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Semiconductor Electronics :

Materials, Devices & Simple Circuits.

Classification of Metals, conductors and Semiconductors :-

On the basis of conductivity -

On the basis of the relative values of electrical conductivity (σ) or resistivity ($\rho = 1/\sigma$), the solids are broadly classified as :

(i) Metals :- They ~~proce~~ possess very low resistivity (or high conductivity).

$$\rho \sim 10^{-2} - 10^{-8}\ \Omega m$$
$$\sigma \sim 10^{2} - 10^{8}\ Sm^{-1}$$

(ii) Semiconductors :-
They have resistivity or conductivity intermediate to metals and insulators.

$$\rho \sim 10^{-5} - 10^{6}\ \Omega m$$
$$\sigma \sim 10^{5} - 10^{-6}\ Sm^{-1}$$

(iii) Insulators :- They have high resistivity (or low conductivity).

$\rho \sim 10^{11} - 10^{19}\ \Omega m$
$\sigma \sim 10^{-11} - 10^{-19}\ S m^{-1}$

1. Energy Band Diagrams :-

The electrons in the same orbit exihibit different energy level. The grouping of these different energy level is known as the energy band.

Valence band :-

The valence electron contain a series of energy level and form an energy band known as the valence band. The valence band has the highest occupied energy.

Conduction Band :-

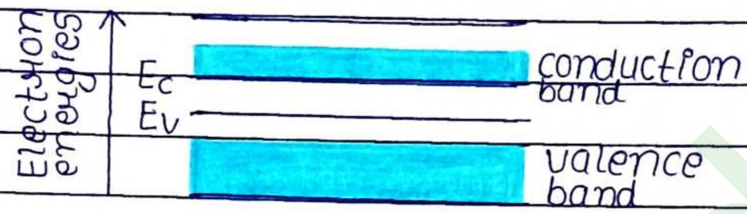
The valence electrons are not tightly held to nucleus due to which a few of these valence electrons leave the outermost orbit even at room temp. and become free electron to conduct the current and are known as conduction e^-.

Energy gap band :-

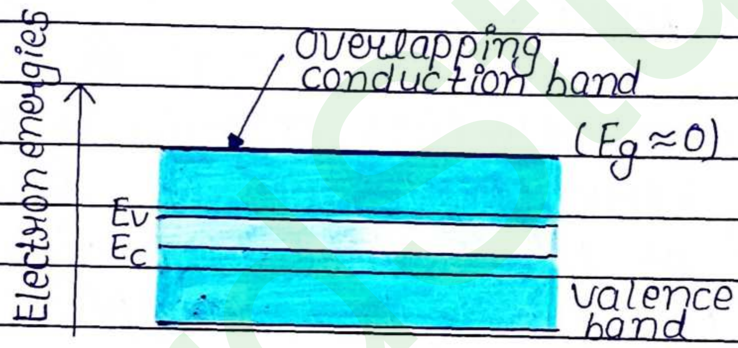
Energy gap between conduction band and valence in solid is called energy gap band.

2. On the basis of energy bands :-

Diagram of energy bands

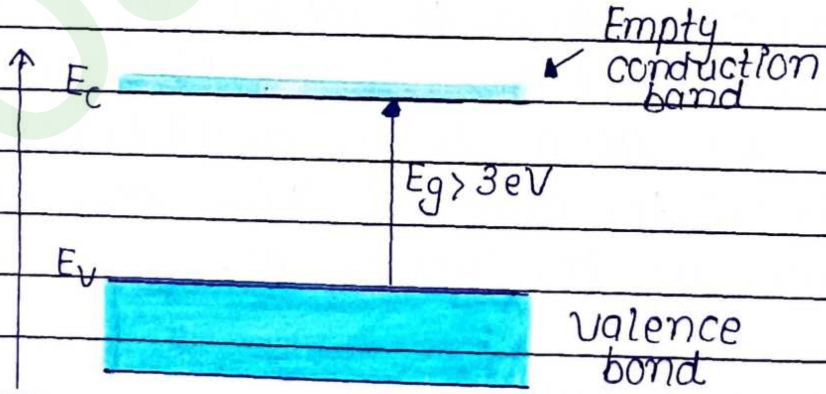


1. Metals



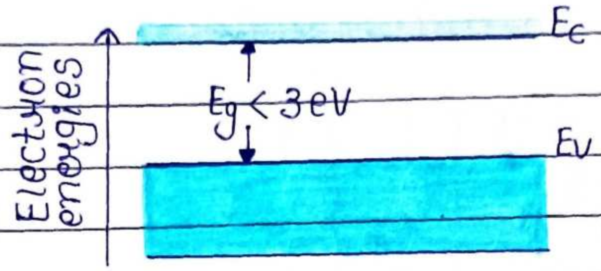
eg :- Cu, Ag, Al etc.

2. Insulators



eg :- Rubber, wood, plastic.

3. Semiconductors



eg :- Ge, si

Note :- They do not conduct at low temperature but as the temperature increases, they start conducting.

On basis of Purity, Semiconductors are of two types :-

(i) Intrinsic semiconductor
(ii) Extrinsic Semiconductor

Intrinsic semi-conductor :-

Pure semi-conductor are known as intrinsic semi-conductors. [Ge, si]

Note :- Number of electron = No. of holes.
Net charge on lattice will be zero.
Majority charge carrier are both holes and electrons.

They have low conductivity at room temperature.

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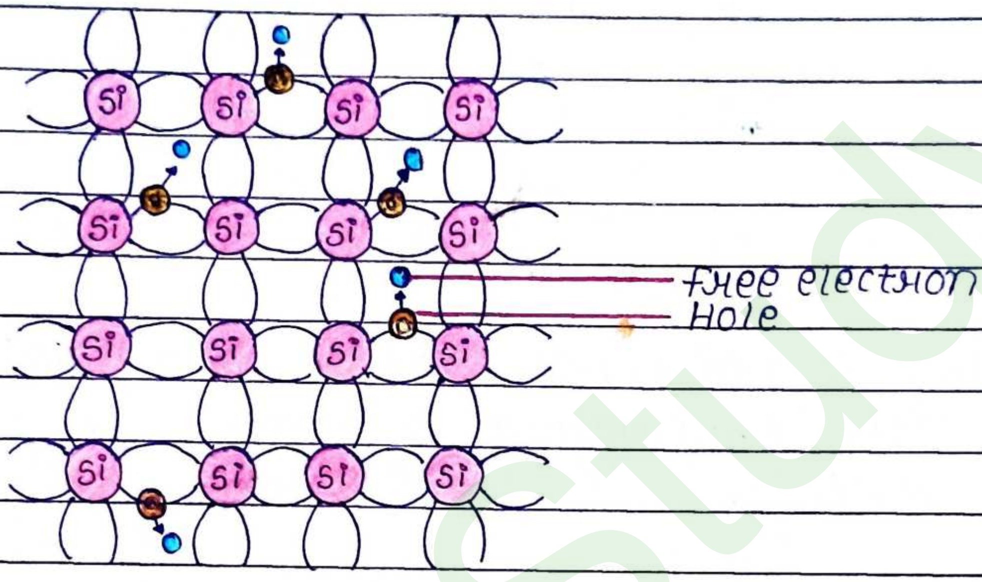
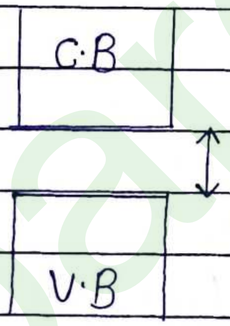
2-D representation of pure semiconductor :-

Intrinsic semiconductors



Energy band gap diagram :-



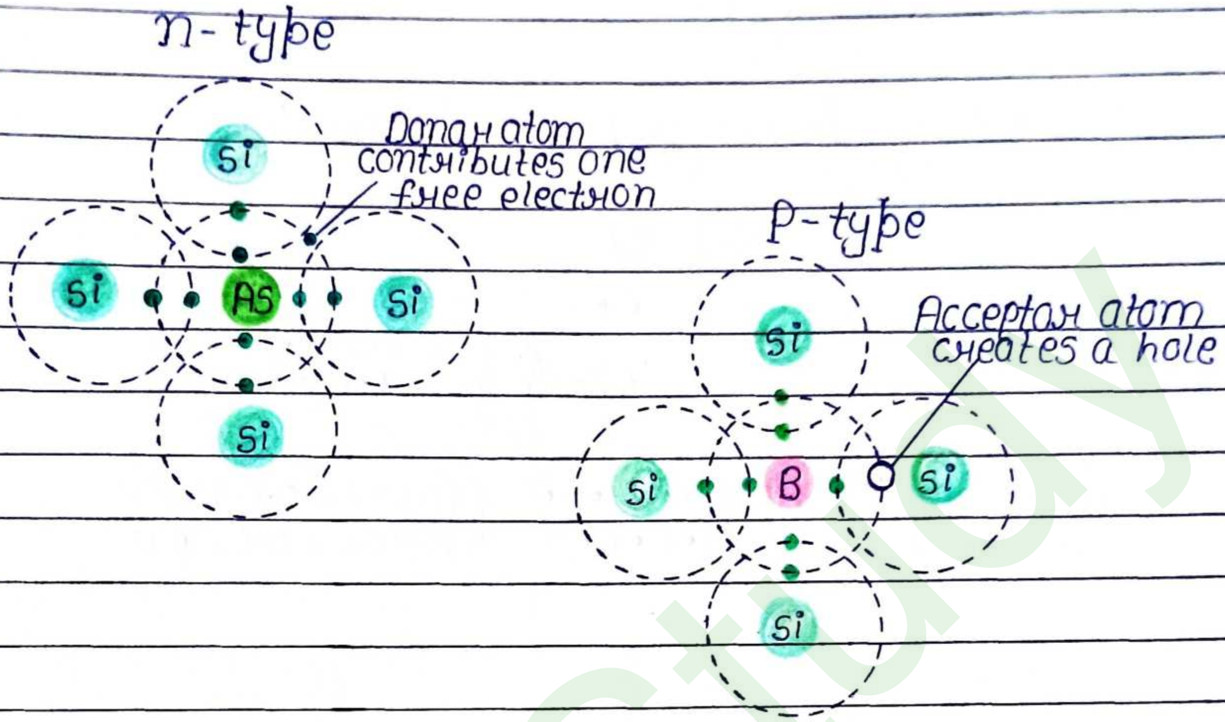
$E_g = 0.72$ eV for Ge
$E_g = 1.1$ eV for Si

* Extrinsic semiconductor :-

These are made by doping some impurity to pure form of semi-conductors.

These are of two types — conductivity high
(i) P- type semiconductor
(ii) n- type semiconductor

2-D representation of doped semiconductor :-



Doping :-

Doping of semiconductors is a process where small amounts of impurities are added to a semiconductor material to alter its electrical conductivity.

Fermi Level :-

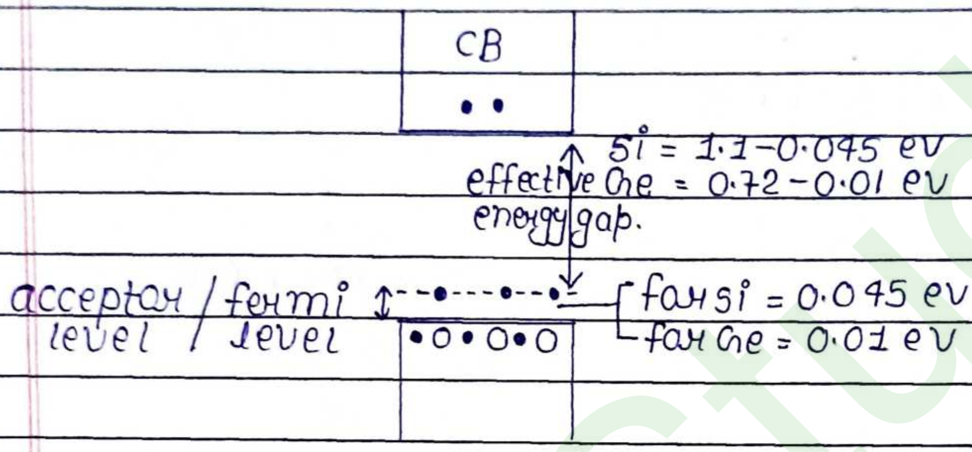
The highest energy level that an electron can occupy at the absolute zero temperature is known as the Fermi Level.

→ P-type semiconductor :-

When a trivalent impurity is added to a pure semi-conductor then semi-conductor is so formed are known as p-type semiconductor.

↳ It is also known as acceptor type semi-conductor.

Energy band gap diagram :-



Note :- Number of holes > Number of e⁻
Net charge will be zero.
Majority charge carriers are holes.

eg. Al doped with si, Indium → Ge

↳ n- type semi-conductor :-

When a pentavalent impurity is added in a pure semi-conductor the semi-conductor so formed are known as n- type semi- conductor.

It is also known as donar type semi-conductor.

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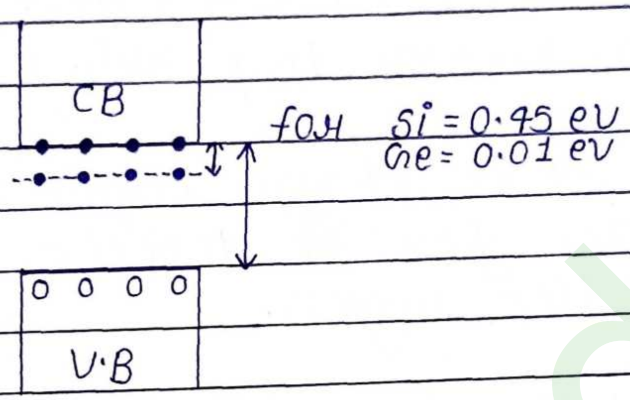
Energy band gap diagram :-



Note :- No of $e^- >$ No. of holes.
Net charge will be zero.
Majority charge carriers are electron.

eg. P doped with Si , Antimony → Ge

Note :- Conduction is low in p-type as compared to n-type semi-conductor.

* Semiconductor Devices :-

P-n Junction Diode —

A p-n junction is an arrangement made by a close contact of n-type semiconductor and p-type semi-conductor.

Formation of Depletion Region in p-n junction

- During formation of P-n junction, due to the concentration difference across P and n sides, hole diffuse from p-side to n-side ($p \rightarrow n$) and electrons diffuse from n-side to p-side ($n \rightarrow p$).

- This space charge region on either side of the junction together is known as depletion region.

- Depletion region is free from mobile charge carriers.

- Width of the depletion region is of the order of 10^{-6} m.

- The potential difference developed across the depletion region is called the potential barrier.

- Due to the potential difference generated, it stops further diffusion of majority carriers from both sides.

- The value of barrier potential lies between 0.3V - 0.7V depends on the type of material used.

- Barrier potential : around 0.7V for si, 0.3V for Ge.

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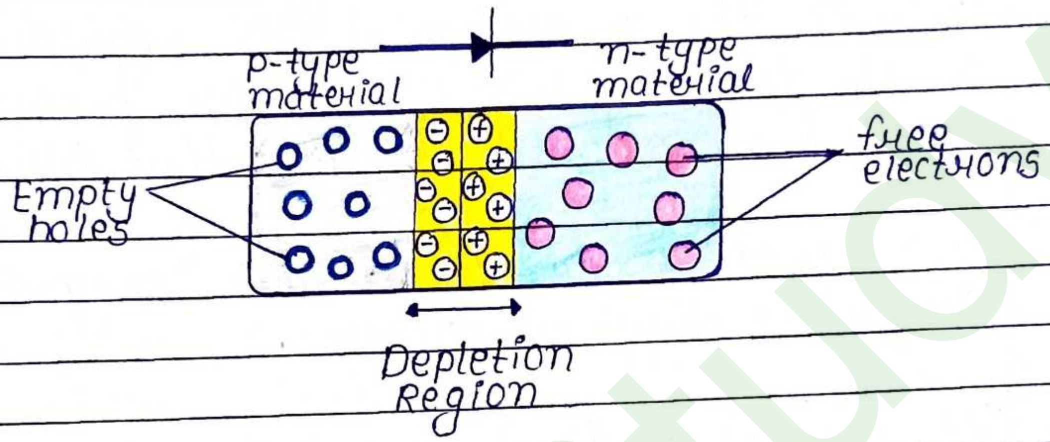
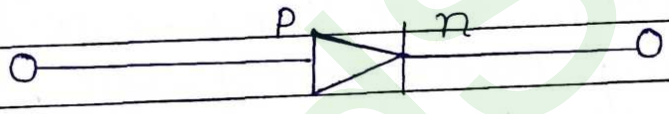
Unbiased P-n junction Diode :-

Unbiased P-n junction -



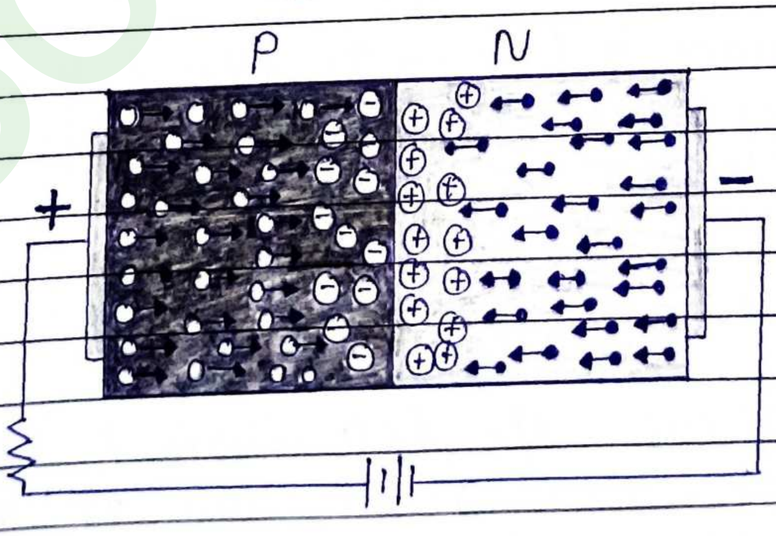
Symbol :



* Biasing :-

The connection of p-n junction diode with battery is called Biasing.

Forward Biasing of P-n junction Diode :-



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Imagine you have your p-n junction with that "hill" (barrier) in the middle.

1. When you connect a battery with its positive side to the p-side and its negative side to the n-side, it's like you're pushing from both sides to flatten that hill.

2. This "push" makes the middle "no-go-zone" (depletion region) smaller.

3. If you push hard enough (apply enough voltage, i.e. greater than barrier potential), the electrons from the n-side can now easily jump over to the p-side, and the holes from the p-side can easily jump over to the n-side.

4. This jumping of charges means electricity can now flow easily through the diode.

So, forward biasing is like helping the charges cross the barrier, allowing current to flow.

Case I. if $V < V_B$

In this case, the hole from P side and electrons from n side are not able to cross the depletion layer. Therefore, no

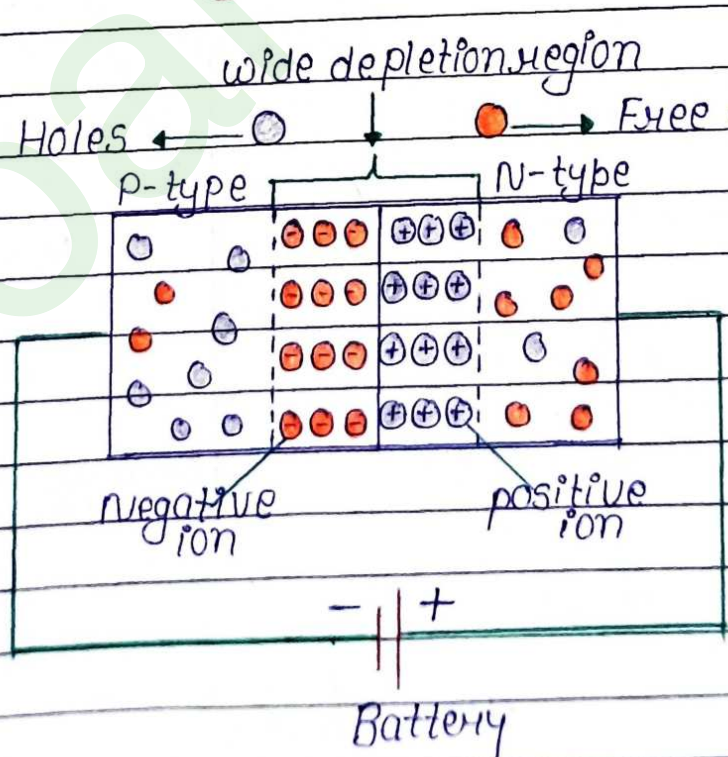
Current will flow and hence p-n junction diode will not conduct or we can say a very small amount of current due to minority charge carries.

Case II :- if $V \geq V_B$

In this case, the holes from the p-side and electrons from the n-side are able to cross the depletion layer and hence a large amount of current will flow. Thus, the p-n junction diode will conduct.

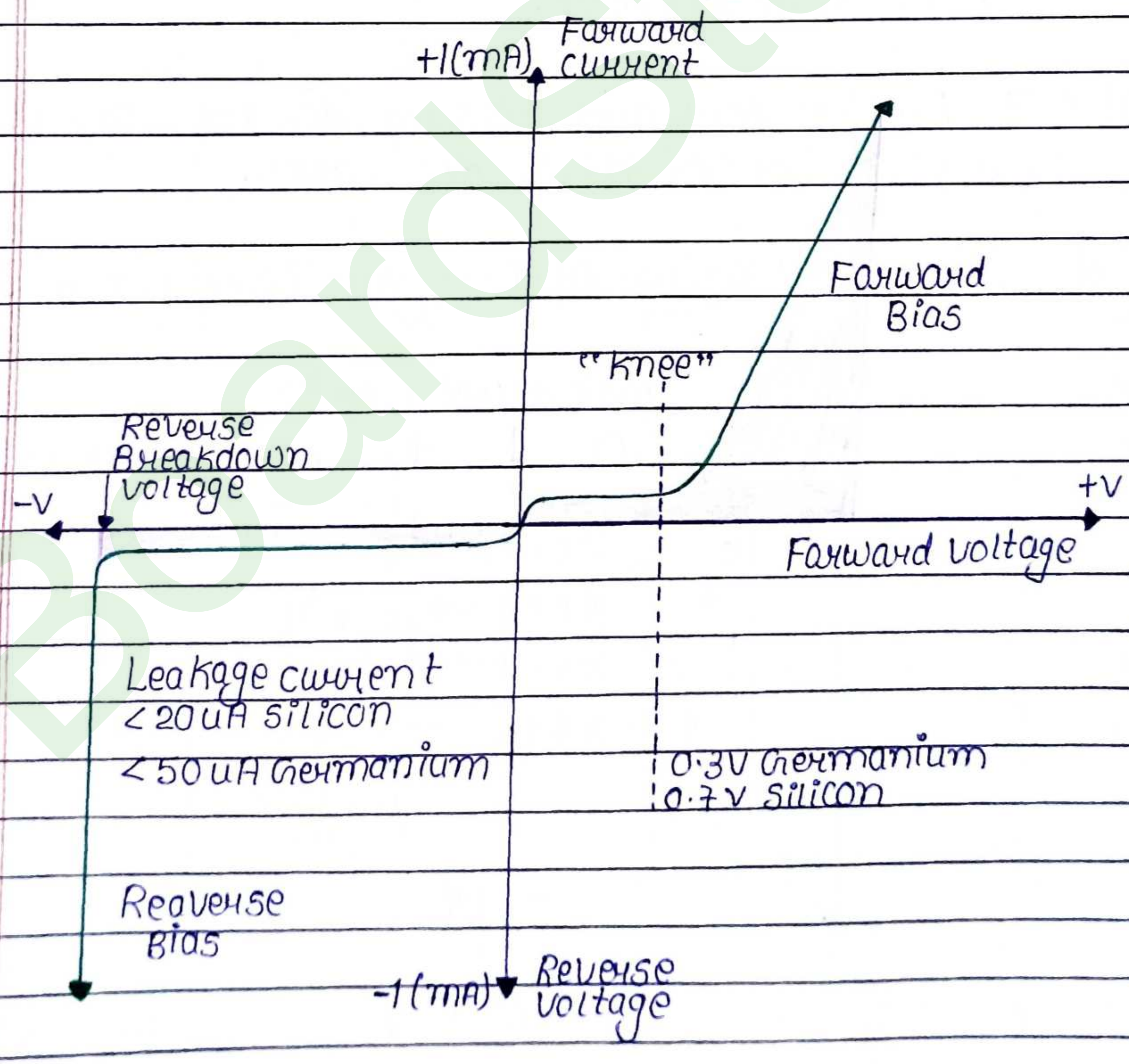
Note :- During forward biasing, we can say that resistance of diode decreases.

* Reverse Biasing of P-n junction Diode :-



- Battery's higher potential to n-side, lower potential to p-side
- "Pulls" electrons and holes away from the junction.
- Increases the width of the barrier (depletion region).
- Makes it very difficult for current to flow (only a tiny leakage current)

* V-I characterstics of p-n junction diode :-



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The V-I characteristic curve of a P-n junction diode shows the relationship between the voltage applied across the diode and the current flowing through it. It is typically divided into three regions :

1. Forward Bias :-

- When the p-side is connected to the positive terminal and the n-side to the negative terminal, the diode is forward biased.
- Initially, the current is very small.
- As the forward voltage increases and exceeds the barrier potential (around 0.7V for si, 0.3V for Ge), the current increases exponentially.
- Knee voltage :- It is that forward bias voltage beyond which the current start increasing rapidly.

2. Reverse Bias :-

- When the p-side is connected to the negative terminal and the n-side to the positive terminal, the diode is reverse biased.
- A very small current, called the reverse saturation current (I_s), flows due to minority carriers.

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- This current is almost independent of the reverse voltage until the breakdown voltage is reached.

- Reverse breakdown voltage – It is that reverse bias voltage at which current will increase abruptly.

3. Breakdown Region :-

Beyond the breakdown voltage in reverse bias, the current increases sharply even for a small increase in voltage. This can damage the diode if not current-limited.

In summary, the diode allows significant current to flow only when it is forward biased above the threshold voltage.

* Rectifier :-

An electrical device which converts an alternating current into a direct one by allowing a current to flow through it in one direction only.

Principle :-

It is based on the fact that p-n junction diode will conduct heavily in forward bias and will not conduct in reverse bias.

Type Of Rectifier :-

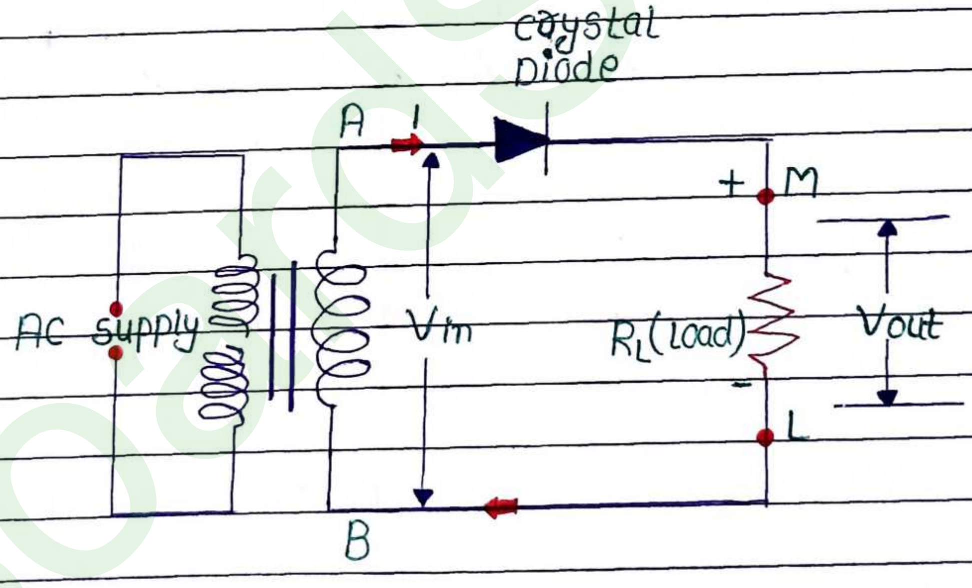
There are two type of rectifier.

(i) Half wave Rectifier
(ii) Full wave Rectifier

(i) Half wave Rectifier :-

The rectifier which give output only for positive half cycle but not for negative half cycle is called Half wave rectifier.

Construction :-



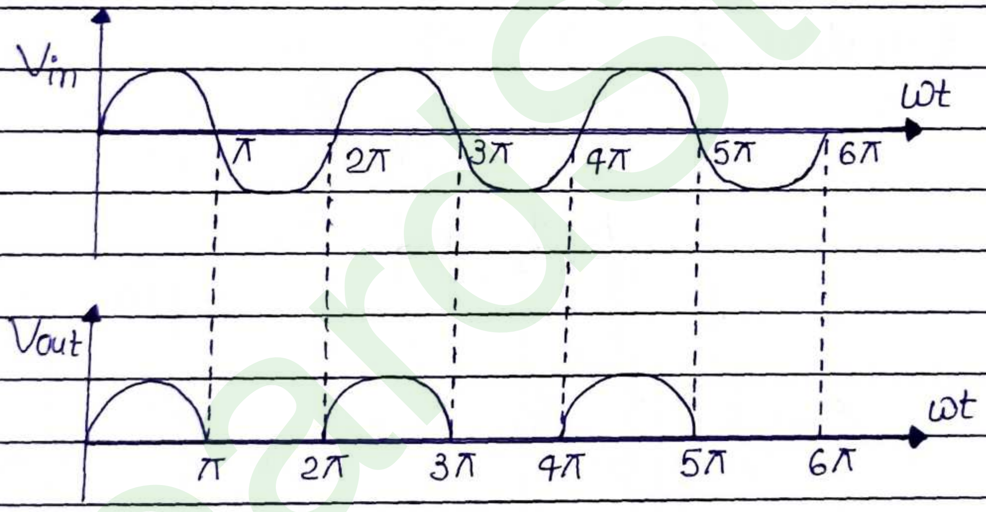
Working Principle :-

- During the positive half-cycle of the AC input, the diode is forward-biased, allowing current to flow through it and the load resistor (R_L). Thus, the output voltage across R_L follows the positive half of the input.

- During the negative half-cycle of the AC input, the diode is reverse-biased, blocking the current flow. Hence, the output voltage across R_L is zero.

Output waveform :- The output is a series of positive half-cycles, resulting in a pulsating DC.

Input and Output waveform :-

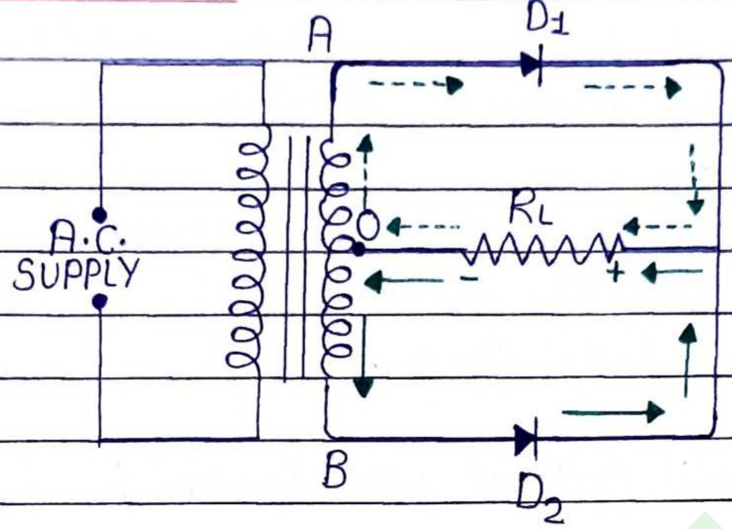


Advantages :- Simple circuit, low cost.

Disadvantages :- Low efficiency, pulsating DC output.

(ii) Full wave Rectifier :- The rectifier which gives output for positive half cycle as well as negative half cycle is called full wave rectifier.

Construction :-



Working Principle :-

- During the positive half cycle of the AC, the top half of the secondary winding or terminal 1 will become positive.

- While terminal two or the second half of the winding will become negative and the center tap will be at zero potential.

- At the time of the positive half cycle, the diode D1 is forward biased and diode D2 is reverse biased. This is because it is connected to the bottom of the secondary winding.

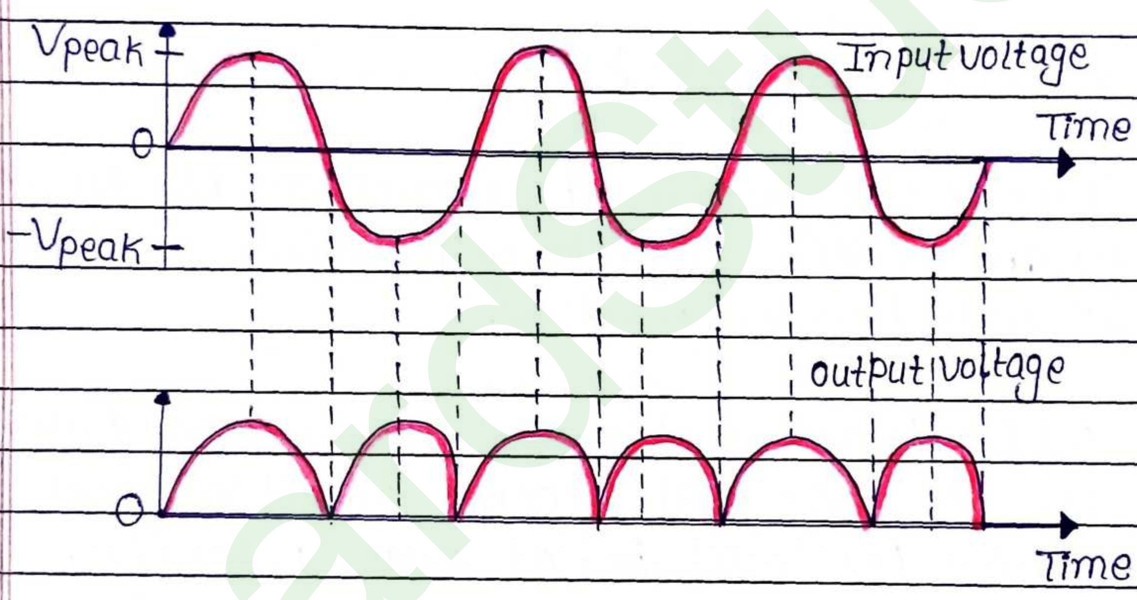
- Hence, D_1 will let the current flow, and D_2 will block the flow through it.

- In the case of a negative half cycle, the diode D_1 is reverse biased and the diode D_2 is forward biased.

- This is because the top half of the Secondary circuit becomes negative, while the bottom half of it becomes positive.

- Therefore, in a full wave rectifier, DC Voltage is obtained for both positive as well as negative half cycle.

Input and Output waveform :-



Disadvantages :-

- More components required.

Advantages Over Half-wave Rectifier :-

- Higher efficiency.
- Higher DC output voltage.

Efficiency of half wave rectifier is 40.2%
& efficiency of full wave rectifier is 80.4%.

This pulsating DC can be converted into pure DC by use of filter circuit like capacitor, inducer, etc.