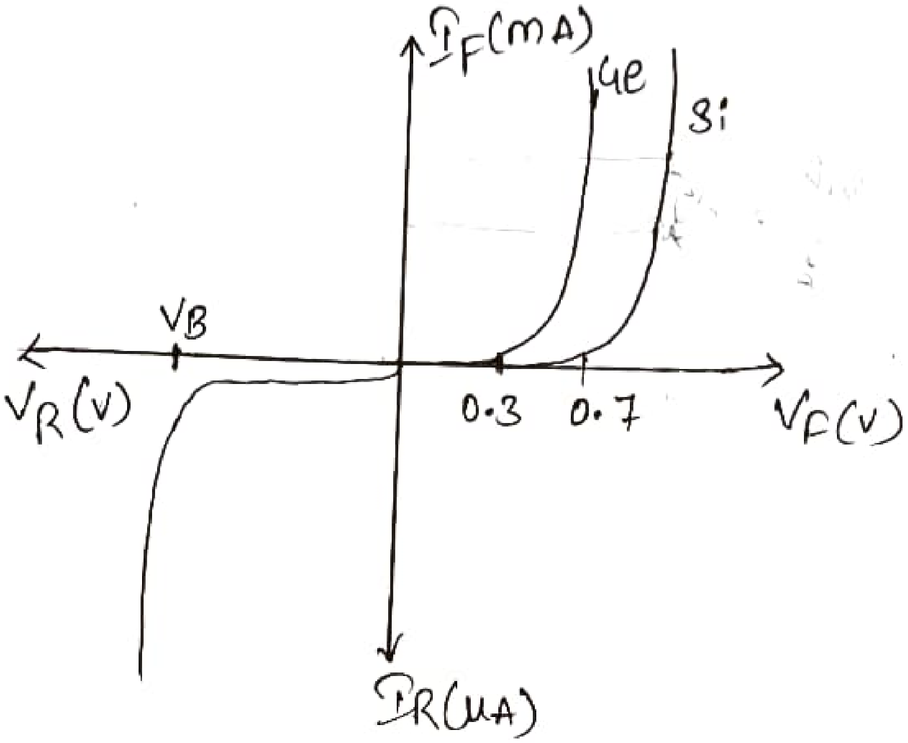


Ideal diode



practical diode

Volt-ampere (V-I) characteristics of diode (practical)



Forward characteristics :- under forward bias diode acts as a closed circuit. Initially with increase in forward voltage there is no current observed upto certain voltage called cut-in voltage or threshold voltage (V_γ)

($V_\gamma = 0.7V$ for Si, and $V_\gamma = 0.3V$ for Ge)

⇒ Beyond cut in voltage for a small increase in forward voltage, forward current increases exponentially.

The diode current equation is given by

$$I_D = I_0 \left(e^{V/\eta V_T} - 1\right)$$

$$I_D \simeq I_0 (e^{V/\eta V_T})$$

where $V_T = \frac{KT}{q} = \frac{T}{11,600}$, volt-equivalent temperature

K = Boltzman's constant = 1.38×10^{-23} J/K

T = Temperature in Kelvin

q = charge of electron (or) hole = 1.602×10^{-19} C

V = applied voltage.

η = a constant

η = 1 for Ge

= 2 for Si

Reverse characteristics :-

under reversebias diode acts as open circuit. with increase in reverse voltage there is no current flow upto certain voltage called breakdown voltage (V_B)

→ practically a small leakage current flows from "0" to "V_B" which is in the order of "µA".

→ Beyond "V_B" with increase in reverse voltage, the reverse current or leakage current starts flowing. & with increase in reverse ~~curren~~ voltage current also increases.

→ It is not advisable to operate a diode above "VB", if operated the diode will be damaged.

→ under reverse bias diode offers very high resistance in order of several mega ohms/MΩ

Forward Resistance :-

→ Static Forward Resistance :- The resistance offered by the p-n Junction under d.c conditions in forward bias is called static forward Resistance. This is denoted by R_F and is calculated at a particular point on the forward characteristics.

for example at point E, the static resistance R_F is

$$R_F = \frac{\text{Forward d.c Voltage}}{\text{Forward d.c current}} = \frac{OA}{OC}$$

→ Dynamic forward resistance:- The resistance offered by the p-n Junction under a.c conditions in forward bias is called dynamic forward resistance.

For eg:- consider the change in voltage from point A to B, this is denoted as ΔV, the corresponding change in the forward current is from point C to D. It is denoted as ΔI, thus the slope is $\Delta I / \Delta V$, the reciprocal of the slope is dynamic resistance r_f

$$r_f = \frac{\Delta V}{\Delta I} = \frac{1}{\Delta I / \Delta V} = \frac{1}{\text{slope of the characteristic}}$$

Generally value of r_f is very small.

* **Reverse resistance :-**

→ Reverse static resistance :- This is reverse resistance under d.c conditions.

$$R_R = \frac{\text{Applied reverse voltage}}{\text{Reverse saturation current}} = \frac{OQ}{I_0}$$

→ Reverse Dynamic resistance :- This is the reverse resistance under a.c conditions. It is the ratio of incremental change in the reverse voltage applied to the corresponding change in the reverse current.

$$r_r = \frac{\Delta V_R}{\Delta I_R}$$

** **Diode current Equation:-** It gives the mathematical relationship between applied voltage 'V' and current through the diode. 'I'. It is given by

$$\boxed{I = I_0 \left[e^{V/\eta V_T} - 1 \right]} \text{ Amp}$$

where
I_0 – Reverse saturation current
V – applied voltage
η – 1 for Ge
– 2 for Si, and $V_T = 26mV$, $V = \frac{T}{11600}$ volts

The factor η is called emission coff or ideality factor

This factor takes into account the effect of recombination taking place in the depletion region.

* EFFECT OF TEMPERATURE :-

→ The overall diode characteristics depends on the temperature

— ON FORWARD VOLTAGE :- $I_0 = K T^m e^{-V_{G0}/\eta V_T}$

where K = const independant of temp
m = 2 for Ge
= 1.5 for Si
V_{G0} - forbidden Energy gap.

As the temp increases, the value of I_0 increases and hence the diode current increases. To keep diode current increases. To keep diode current constant it is necessary to reduce the applied voltage V of the diode.

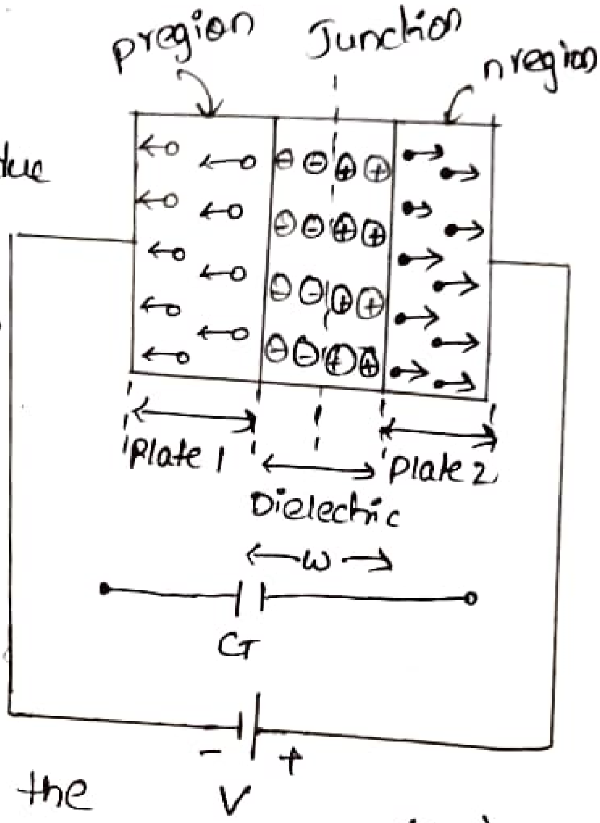
→ Practically the value is assumed to be
$-2.5\ mV/°C$.

- On Reverse saturation current :- Experimentally it is found that the reverse saturation current (I_0 increases) approximately double for every 10°C rise in temp.

I_{O2} =

* TRANSITION CAPACITANCE (C_T) :-

When a diode is reverse biased, reverse current flows due to minority carriers. majority charged particles i.e electrons in n-region and holes in P-side move away from the Junction. This increases the width of the depletion region. As the charged particles move away from the junction there exists a change in charge (dQ) with respect to the applied reverse voltage (dv). This is nothing but a capacitive effect. such a capacitance which comes into the picture under reverse biased condition is called transition capacitance / space charge capacitance / barrier capacitance



$$C_T = \frac{dQ}{dv}$$

As applied reverse biase voltage increases, it increases the Barrier potential (V_B). This increases the width of barrier i.e.. depletion layer

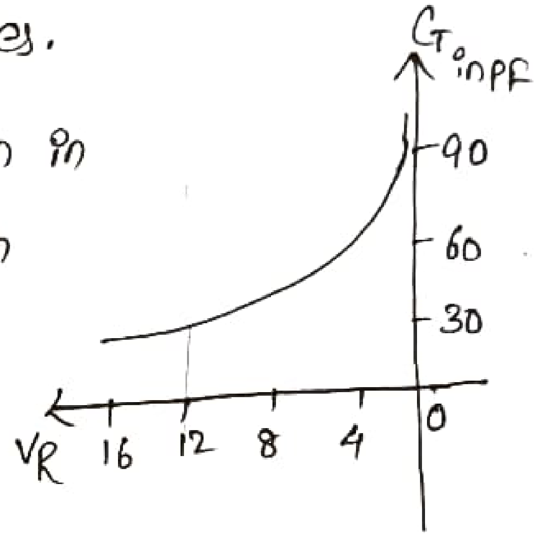
$$W \propto \sqrt{V_B}$$

The transition capacitance $C_T = \frac{\varepsilon A}{W}$

$\therefore C_T \propto \frac{1}{W}$

Hence transition capacitance C_T decreases as the reverse bias voltage increases.

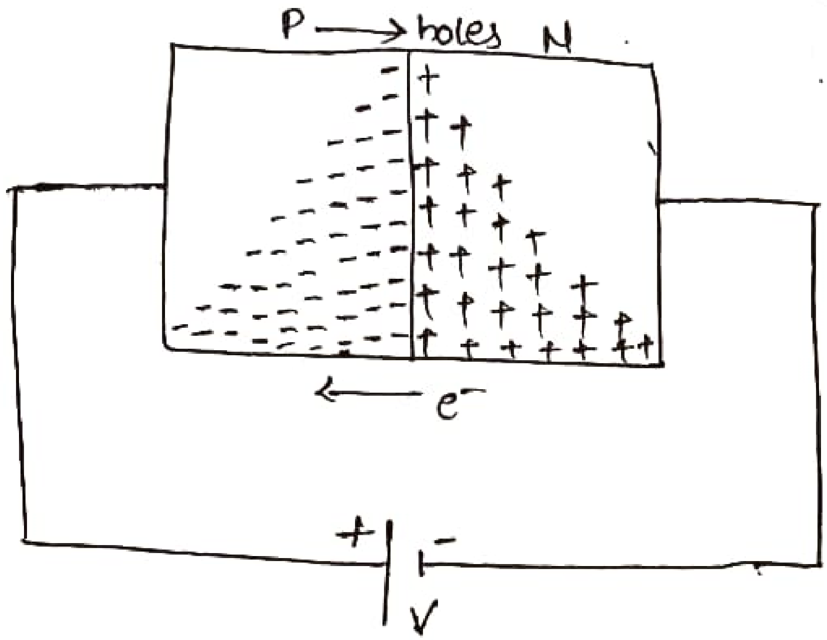
The graph shows the variation in the transition capacitance with the applied reverse voltage. C_T varies from 80 PF to less than 5 PF as V_R changes from 2V to 15V.



* **Diffusion Capacitance (C_D):-**

During forward biased condition, an another capacitance comes into existance called diffusion capacitance or storage capacitance (C_D).

In forward biased condition, the width of the depletion region decreases and holes from p side get diffused into n-side while e's from n-side move into the p side.



As the Applied voltage increases. concentration of injected charged particles increases. this rate of change of the injected charge with applied voltage is defined as diffusion capacitance.

$$C_D = \frac{dQ}{dV} \Rightarrow C_D = \frac{\tau I}{\eta V_T}$$

τ = mean life time.

C_D is proportional to current, the value of C_D is of order (nF) nano farrads. to micro farrads (μF). while C_T is of order pico farrads (pF). so C_D is much larger than C_T.

Diode switching times :-

→ Diode can be used as an electrical switch

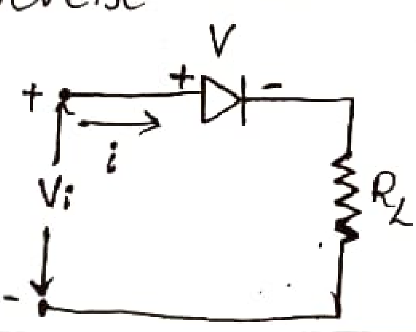
→ when the diode is forward bias - It will act as closed circuit and when ever it is reverse biased acts as open circuit.

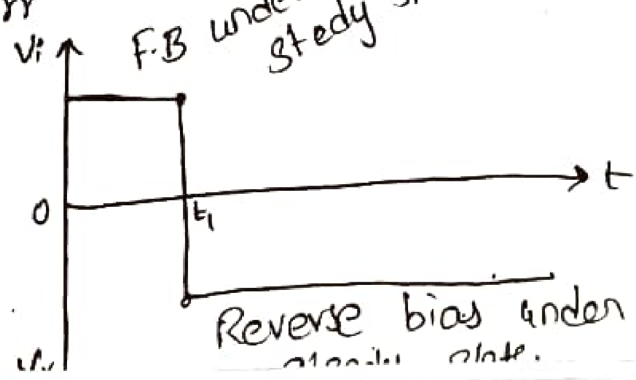
→ Forward bias indicate - ON state / switch
Reverse bias indicate - OFF switch.

* forward recovery time (t_{fr})
* Reverse recovery time (t_{rr})

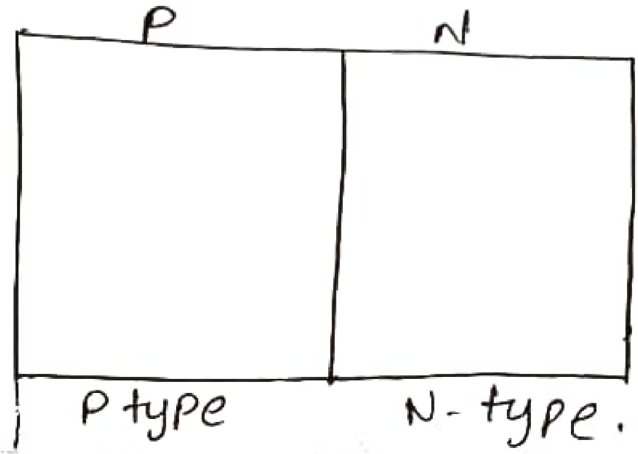
→ **Forward recovery time** :- The time interval taken by the diode to switch from reverse biased (OFF) to a forward bias (ON) is t_{fr}.

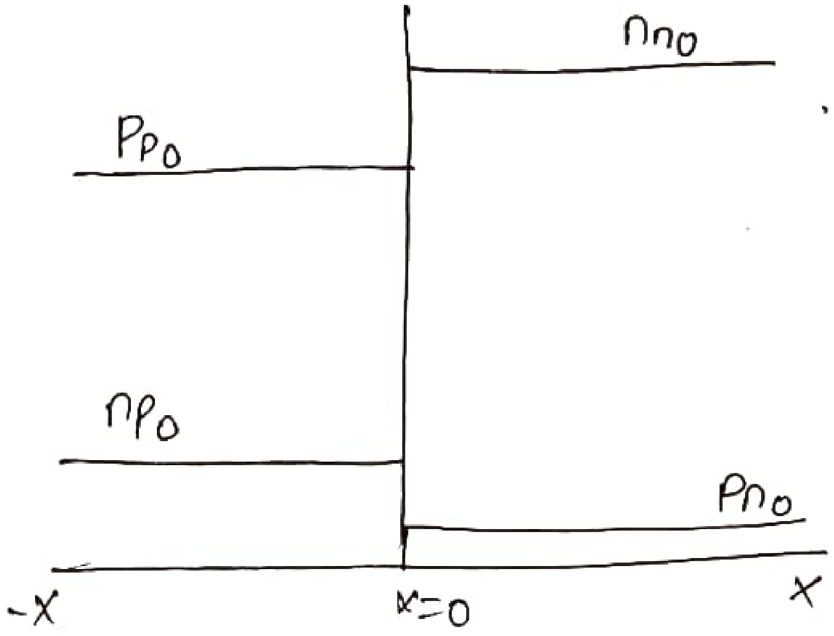
→ **Reverse recovery time** :- The time interval taken by the diode to switch from forward bias to reverse bias is t_{rr}.





Open cuircuit P-N diode





Diode Switching times :-

→ The Response of a system to any sudden change from an equilibrium position is called as transient response.

→ The sudden change from forward to reverse and from reverse to forward bias, affects the circuit.

→ The time taken before the diode recovers its steady state is called as "Recovery time".

→ The time interval taken by the diode to switch from forward biased state to reverse biased state is called as "Reverse Recovery time".

→ The time interval taken by the diode to switch from reverse biased state to forward biased state is called as "Forward recovery time".

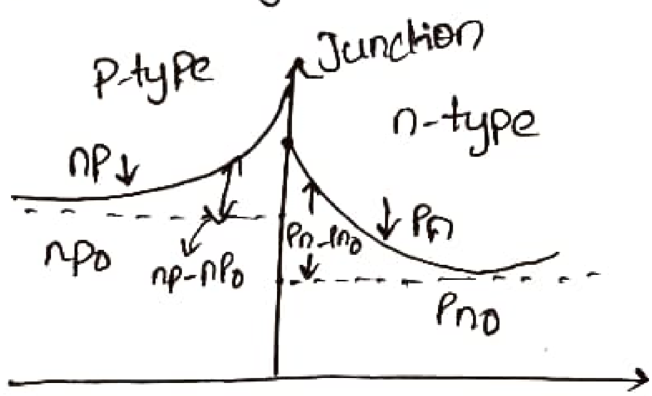
During forward biased condition:-

When the voltage is applied, due to the forward biased condition, the majority carriers of one side move towards the other side.

They become minority carriers of the other side. This concentration will be more at the junction.

→ The minority carriers are more near to junction and less far from junction.

→ For Example while electrons coming from one end of the region to other end close to the junction these electrons will be high while they move towards p-region there is a posibility of recombination of electrons with these holes there -fore the minority carrier concentration decreases.

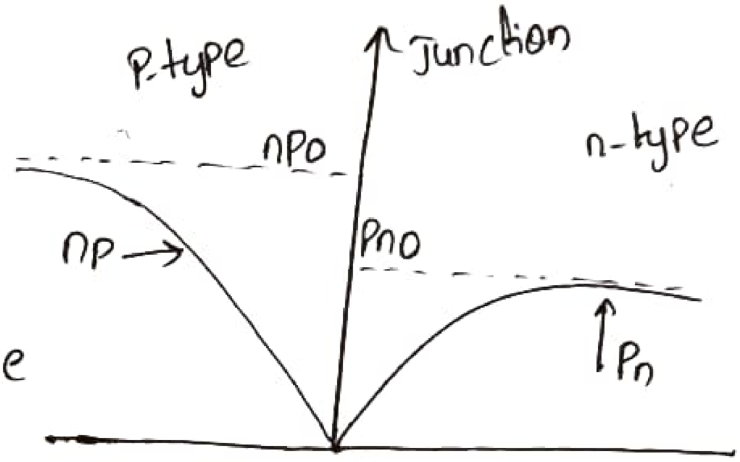


During reverse biased condition:-

→ majority carriers doesn't conduct the current through the junction & hence don't participate in current conduction, the switching diode behaves as a short circuited for an instance in reverse direction

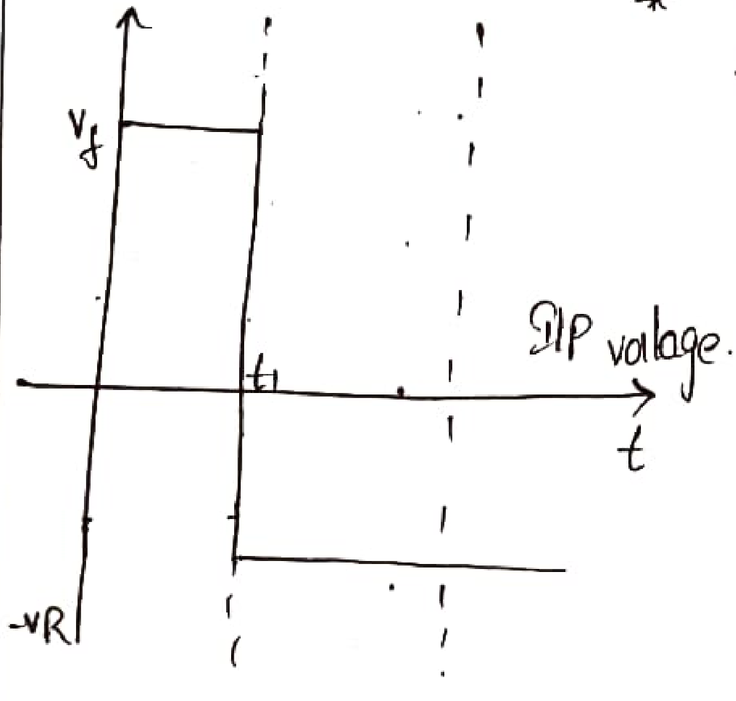
→ The majority carriers will cross the junction & conduct the current, which which is called as "Reverse Saturation current"

→ The time required for the diode to change from the forward bias to reverse bias called "Reverse Recovery time" (trr).



following graph shows the diode switching times.

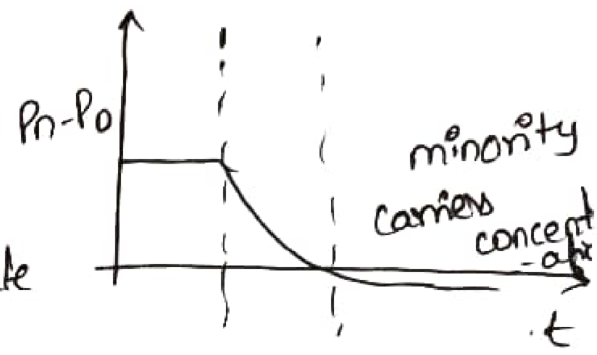
1. Storage time :- (ts)



* The time period for which the diode remains in the conduction state even in the reverse biased state. is called as storage time.

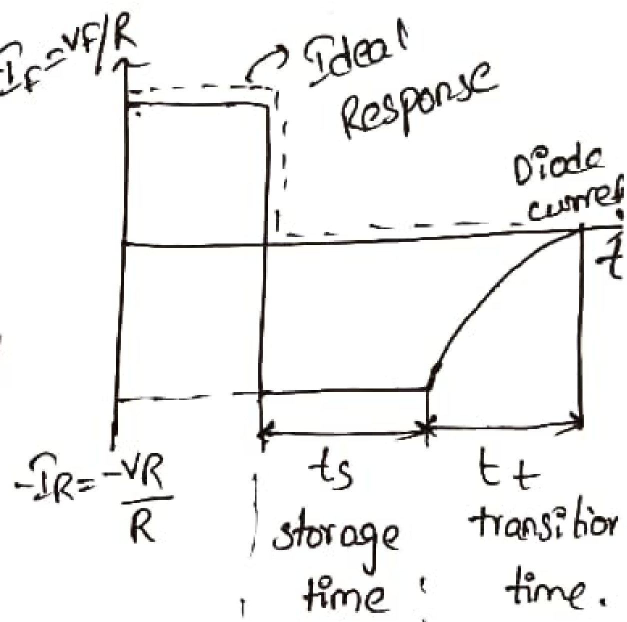
* Transition time :- (t_t)

The time elapsed in returning back to the state of non-condition, i.e, steady state reverse bias, is called as transition time.



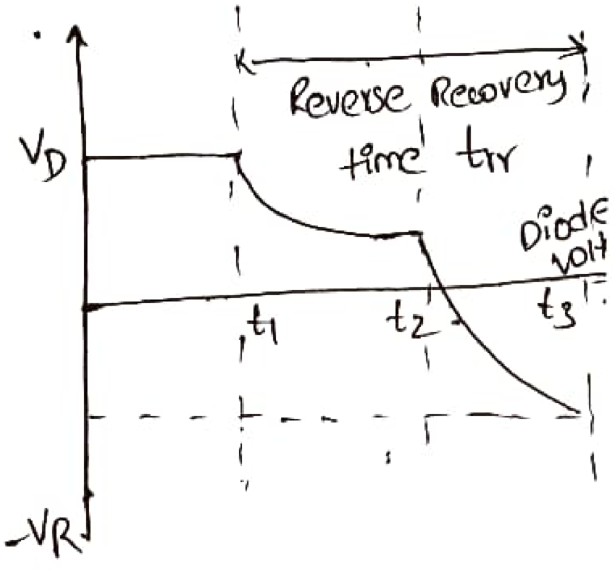
* Reverse recovery time :-

The time required for the diode to change from forward bias to reverse bias is called as " Reverse recovery time".



* Forward recovery time :-

The time required for the diode to change from reverse bias to forward bias is called as " Forward recovery time".



** BREAK DOWN MECHANISMS :-

1. **Avalanche Breakdown** :- The applied reverse bias causes a small reverse current I_0 to flow in the diode. This is due to the movement of minority charge particles. The polarity of reverse bias voltage is such that only the minority carriers are able to cross the junction. As the applied reverse bias voltage becomes larger, the minority carriers increasingly accelerate.

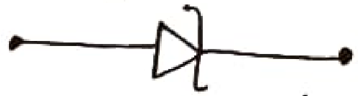
There are collisions b/w the carriers & e̅s involved in the covalent bonds of the crystal structure.

— If the applied voltage is such that the travelling e̅s do not have high velocity the the collisions take some energy away from them, altering their velocity. If the applied voltage is increased, the velocity and hence K.E $(=\frac{1}{2}mv^2)$ of e^- increases. If such an e^- dashes an e^- involved in covalent bond, then the collision gives bond-valence e^- enough energy to enable it to break its covalent bond. Thus one e^- by collision creates an e^--hole pair.

These secondary particles are also accelerated and participate in collisions that generates new pairs. This phenomenon is known as carrier multiplication or Avalanche- multiplication or self- sustained multiplication. At this stage & junction is said to be in break down & current starts increasing rapidly.

Zener Breakdown:- When a p-n junction is heavily doped. the depletion region is very narrow. So under reverse bias condition, the electric field across the depletion layer is very intense., of the order of 10^8 v/m or 10^6 v/cm such an intense field is enough to pull the e's out of the valence bonds of the stable atoms. So this is not due to the collision of carriers with atoms. Such a creation of carriers is called Zener Effect which is diff than the avalanche effect. These minority carriers constitute very large current and the mechanism is called Zener breakdown.

ZENER DIODE:- The zener diode is a silicon p-n junction diode except that it is properly doped to have a very sharp and almost vertical breakdown. They are exclusively operated under reverse biased conditions. and designed to operate in break down region.



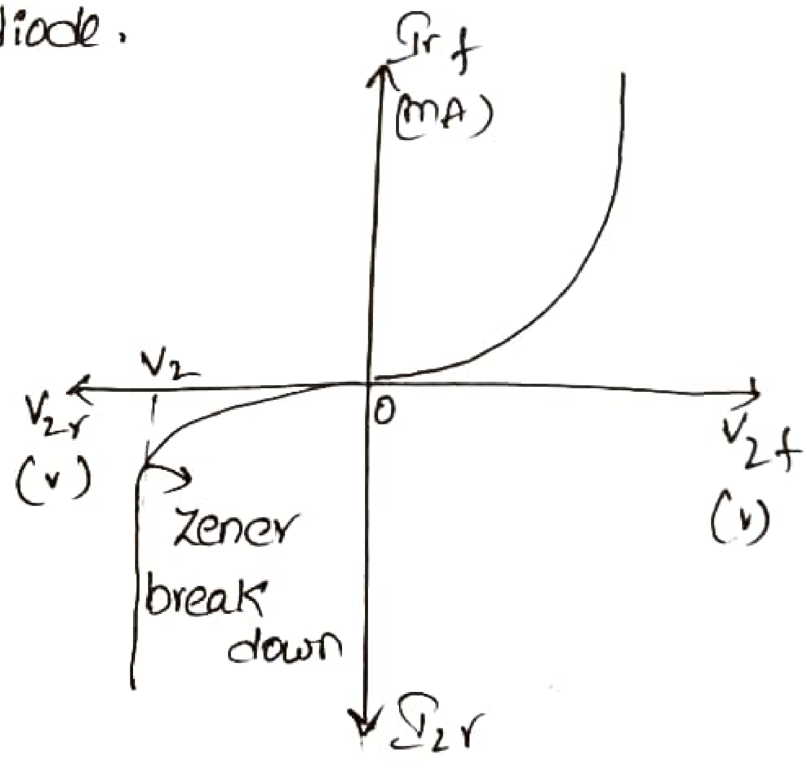
A zener diode is heavily doped p-n junction diode here, the depletion region is very narrow. When the reverse bias across the diode is increased, breaking of covalent bonds takes place by the intense electric field ($\approx 10^8 v/m$) set up across the depletion layer. It produces a large no of $\bar{e}$-hole pairs resulting in a sharp increase in reverse current.

→ **Applications:-**

1. As a voltage regulator element.
2. used in various protection circuit.
3. In limiter circuits.

→ **Characteristics of zener diode:-** In the forward bias condition, the normal pn diode and the zener diode operate in similar fashion.

In the reverse biased condition, the zener diode carriers reverse saturation current till the reverse voltage applied is less than the reverse breakdown voltage. when the reverse voltage exceeds breakdown voltage, the current through it changes drastically. but the current voltage across it remains almost constant. Such a break-down region is a normal operating region for zener diode.



→ when the reverse voltage to a zener diode is increased, initially the current through it is very small (μA). This is reverse leakage current. At certain reverse voltage, current through zener

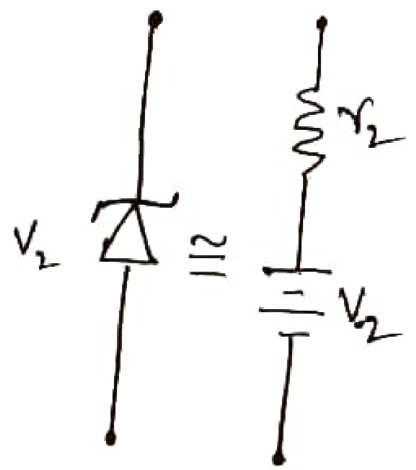
Zener diode increases rapidly. The change from a low value to large value of current is very sharp and well defined. This voltage is called Zener break down voltage (zener voltage) V_z.

Note:-

Zener diode & Equivalent circuit

Dynamic resistance

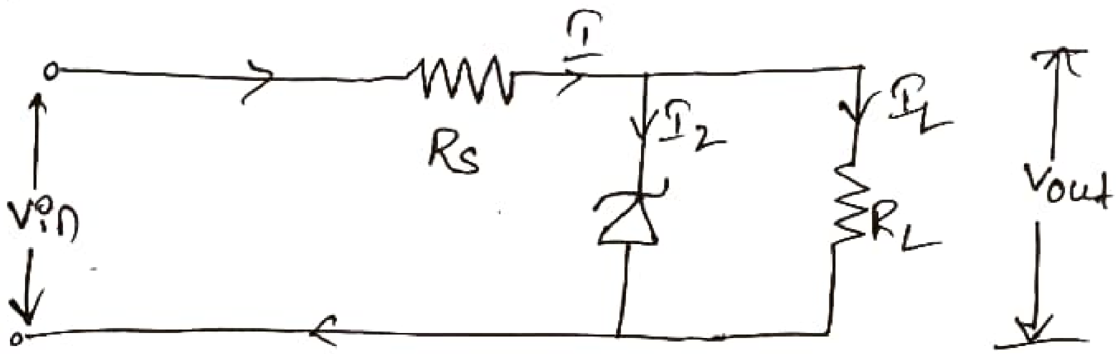
$$r_z = \frac{1}{slope} = \frac{1}{\Delta I_z / \Delta V_z}$$



→ Zener diode as Voltage regulator:-

Zener diode is a junction diode which is highly doped and operated in reverse bias.

From the typical characteristics of Zener diode it may be seen that, when it is reverse biased, a small, reverse saturation current flows through it until a certain voltage. called breakdown voltage or Zener voltage, Beyond this voltage the reverse current increases sharply, but voltage remains almost constant. Thus a Zener diode acts as voltage regulators.



The figure shows a simple Zener voltage regulator It is used to maintain a stabilized voltage accross load R_L inspite of variations in either the supply voltage or the load or both. The zener diode is reverse biased with unregulated d.c. input. i.e P-type of zener is connected to negative of the input voltage and n-type is connected to positive. the value of <u>series</u> <u>Resistor</u> <u>Rs</u> is so choosen that initially the zener diode operates in the breakdown region.

Let I be the current down from the Supply. I_Z is the current through the zener diode and I_L is the current through the load R_L using K.C.L and K.V.L laws

$$I = I_Z + I_L \quad \text{——— (1)}$$

and

$$V_{out} = V_{in} - IR_S = I_L R_L \quad \text{——— (2)}$$

A Voltage regulator o/p always remains constant So that for load regulation Vout should not change with the load.

from (2) :- $V_{out} = V_{in} - IR_S$

$$\Delta V_{out} = \Delta V_{in} - \Delta I R_S$$

$V_{in} \rightarrow$ is constant, hence $\Delta V_{in} = 0$

$V_{out} \rightarrow$ is constant, hence $\Delta V_{out} = 0$

and R_S is fixed

$$\therefore \Delta I = 0$$

from eqn (1) $\Delta I = \Delta I_Z + \Delta I_L = 0$

$$\Delta I_Z = -\Delta I_L$$

As the supply Voltage is fixed, if the load increases, the current I_Z decreases, if increases the zener current I_z correspondingly, Thus Vout across the load will remain constant.

* (B). Voltage regulation with a varying supply voltage (with const load)

from ② $\Rightarrow \Delta V_{out} = \Delta V_{in} - \Delta I \cdot R_s$

(for $V_{out} = const$, $\Delta V_o = 0$)

$$\therefore \Delta V_{in} = \Delta I R_s$$

and $V_{out} = I_L R_L \Rightarrow \Delta V_{out} = \Delta I_L R_L = 0$

$$\therefore \Delta I_L = 0$$

from ① :- $\Delta I = \Delta I_z$

when Supply voltage varies with fixed load R_L the current I and the zener current I_z changes equally to keep the output voltage Vout constant.

WAVE SHAPING:-

→ It is a process of changing the shape of a wave-form.

WAVE SHAPING

- Linear wave shaping
- Non-linear wave shaping

Linear wave shaping

* performed using linear elements (or) R, L, C elements

* The process of where by the form of non-sinusoidal signal is altered by transmission through a linear network is called linear wave shaping

Eg: Low pass & High pass RC ckts

Non-linear wave shaping

→ Along with "resistors", the non-linear element like diode are used in non-linear wave shaping.

→ The process where by the form of a sinusoidal signal are going to be altered by transmitting through a non-linear network is called non-linear wave shaping.

Eg:- clippers, clampers.

Clippers

- Series
  - unbiased series
  - Biased series
- Shunt
  - unbiased
  - biased

Clippers are classified as :-

① → * According to non-linear devices

→ Diode Clippers

→ Transistor clippers.

② * According to biasing:-

→ unbiased clipper

→ Biased clippers.

③ * According to configuration :-

→ series diode clippers

→ Shunt diode clippers.

④ * According to level of clipping

→ positive clippers

→ negative clippers

→ Biased clippers

→ Combination clippers.

→ Clippers:- The clipping circuits consists of linear & non-linear elements like resistors & diodes but not energy storage elements like capacitor.

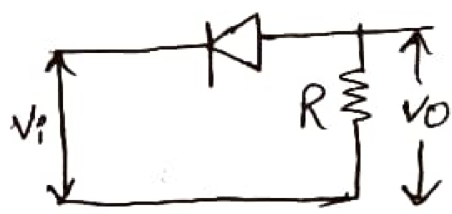
→ A Clipping circuit which removes the undesired part of the waveform & transmits only desired part of signal which is above (or) below referent

→ Clippers are also called as voltage (or) current limiter (or) amplitude selectors (or) slicers.

Among diode clippers, the 2 main types are
1. positive Clipper
2. Negative Clipper.

* **Positive clippers**:- A clipper which removes a portion of the positive half cycle of the input signal is called "positive clipper.

→ Here, the diode is kept in series with "R"



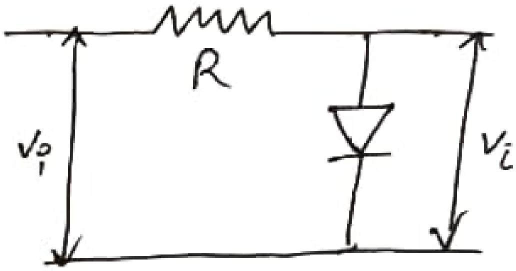
→ when V_i is positive, the diode does not conduct & acts as an open circuit & hence the positive clipper half cycle doesnot appear at the output i.e, the positive half cycle is clipped off.

*Positive series clipper.

→ when V_i is negative, the diode conduct and acts as closed switch.

Therefore, the negative half cycle appear at the output.

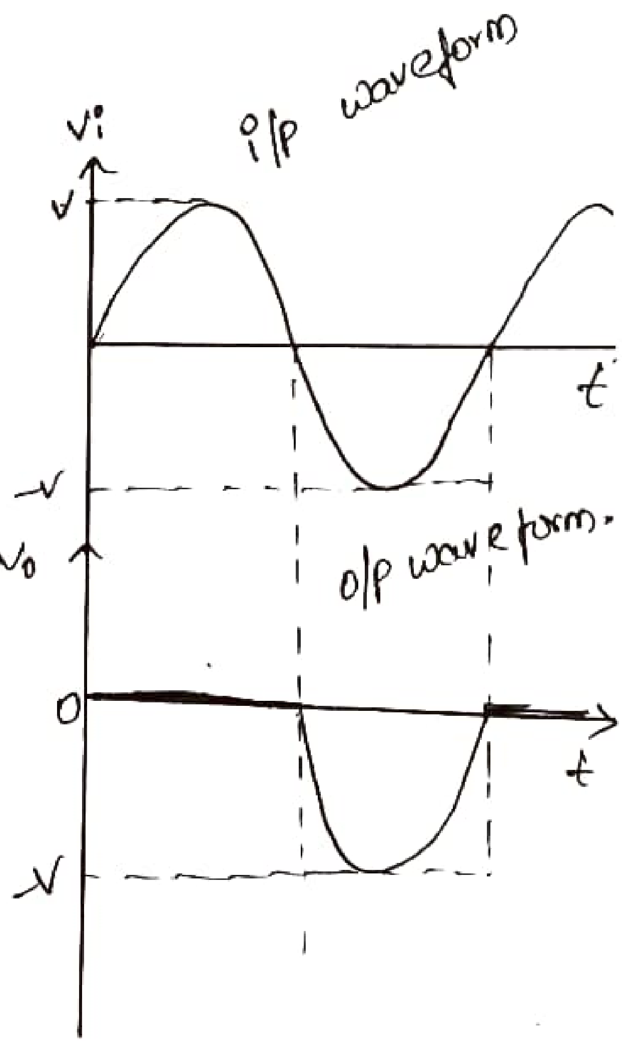
* **Positive shunt clipper:-**



Positive shunt clipper.

→ When V_i is positive, diode conducts & acts as short circuit & hence there is "0" signal at the output i.e, the positive half cycle is clipped off.

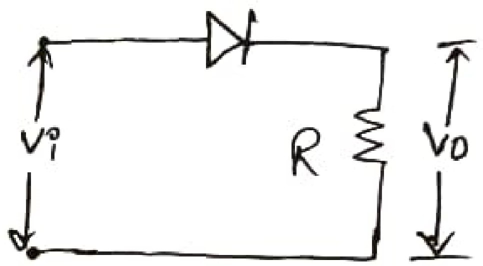
→ When the V_i is negative, diode does not conduct & acts as an open switch, the negative half cycle appear at the output.



Negative clipper :-

→ A clipper circuit that removes the negative half cycle is called "Negative clipper".

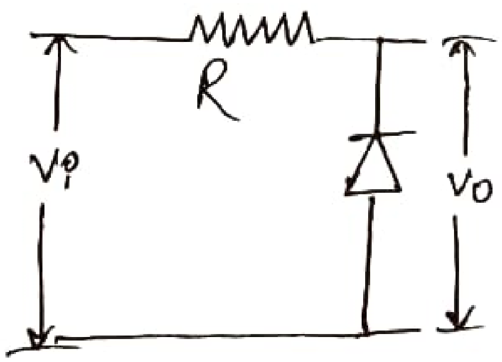
→ In series negative clipper when the i/p voltage is positive, diode conducts & acts as short circuit & hence the positive half cycle of the input signal will appear at the output.



Series Negative clipper

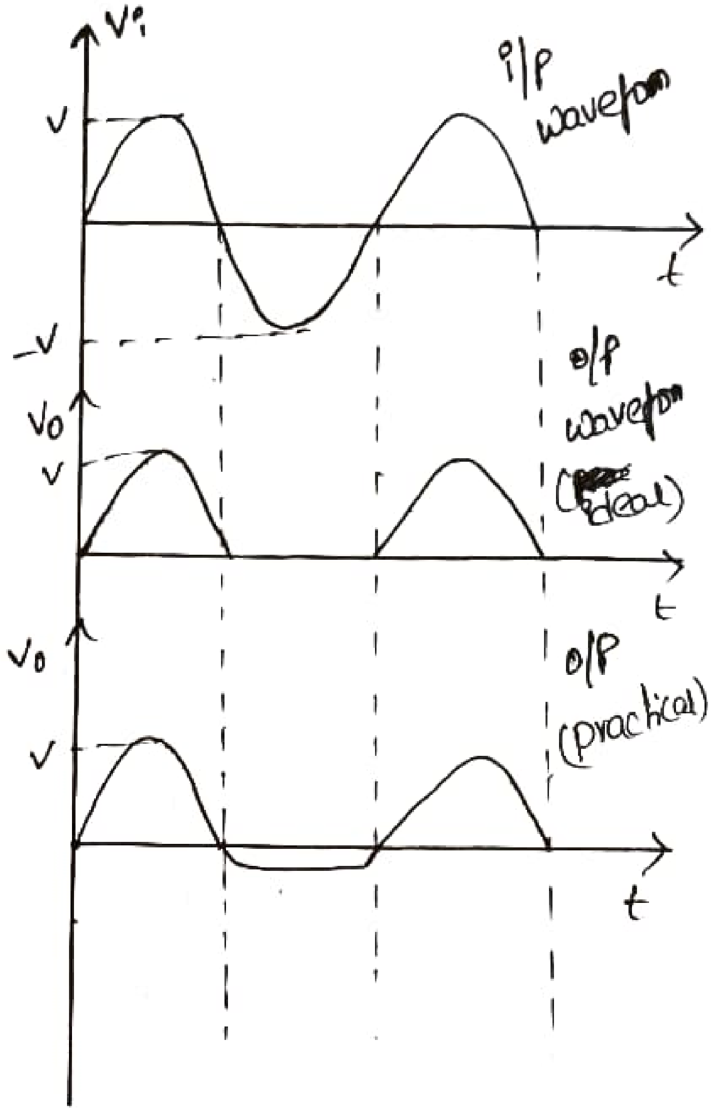
→ During the negative half cycle of i/p signal, the diode does not conduct & acts as an open circuit. the negative half cycle will not appear at the o/p.

→ In shunt negative clipper when the i/p voltage is positive, diode does not conduct & acts as open circuit, The positive half cycle will appear at the output.

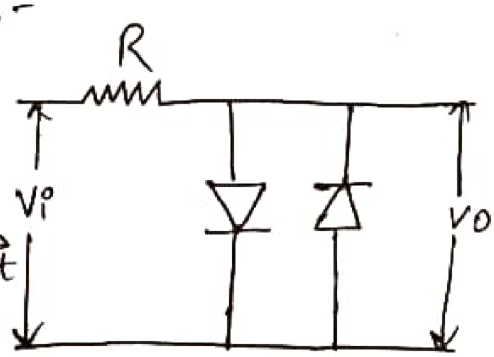


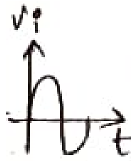
Shunt Negative Clipper.

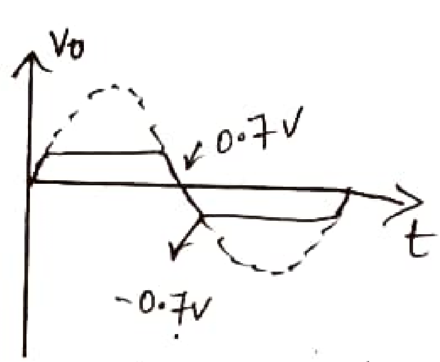
→ When the input voltage is negative, the diode conducts & acts as short circuit & hence there is "0" signal at the output i.e., negative half cycle is clipped off.



* Clipping of both half cycle :-



→ If we connect 2 diodes in inverse parallel as shown,  then both the positive & negative half cycles would be clipped as 'D1' diode clips the positive half cycle & diode "D2" clips the negative half cycle.



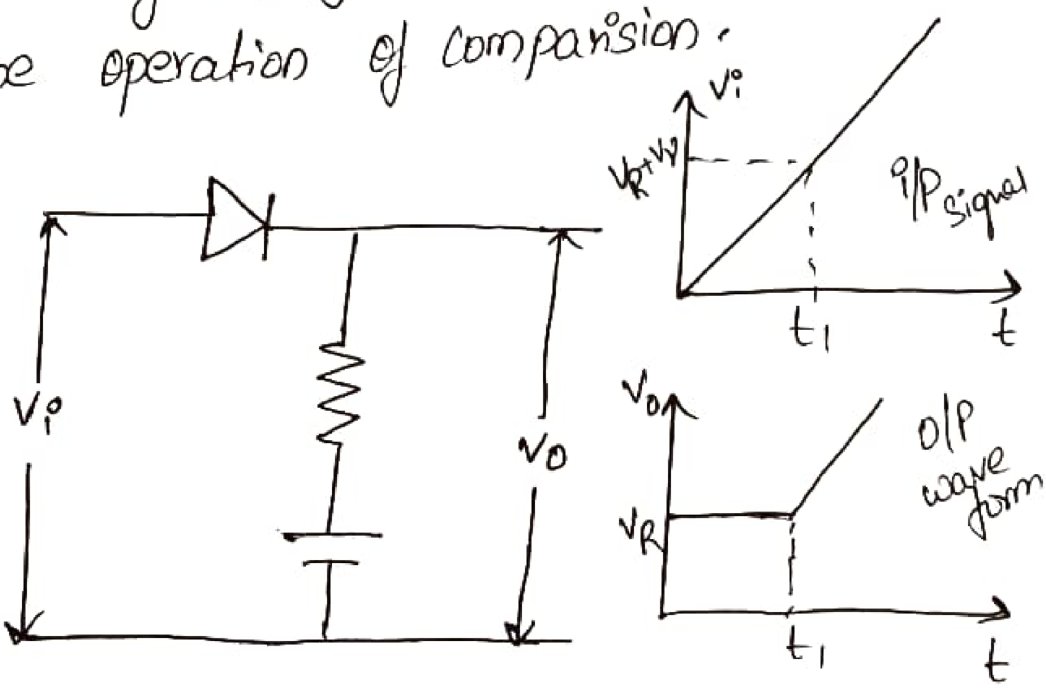
* Applications :-

→ Clippers are employed for different wave generations such as trapezoidal, square (or) rectangular waves.

→ used to eliminate amplitude noise, voltage spikes, & voltage regulation.

* Diode Comparator :-

→ The non-linear circuit which was used to perform the operation of cliping may also be used to perform the operation of comparision.



→ The comparator circuit compares an input voltage 'V_i' with reference voltage V_R.

→ The comparator output is independent of the signal until it attains the reference level.

→ like wise diode clipping circuits can be used to clip the positive half cycle, negative half cycle (or) both.

→ for ideal diodes the output waveform above would be "0", However due to the forward bias voltage drop across the diode, clipping occurs at ~~+0.~~ +0.7V & -0.7V.

* Advantages:-

1. To Eliminate the unwanted noise present in the amplitudes.
2. These can work as square wave converters, as they can convert sinwaves into square waves by clipping.

* Drawbacks:-

In shunt clipper, when diode is in "off" condition, transmission of i/p signal should take place to output. But incase of high frequency input signals, diode capacitance affects the circuit operation adversely & the signal gets attenuated.

→ when the i/p signal & reference level become equal there will be a sharp pulse at the comparator output.

→ The i/p signal is taken as ramp waveform, the i/p waveform crosses the voltage level

$V_i(t) = V_R + V_r$ at time $t = t_1$

→ The output remains constant at $V_0 = V_R$ until $t = t_1$.

→ After $t = t_1$ "V_0" raises along with i/p signal "V_i".

RECTIFIERS

* **Rectifier:-** Rectifier is a circuit which convert A.c power to D.c power.

Need for rectification:-

→ All electronic circuits functions on D.c power only

→ Desired value of Dc power supply can be generated.

→ Ac power is economical and availability is more.

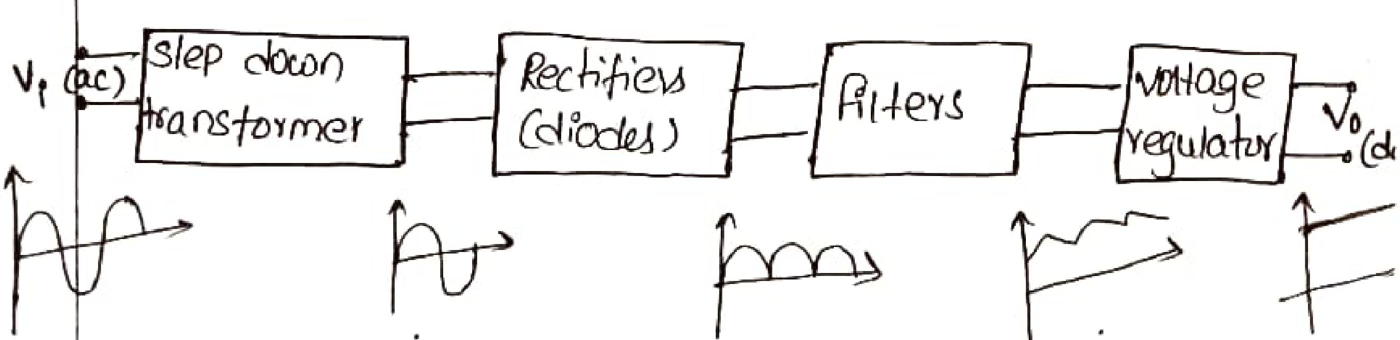
→ Hence a rectifier is a better replacement of batteries.

Regulated Power Supply:-

A rectifier converts Ac to DC power.

→ It has 4 sections. 1) transformer
2) diode
3) filter
4) voltage regulator.

The block diagram of RPS is.



Operation :-

→ The step down transformer converts high voltage AC power to low voltage AC power.

→ The output of step down transformer is connected to diodes. the diodes convert AC voltage in to unidirectional voltage (DC voltage). the output of diode is a "pulsating DC".

→ In order to get pure DC output a filter circuit is used.

→ The function of filter circuit is to convert pulsating DC in to pure DC.

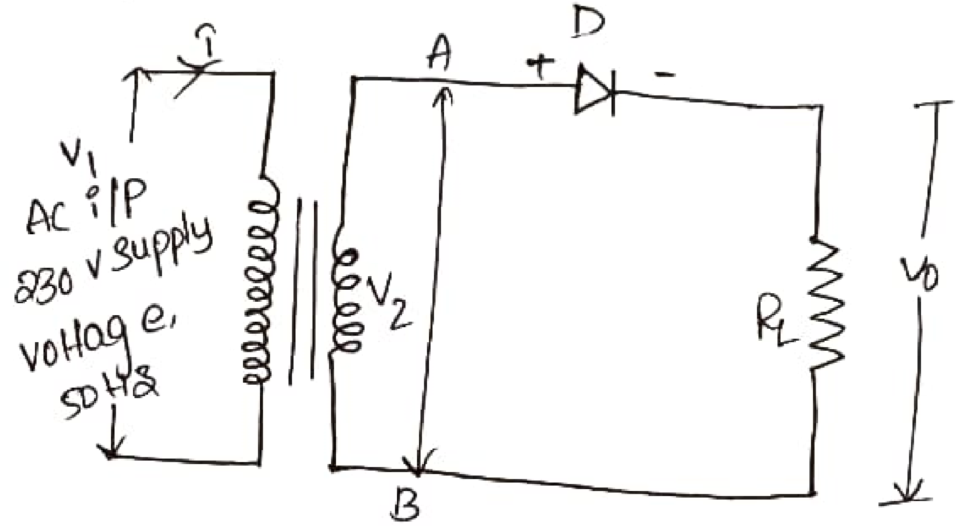
→ The filter circuit consists of R, L, C components.

→ In order to provide a constant & regulated DC. voltage to load, the output of filter circuit is given to voltage regulator.

Hence the regulated power supply provides a constant DC output to the load.

Half-wave rectifiers:-

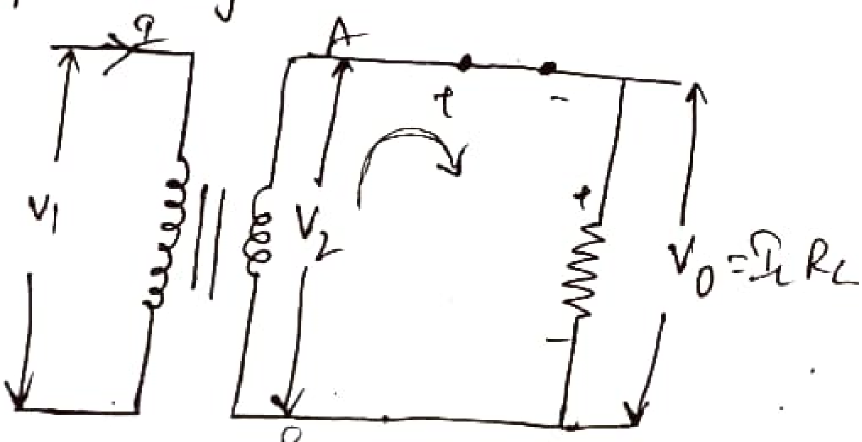
A half-wave rectifier circuit is shown below.



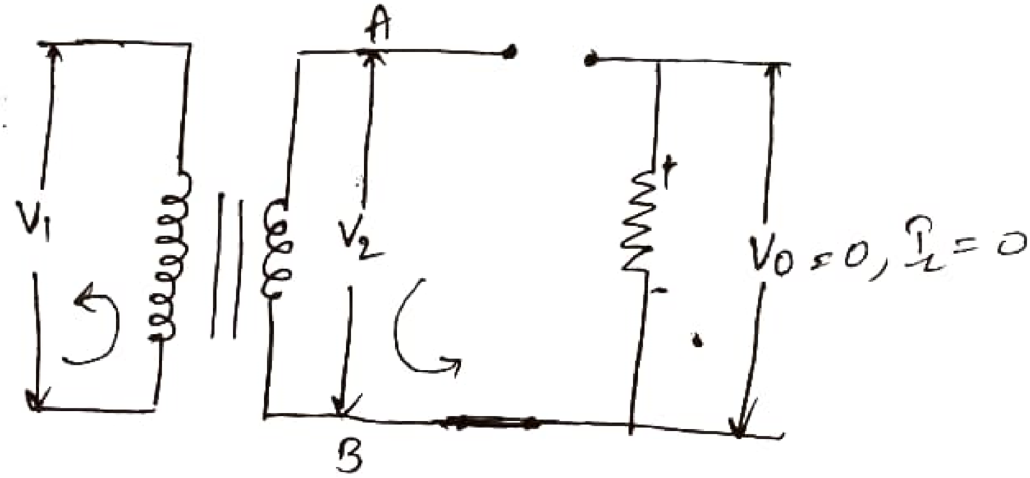
A half-wave rectifier consists of step-down transformer where a diode is connected in serie to the load to the secondary.

Operation :-

→ **Positive cycle:-** During positive cycles the reference point A is at higher potential when compared to B. Therefore diode gets forward bias and acts as closed circuit. The load current I_L flows through R_L & output voltage is taken across R_L.



Negative cycle :- During negative cycles the reference point B is at higher potential and point A is at lower potential. Therefore diode gets reverse biased and acts as open circuit. Hence load current I_L is zero and there by V_L is also zero.



→ Hence a half wave rectifier conducts output current only for half of total input current i.e, positive cycles only.

As the output is unidirectional, hence a half wave rectifier converts AC power to DC power.

→ The efficiency of half wave rectifier is very poor as it conducts output current only for half of total input cycle. It is given as 40.6%.

→ The ripple factor is 1.21.

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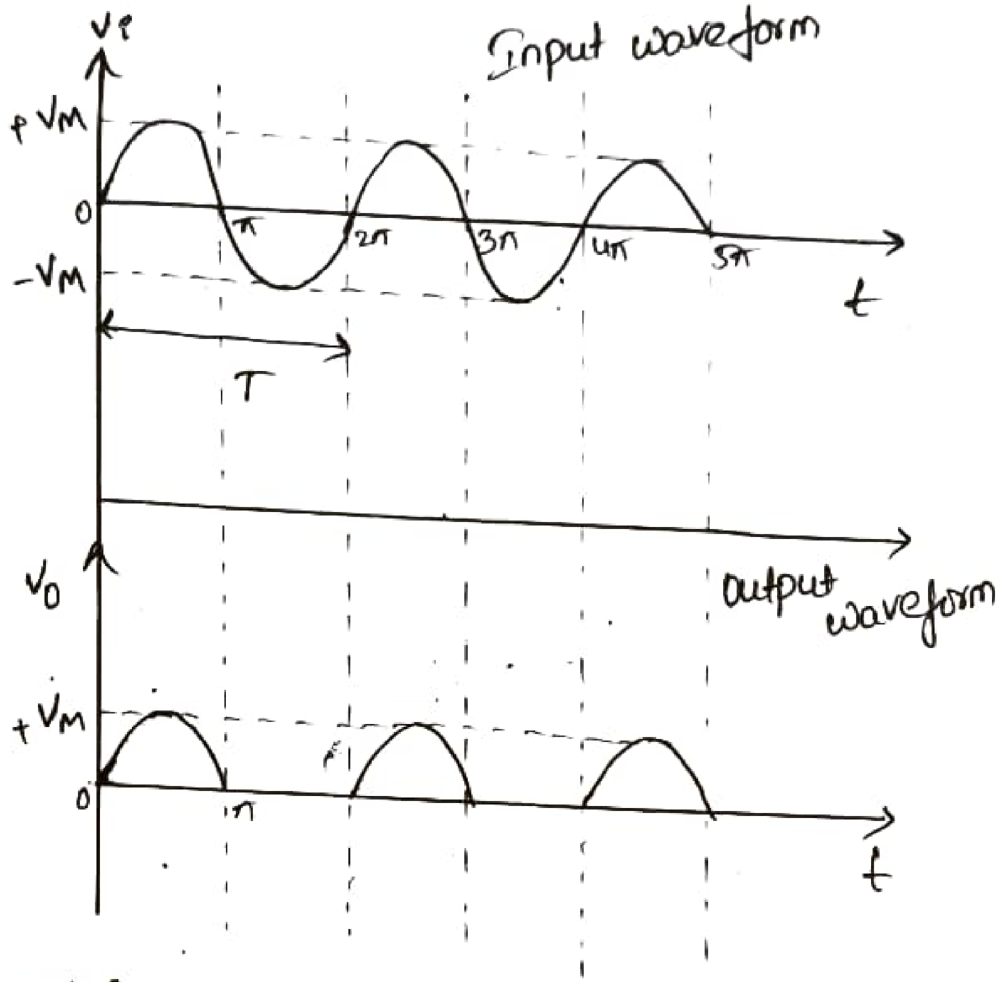


* Advantages :-

→ It is a Simple circuit & it is easy to use

→ Have low no. of component, therefore it is cheap

* Disadvantages :-

→ The ripple factor of halfwave rectifier is 1.21, which is quite high. The output contains lot of varying components.

→ The circuit has low transformer utilization factor.

→ The maximum theoretical rectification efficiency is found to be 40%. The practical value is is less than this. This indicates that half wave rectifier is quite inefficient.

* **Average (or) DC output current (I_{dc} (or) I_{avg}):-**

It is the ratio of area under the curve to period cycle.

$$I_{dc} \text{ (or) } I_{avg} = \frac{\text{Area of the curve}}{\text{period of the cycle.}}$$

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

$$I_{dc} = \frac{I_m(-\cos\omega t)_0^{\pi}}{2\pi}$$

$$I_{dc} = \frac{I_m}{2\pi}(-\cos\pi + \cos 0)$$

$$= \frac{I_m}{2\pi}((-(-1)+1)) = \frac{I_m}{2\pi}(2)$$

$$\boxed{I_{dc} = I_m/\pi} \quad \text{——— (1)}$$

* **Average (or) DC output voltage (V_{avg} (or) V_{dc}):-**

$$V_{dc} = I_{dc}R_L = \frac{I_m}{\pi} \cdot R_L \quad (\because I_{dc} = I_m/\pi)$$

$$V_{dc} = \frac{V_m R_L}{\pi(R_f + R_L)} \quad (\because \text{If } R_L >> R_f, R_f + R_L \cong R_L)$$

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

* $\boxed{V_{dc} = V_m/\pi}$ ——— ②

* **RMS output voltage (V_{rms}):-**

$$V_{rms} = \sqrt{\frac{\text{Area of the square waveform over full cycle}}{\text{Period of the cycle.}}}$$

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

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

$V_0 = V_m \sin\omega t$ for $0 \le \omega t \le \pi$

$V_0 = 0$ for $\pi \le \omega t \le 2\pi$

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

$$= \sqrt{\frac{V_m^2}{4\pi}\left[(\omega t)_0^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]}$$

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

$$= \sqrt{\frac{V_m^2}{4\pi}(\pi - 0)}$$

$$\sqrt{\frac{V_m^2}{4\pi}(\pi)} = \sqrt{\frac{V_m^2}{4}}$$

$$\Rightarrow \boxed{V_{rms} = \frac{V_m}{2}} \quad \text{——— (3)}$$

* **IRms**

Similarly $I_{rms} = I_m/2$

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

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

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

$$\boxed{I_{rms} = I_m/2} \quad \text{——— (4)}$$

* **Form factor**:- It is the ratio of rms voltage to DC voltage

$$\text{Form factor} = V_{rms}/V_{DC}$$

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

$$\boxed{\text{Form factor} = 1.57} \quad \text{——— (5)}$$

* **Peak factor**:- The peak factor is given by

$$P = \frac{\text{Peak value}}{\text{rms value}}$$

$$P = \frac{V_m}{V_m/2} = 2$$

$$\boxed{P = 2}$$

* **Ripple factor**:- It is defined as the Ac component present in the output of a rectifier circuit.

→ Ripple factor is a measurement of the fluctuating components. (or) harmonic components present in rectifier circuit.

Ripple factor:-

$$\frac{\text{rms value of alternating component of waveforms}}{\text{Average value of the waveform.}}$$

$$\gamma = \frac{V'_{rms}}{V_{dc}} \quad \text{—— (1)}$$

→ V'_{rms} = Value of Ac component in voltage

V_{dc} = Value of dc in voltage

V_{rms} = rms Value of current.

V_{rms} = rms value of current

$$V_{rms}^2 = {V'_{rms}}^2 + V_{dc}^2$$

$$\boxed{{V'_{rms}}^2 = V_{rms}^2 - V_{dc}^2} \longrightarrow (2)$$

Substitute eqn (1) & (2)

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

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

$$\gamma = \sqrt{\left(\frac{(V_m/2)}{(V_m/\pi)}\right)^2 - 1} \qquad \left(\because V_{rms} = V_m/2, \quad V_{dc} = V_m/\pi\right)$$

$$\gamma = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1} = 1.21$$

$$\boxed{\gamma = 1.21}$$

* **Efficiency:-** The ratio of Dc power delivered to the resistor load and Ac input power at the secondary of the transformer.

$$\text{Efficiency}(\eta) = \frac{\text{Dc output Power}}{\text{Ac input power}} \times 100\%.$$

$$= \frac{P_{DC(o)}}{P_{AC(i)}} \times 100\%.$$

$P_{DC} = V_{DC} I_{DC}$; $P_{AC} = V_{rms} I_{rms}$

$$\eta = \frac{V_{DC} I_{DC}}{V_{rms} I_{rms}} = \frac{V_m/\pi \cdot I_m/\pi}{V_m/2 \cdot I_m/2} = \frac{4}{\pi^2}$$

$$\eta = \frac{4}{\pi^2} \times 100\%.$$

$$\boxed{\eta = 40.6\%.}$$

* **Peak Inverse voltage (PIV):-** It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction.

For half wave rectifier: $\boxed{PIV = V_m}$

* **Transformer utilization factor (TUF) :-**

$$TUF = \frac{\text{DC power delivered to the load}}{\text{AC rating of transformer secondary.}}$$

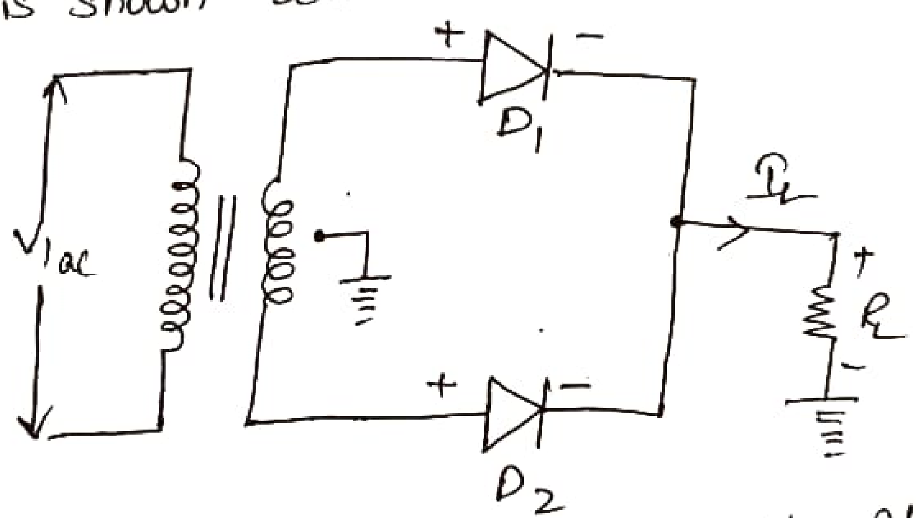
$$= P_{DC} / P_{AC \text{ rated}}.$$

$$= \frac{V_{DC} I_{DC}}{V_{rms} I_{rm}} = \frac{V_m/\pi \cdot I_m/\pi}{V_m/\sqrt{2} \cdot I_m/2}$$

[$\because V_{rms} = \frac{V_m}{\sqrt{2}}$ rated voltage of secondary transformer]

$$TUF = \frac{2 \cdot \sqrt{2}}{\pi^2} = \boxed{0.287}$$

* **FULL WAVE RECTIFIER :-** The fullwave rectifier circuit is shown below :-



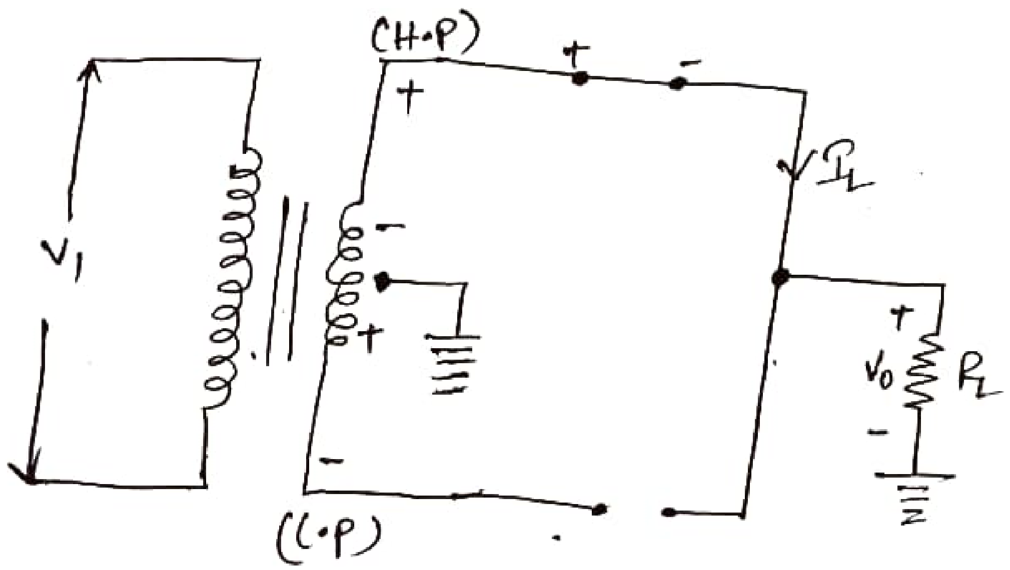
→ A full wave rectifier circuit consists of stepdown transformer with center tapped secondary, & diodes are connected to secondary as shown in figure, where the output of diode is given to load.

→ A full wave rectifier is a better circuit than half wave rectifiers as it conducts output current for both half cycles of input.

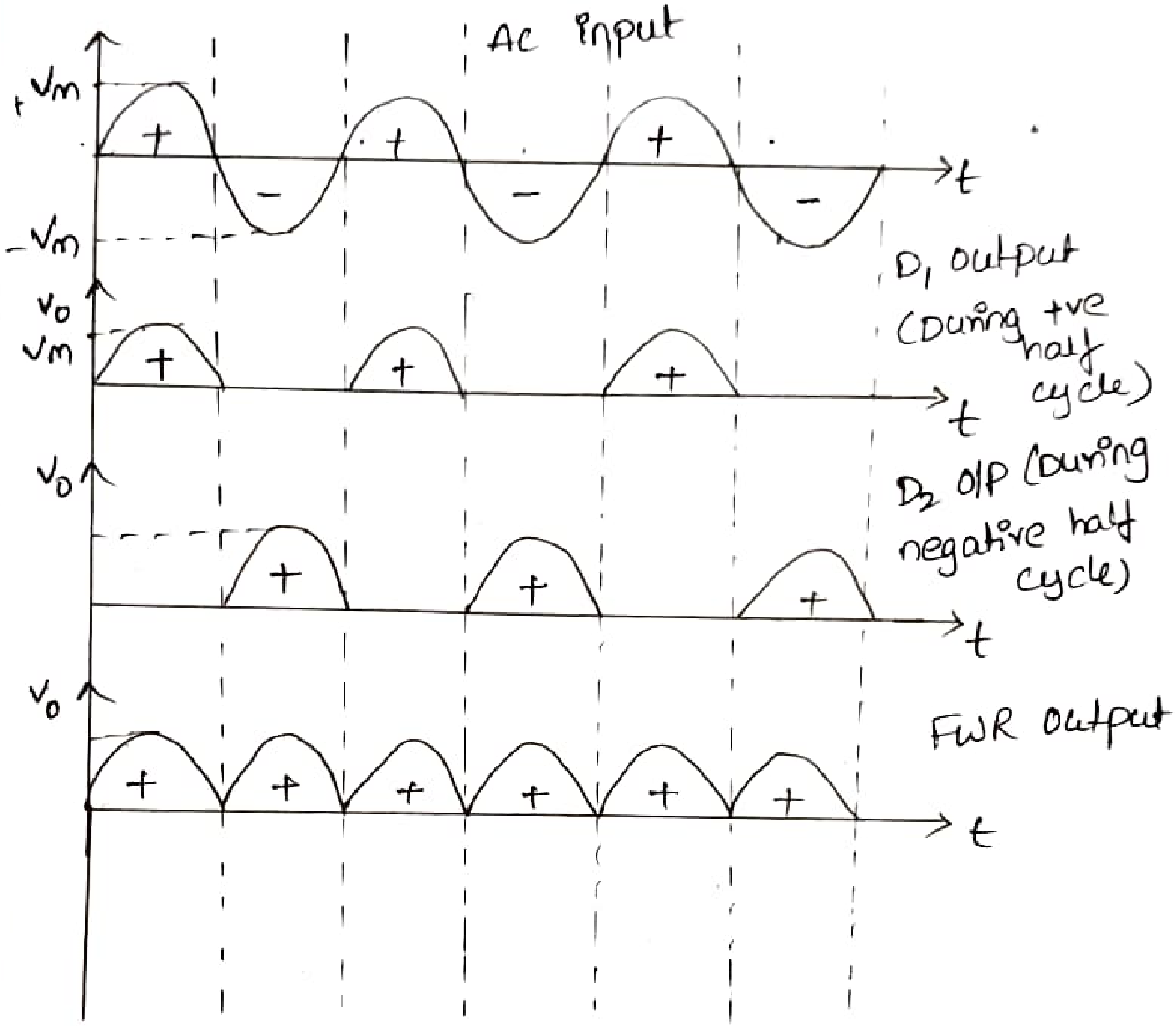
* Operation :-

a. positive half cycle :- During positive half cycle the reference point A is at higher potential and point B is at lower potential. Therefore diode D_1 gets forward biased and D_2 gets reverse biased.

→ The diode D_1 gets closed and D_2 acts as open circuit. The load current I_L flows through R_L due to diode D_1. The output voltage $V_0 = I_L R_L$



* Input and output waveform of fullwave rectifier.



* Advantages of fullwave rectifier :-

→ Ripple factor of Fullwave rectifier is less than the half wave rectifier

→ Efficiency is greater than halfwave rectifier.

* Disadvantages

→ The PIV of each diode is "$2V_m$".

→ The circuit will be Expensive because of center tapped transformer.

1. DC (or) average value :- It is the ratio of area under the complete cycle to time period of one cycle.

$$V_{DC} = \frac{\text{Area under complete cycle}}{\text{Time period of one cycle.}}$$

$$V_0 = V_m \sin\omega t \qquad 0 \le \omega t \le \pi$$

$$= V_m \sin\omega t \qquad \pi \le \omega t \le 2\pi$$

$$V_{DC} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin\omega t \, d(\omega t) \qquad \left(\because \frac{1}{2a}\int_0^{2a} x = \frac{2}{2a}\int_0^{a} x\right)$$

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

$$= \frac{V_m}{\pi}\int_0^{\pi} \sin\omega t (d\,\omega t) = \frac{V_m}{\pi}\left\{-(\cos\omega t)_0^{\pi}\right)$$

$$= \frac{V_m}{\pi}(-\cos\pi + \cos 0)$$

$$V_{DC} = \frac{V_m}{\pi}(-(-1)+1) = \frac{2V_m}{\pi}$$

$$\boxed{V_{DC} = \frac{2V_m}{\pi}} \quad \text{———} \; (1)$$

2. DC (or) Average value of load current :-

$$V_{DC} = I_{DC} \cdot R_L \quad ; \quad I_{DC} = \frac{V_{DC}}{R_L}$$

$$I_{DC} = \frac{2V_m}{\pi R_L} \quad \left(\because V_{DC} = 2V_m/\pi\right)$$

$$\boxed{I_{DC} = \frac{2I_m}{\pi}} \quad (2) \quad \left(\because I_m = V_m/R_L\right)$$

(3) RMS load Voltage (V_{rms}):-

$$V_{rms} = \sqrt{\frac{\text{area of the square of load voltage over full cycle}}{\text{Period of the cycle.}}}$$

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

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

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

$$\left(\because \sin^2\omega t = \frac{1-\cos 2\omega t}{2}\right)$$

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

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

$$\therefore \boxed{V_{rms} = \frac{V_m}{\sqrt{2}}} \longrightarrow (3)$$

(4) RMS load current :- (I_{rms})

$$V_{rms} = I_{rms} R_L \qquad \left(\because V_{rms} = \frac{V_m}{\sqrt{2}}\right)$$

$$I_{rms} = V_{rms}/R_L = \frac{V_m}{\sqrt{2}\, R_L} \qquad \left(\because I_m = \frac{V_m}{R_L}\right)$$

$$\boxed{I_{rms} = I_m/\sqrt{2}} \longrightarrow (4)$$

(5) Form factor :- (F)

$$= \frac{V_{rms}}{V_{DC}} = \frac{V_m/\sqrt{2}}{2V_m/\pi} \qquad \left[\begin{array}{l}\because V_{rms} = \frac{V_m}{\sqrt{2}} \\ V_{DC} = 2V_m/\pi\end{array}\right]$$

$$F = \pi/2\sqrt{2}$$

$$\boxed{F = 1.11} \longrightarrow (5)$$

(6) Ripple factor :- It is defined as the AC component present in the output of a rectifier circuit.

$$\gamma = \frac{V'_{rms}}{V_{DC}} = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1} = \sqrt{\left[\frac{(V_m/\sqrt{2})}{2V_m/\pi}\right]^2 - 1}$$

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

* $\boxed{\gamma = 0.48}$ → (6)

* **Efficiency:-** $\eta = \frac{P_{DC}\,(\text{output})}{P_{AC}\,(\text{input})}$

$P_{DC} = V_{DC} I_{DC}$; $P_{AC} = V_{rms} I_{rms}$

$V_{DC} = 2V_m/\pi$; $I_{DC} = 2I_m/\pi$,

$V_{rms} = V_m/\sqrt{2}$; $I_{rms} = I_m/\sqrt{2}$

$$\eta = \frac{2V_m/\pi \cdot 2I_m/\pi}{V_m/\sqrt{2} \cdot I_m/\sqrt{2}}$$

$$\eta = 8/\pi^2 = 81.2\%$$

$\boxed{\eta = 81.2\%}$ → (7)

9 * **Peak Inverse voltage:-** For full wave rectifier the maximum reverse voltage that is appeared across secondary of transformer is given as "$2V_m$"

$\boxed{PIV = 2V_m}$ → (8)

10 Transformer utilization factor (TUF) :-

TUF for ~~primary~~ secondary = 2 × TUF (HWR)

= 2 × 0.287

= 0.574

TUF for ~~secondary~~ Primary = $\frac{V_{DC} \cdot I_{DC}}{V_{rms} \cdot I_{rms}} = \frac{2V_m/\pi \cdot 2I_m/\pi}{V_m/\sqrt{2} \cdot I_m/\sqrt{2}}$

= 0.812

The average TUF for FWR using center tapped transformer is

$= \frac{\text{TUF of primary} + \text{TUF of secondary}}{2}$

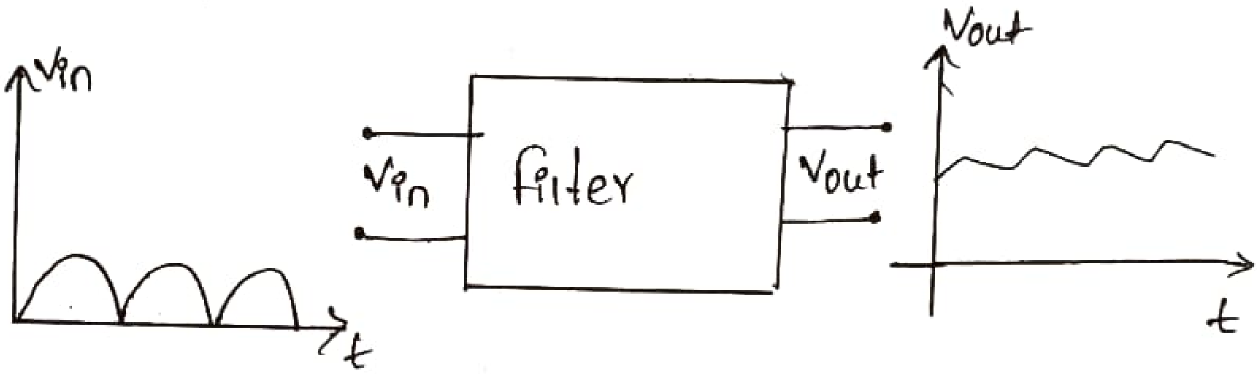
$= \frac{0.574 + 0.812}{2} = 0.693$

* **TUF = 0.693**

7 Peak factor :- $\frac{\text{Peak value}}{\text{rms value}}$

$= \frac{V_m}{\frac{V_m}{\sqrt{2}}} = \sqrt{2} = 1.414$

* **FILTER:-** The output of the rectifier contains dc component. as well as Ac component. filters are used to minimize undesirable Ac. i.e ripple, leaving only the DC component to appear at the output.



→ The output of the fullwave rectifier is input to the filter circuit.

→ But here the output of filter also contain some amount of Ac. components. To avoid such ac component some filters are used.

* **Some Important filters are:-**

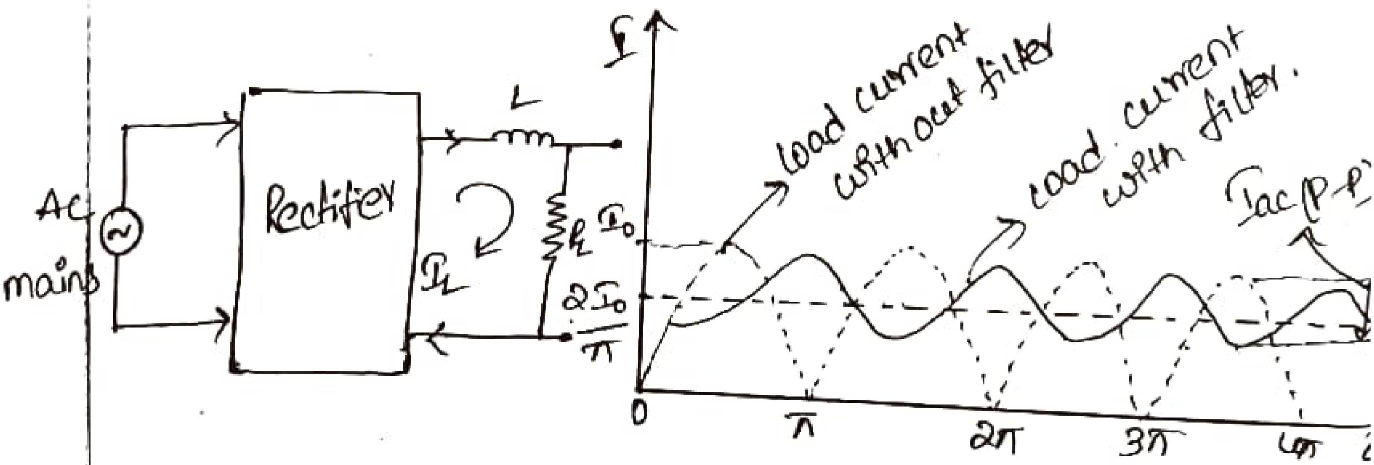
→ Inductor filter (or) choke filter

→ capacitor filter

→ LC or L-section filter

→ CLC or π-type filter.

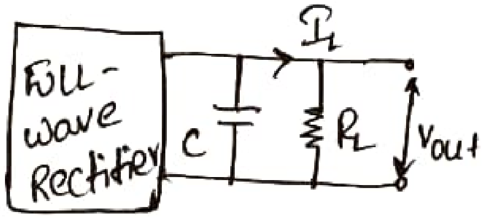
* **Series Inductor filter:-** An inductor is connected in Series with load of the rectifier, it is also called as 'Choke filter'. The fundamental property of an inductor is to "oppose any changes in the current passing through it". Thus an inductor presents high impedence to A.C and none to d.c. The inductor stores energy in it as magnetic field when the current is above its average value and delivers that energy to circuit when the current tends to fall below the average level. Thus it reduces the pulsation of rectifier o/p

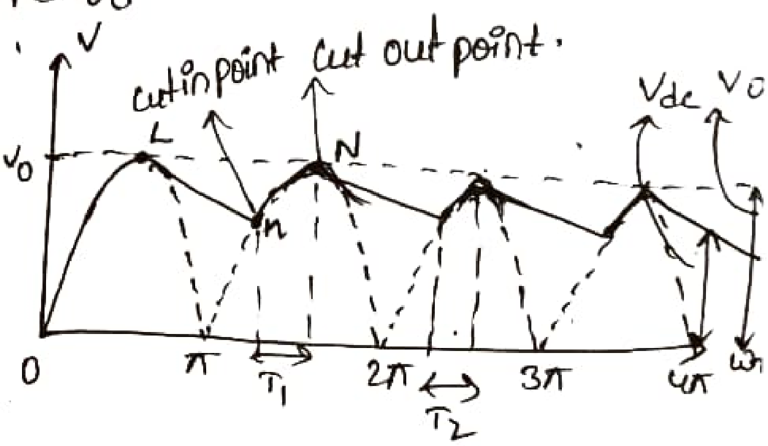


As shown in fig:- when o/p current tends to rise above the average value magnetic energy is stored in the inductor which has the effect of toning down or smoothing the sudden rise in current. However, when current tends to fall below the average value, this stored energy is returned to the circuit. in an effort to prevent the current from falling down.

* In this way, current variation are reduced to the minimum. Thus the current through the load never drops to zero.

* SHUNT CAPACITOR FILTER:- To achieve the filtering action, a suitable capacitor 'c'. is connected across the rectifier and in parallel with load R_L. This type of filter is known as "shunt capacitor filter". The action of the filter depends upon the fact to that, the capacitor stores energy during the conduction period. and delivers this energy to the load during the non-conducting period





→ when the output voltage of the rectifier increases, the capacitor charges up almost equal to the peak value of the rectifier output (V_0). i.e at the end of first quarter cycle (L) and stores energy in its electric field. During the subsequent half cycle, when the output of the rectifier drops to '0'.

and then rises again the capacitor discharges exponentially through the load. and maintains a voltage across it at a higher value in comparision with rectifier without filter. It is represented by the line LM.

→ At point M the capacitor begins to recharge to the peak and then discharges again. This cycle is repeated again & again.

→ The variation being much less than in rectifier output. The extent of these variations depends on the time constant 'Rc' of the capacitor and load. If the time constant 'Rc' is large then the capacitor discharges slowly.

→ The fall in voltage of the load is small and the d.c output voltage remains nearly constant.

It is clear that the diode current does not flow during the whole positive half cycle but flows in short pulses. The phase angle θ_1 at which the diode starts conducting is called the cut-in point and the phase angle θ_2 at which it stops conducting is called cut-out point.