P-N JUNCTION DIODE

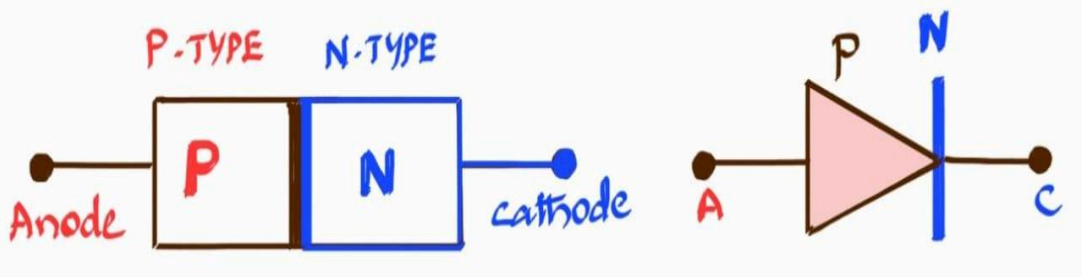
Introduction:

- **Diode:** The word diode is a combination of (i) di - means two and (ii) ode - means electrode.Hence diodes are devices with 2-electrodes.
- **P-N Junction:** P-N Junction is an interface between P-type & N-Type Semiconductor material.
- P-N Junction Diode was discovered by American physicist Russell Ohl in 1939 in Bell Laboratories.It is one of the fundamental devices in electronics.

Definition of P-N Junction diode:

- "A P-N Junction diode is a basic semiconductor device that controls the flow of electric current in a circuit."
- The P-N Junction diode consists of a P-region & N-region separated by a depletion region where charge is stored.
- The P-N Junction diode has 2-terminals that are to be usually connected to the 2-terminals of a battery.

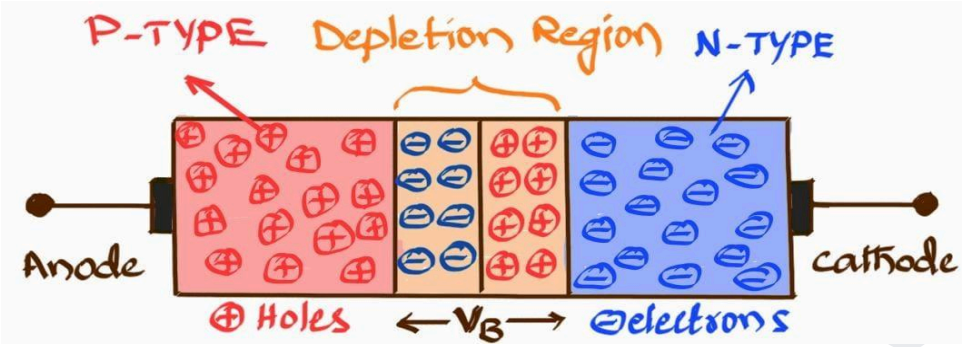
Schematic Symbol:



Formation of P-N Junction diode:

- A P-N Junction diode is formed by joining P-Type Semiconductor with N-Type Semiconductor
- Holes are majority charge carriers and electrons are minority charge carriers in P-Type Intrinsic semiconductor whereas electrons are majority and holes are minority charge carriers in N-Type Intrinsic semiconductor.
- When they are joined, in the region of contact, the free electrons from N-region diffuse into P-region and holes from P-region to N-region due to their concentration gradient.
- As a result, the N-region near the boundary is positively charged and the P-region negatively charged.Hence an electric field E_B appears in a small region "w" on either side of the Junction.

- Since this region is depleted of mobile charge carriers, it is called depletion region / charge free region / Transition region / space charge region.
- The thickness of this region is usually in the order of 10^{-6} m to 10^{-7} m.



- Due to the electric field E_B,the Potential difference appears across the depletion region and this Potential difference V_B is called Built in potential or Barrier Potential or Junction barrier.
- The Built in potential at room temperatures are as follows: Si => 0.7V and Ge => 0.3V.

Bias:

- When a dc voltage is applied to a P-N junction diode , it is said to be biased.
- A P-N Junction diode can be biased in 2 ways:

1. Forward Biased (FB): A P-N junction diode is said to be forward biased when the positive terminal of the external voltage source(battery) is connected to the p-type material and the negative terminal to the n-type material.

- This reduces the width of the depletion region, allowing current to flow easily through the diode.

2. Reverse Biased (RB): A PN junction diode is said to be reverse biased when the positive terminal of the external voltage source(battery) is connected to the n-type material and the negative terminal to the p-type material.

- This increases the width of the depletion region, preventing current flow except for a very small leakage current due to minority carriers.

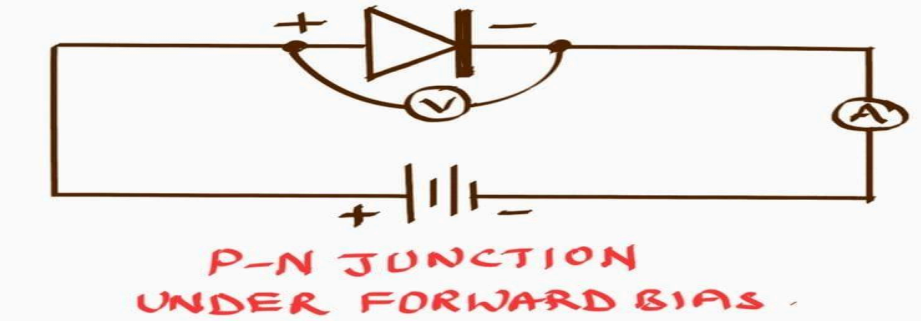
V - I OR Volt-Ampere Characteristics of P-N J Diode:

a) Forward biased V -I characteristics:

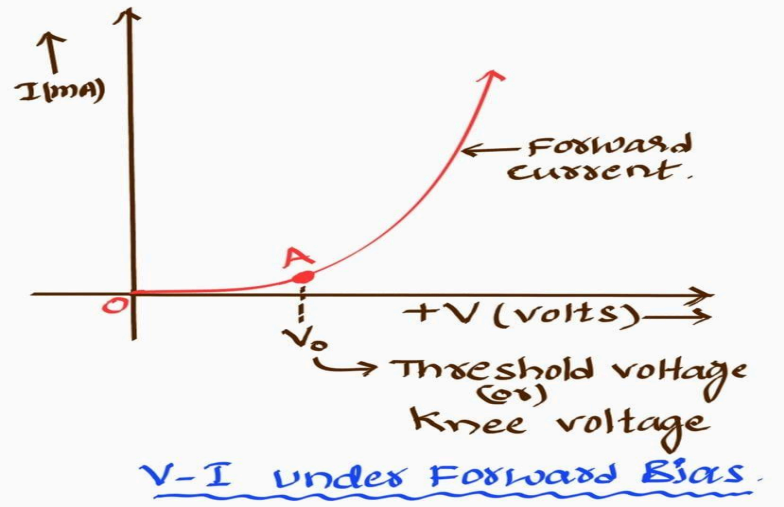
- In a **forward-biased P-N junction diode**:

- The **P-side (anode)** is connected to the **positive terminal** of the battery, and the **N-side (cathode)** to the **negative terminal**. This setup **reduces the potential barrier**, allowing **current to flow** through the diode.

- An **ammeter** is connected **in series** to measure the **current** in the circuit in mA and a **voltmeter** is connected **across the diode** to measure the **voltage drop in volts.**



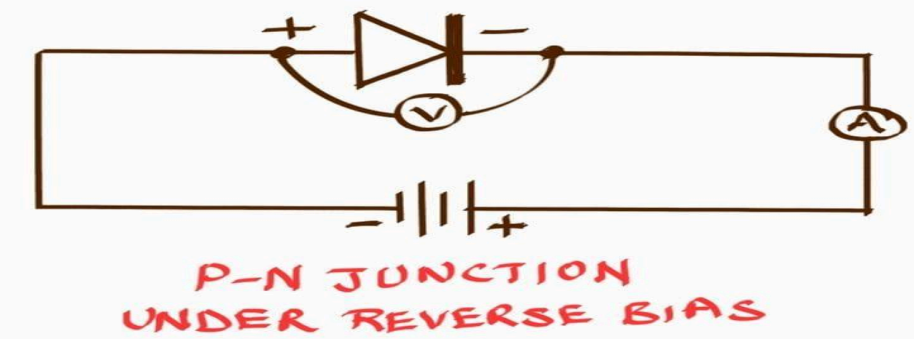
- Now plot a graph by voltage applied (V) on x-axis and the corresponding current (I) on y-axis.



- **From the graph we observe the following V-I Characteristics.**
- (i) When the battery voltage is zero, the diode does not conduct and current is zero.
- (ii) As the forward battery voltage increases, the barrier potential starts decreasing and small current begins to flow up to the point A.
- (iii) The forward current increases slowly at first upto A but as soon as the battery voltage increases, the forward current increases rapidly.
- (iv) The battery voltage at which the forward current starts increasing rapidly is known as threshold | cut in | knee | offset voltage (V_0).
- (v) The V_0 of Ge =>0.2V to & Si => 0.6V to 0.7V.
- (vi) The voltage increases beyond V_0, the forward current increases exponentially and large current flows.

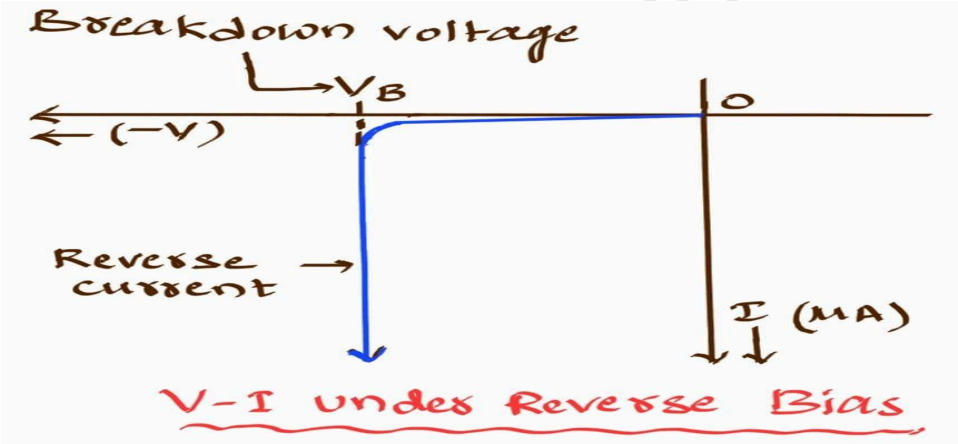
❖ b) Reverse Biased I-V Characteristics

❖ The polarity of the diode is reversed so that it gets reverse biased and current is measured in μA and voltage drop in volts.



❖ Now plot a graph by applied voltage on x-axis and the corresponding current (I) on y-axis.

❖ **Graph:**



❖ **From the graph we observe the following V-I characteristics.**

❖ (i) In the reverse bias, small current flows in the circuit due to applied reverse voltage appears as forward bias to minority charge carriers.

❖ (ii) We also noticed that the reverse current remains small (almost constant) for a voltage up to the breakdown voltage (V_B).

❖ (iii) This small current flows in reverse direction is called reverse saturation current.

❖ (iv) If the reverse voltage is increased further after some voltage, there will be a sudden rise of reverse current.This reverse current depends upon the temperature and this region is named as the breakdown region.

- (v) If the reverse current goes on increasing, at a point we get a condition called Avalanche of free electrons at this state, the junction will be completely broken. This voltage is called breakdown voltage.
- **The two graphs for FB and RB are combined together to get the V-I characteristics of P-N Junction diode, shown below:**

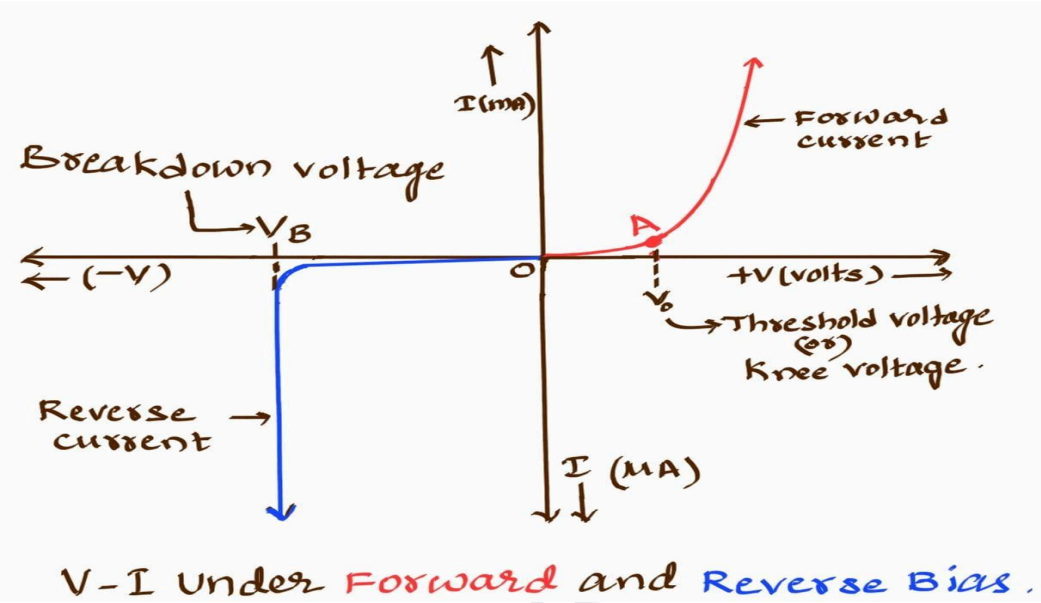
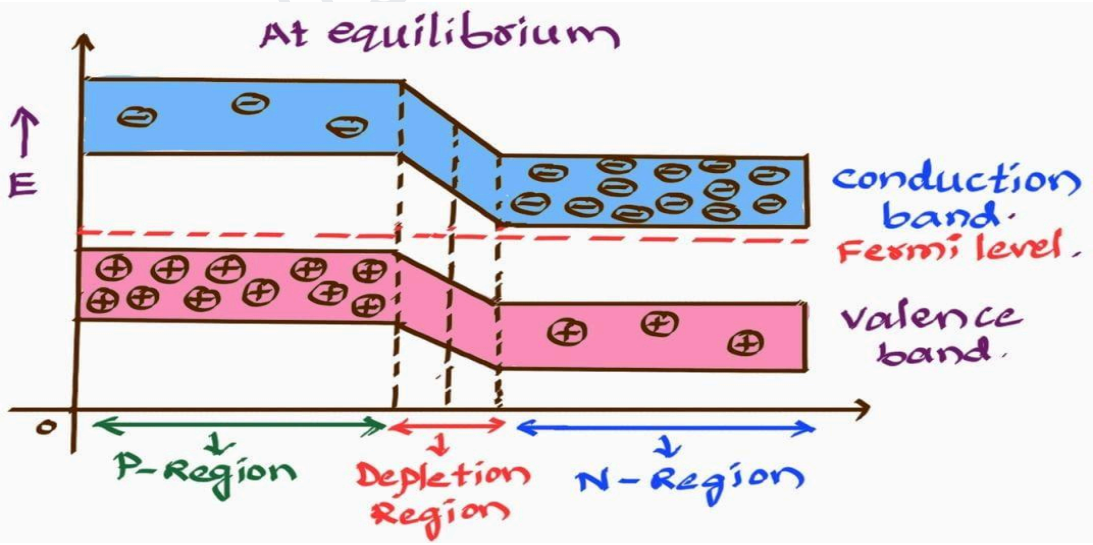


Fig: FORWARD & REVERSE BIAS

- **Energy level diagram of P-N junction diode:**
- The energy band diagram of a PN junction diode at equilibrium illustrates how the energy levels of electrons behave across the junction formed by p-type and n-type semiconductors.



- **EXPLANATION:**
- **1. P-Region:**
- Valence Band is populated with many free holes and Conduction Band filled with few electrons
- The Fermi level is closer to the valence band, indicating holes are majority carriers.
- **2. N Region :**
- Valence Band is filled with few holes and Conduction Band is Populated with many free electrons.
- The Fermi level is closer to the conduction band, indicating electrons are majority carriers.
- **3. Depletion Region :**
- A region where electrons and holes have recombined, creating a zone depleted of free charge carriers.
- An electric field builds up due to uncovered positive and negative ions, creating a Built-in Potential or Barrier Potential (V_B).
- **Energy Bands:** Conduction Band is a higher energy level where free electrons reside.
- Valence Band is a lower energy level where free holes reside
- **Band Bending:** The energy bands bend at the junction due to the electric field created by diffusion of electrons and holes.
- **Equal Fermi Level:** At equilibrium, the Fermi level is constant across the junction, indicating no net current flow.
- **Built-in Potential (V_B):** The energy difference between the conduction bands across the junction represents the built-in potential barrier that opposes carrier flow.

Uses:

- P-N JD is used as an electronic switch.
- It is used in rectifier circuits to convert ac to dc.
- It can be used as a solar cell.
- It can be used as a photodiode (when reverse biased).
- Certain P-N diodes glow on supply of electricity (when forward biased). (LED)

NOTE

- These forward biased or reverse biased is based on the voltage applied.
- No external voltage is applied to the P-NJD, it is considered as zero bias.