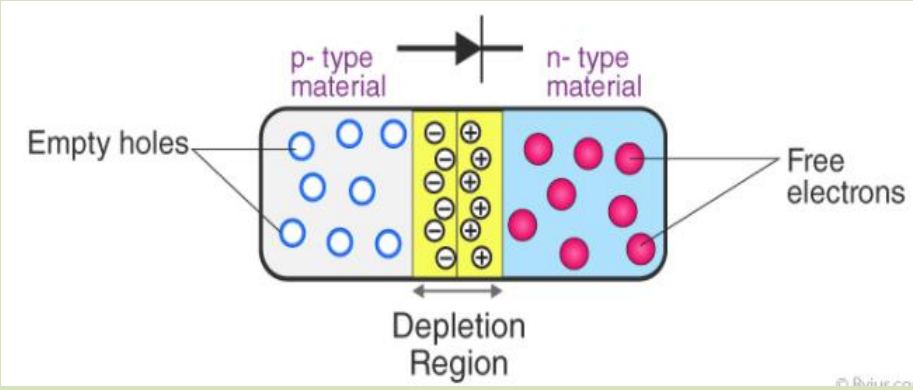
P-N Junction

A p-n junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor. In a semiconductor, the p-n junction is created by the method of **doping**. The p-side of the semiconductor has an excess of holes and the n-side has an excess of electrons.



When an electron diffuses from the n-side to the p-side, an ionized donor is left behind on the n-side, a layer of positive charge is developed on the n-side of the junction. Similarly a hole goes from the p-side to the n-side, and ionized acceptor is left behind in the p-side, resulting a layer of negative charges in the p-side of the junction. This region of positive charge and negative charge on either side of the junction is termed as the **depletion region**. Due to this positive space charge region on either side of the junction, an **electric field direction** from a positive charge towards the negative charge is developed. Due to this electric field, an electron on the p-side of the junction moves to the n-side of the junction.

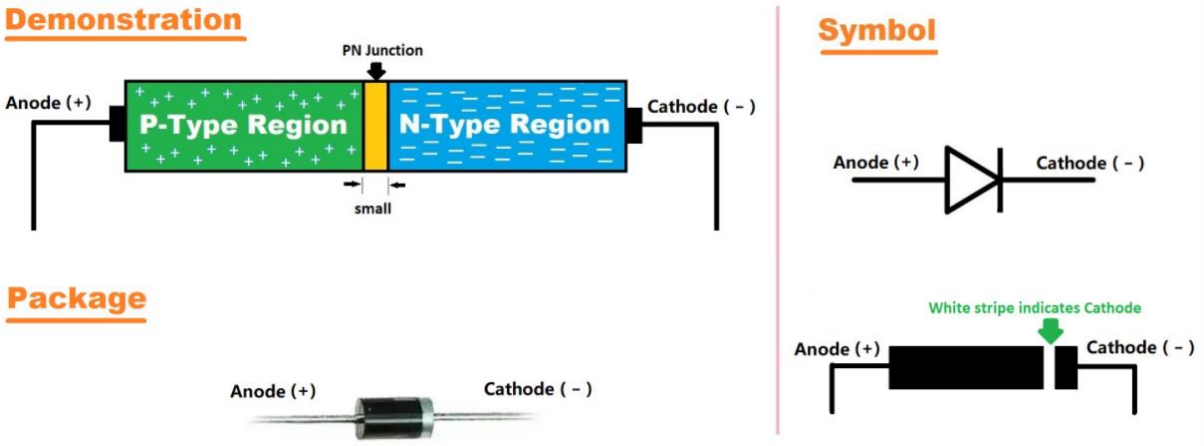
Without any external voltage being applied to the actual PN junction resulting in the junction being in a **state of equilibrium.**

However, if we were to make electrical connections at the ends of both the N-type and the P-type materials and then connect them to a battery source, an additional energy source now exists to overcome the potential barrier.

The effect of adding this additional energy source results in the free electrons being able to cross the depletion region from one side to the other. The behaviour of the PN junction with regards to the potential barrier's width produces an asymmetrical conducting two terminal device, known as the **P-N Junction Diode**.

P-N Junction Diode

P-N junction diode is two-terminal or two-electrode semiconductor device, which allows the electric current in only one direction while blocks the electric current in opposite or reverse direction.



Biasing of P-N Junction Semiconductor Diode

The process of applying the external voltage to a p-n junction semiconductor diode is called biasing. External voltage to the p-n junction diode is applied in any of the two methods.

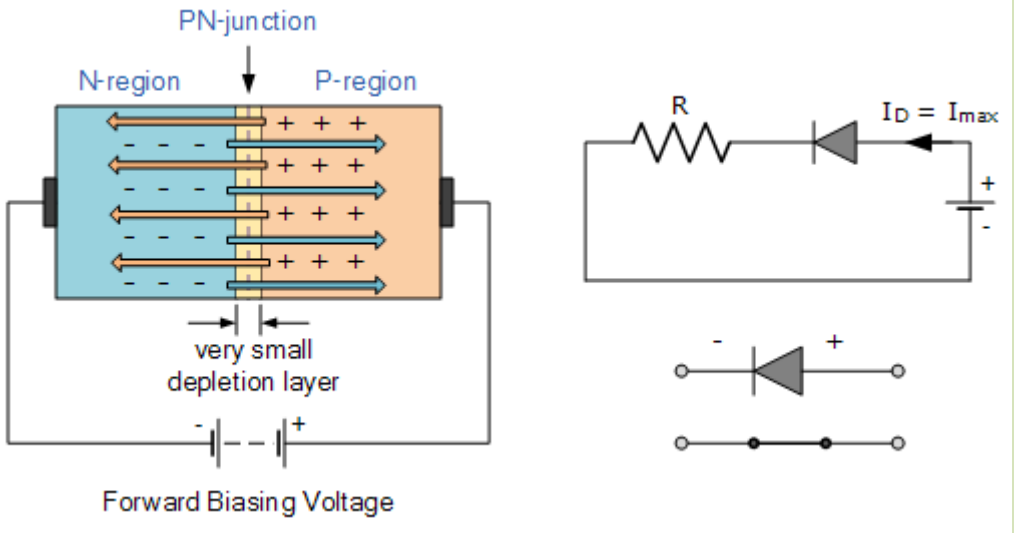
- ***Forward bias:*** The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type. **it allows the electric current flow**.

- ***Reverse bias:*** The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type. **it blocks the electric current flow.**

Forward Bias

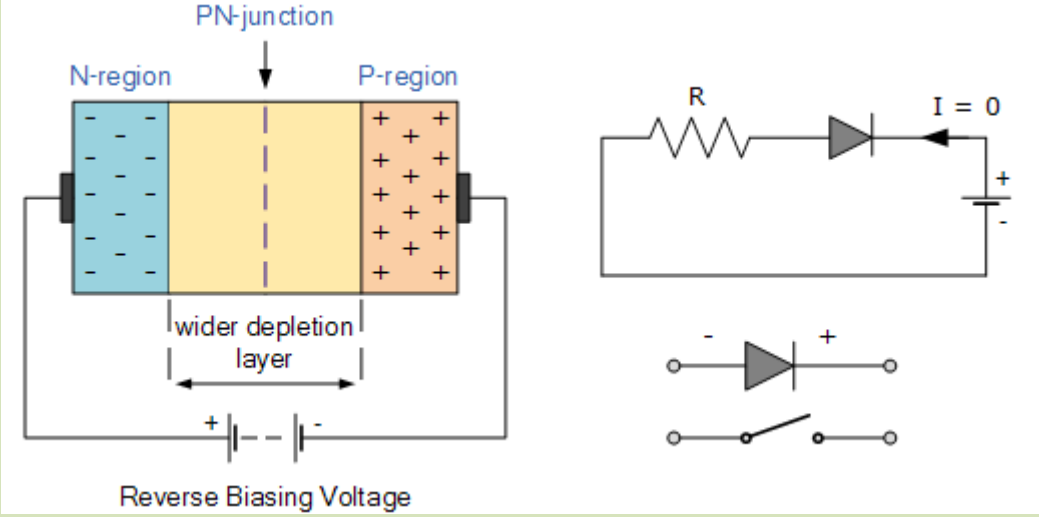
When the p-n junction is forward biased, the **built-in electric** field at the p-n junction and the **applied electric field** are in **opposite directions**. When both the electric fields add up, the resultant electric field has a magnitude lesser than the built-in electric field.

This results in a less resistive and thinner depletion region. The depletion region's resistance becomes **negligible** when the applied **voltage is large**. In silicon, at the voltage of 0.6 V, the resistance of the depletion region becomes completely negligible and the **current flows** across it unimpeded.



Reverse Bias

In this case, the **built-in electric field** and the **applied electric field** are in the **same direction**. When the two fields are added, the resultant electric field is in the **same direction** as the built-in electric field creating a **more resistive**, thicker depletion region. The depletion region becomes more resistive and thicker if the applied voltage becomes larger.



P-N Junction Formula

The formula used in the p-n junction depends upon the built-in potential difference created by the electric field is given as:

$$E_0 = V_T \, ln \left(\frac{N_D N_A}{n_i^2} \right)$$

Where,

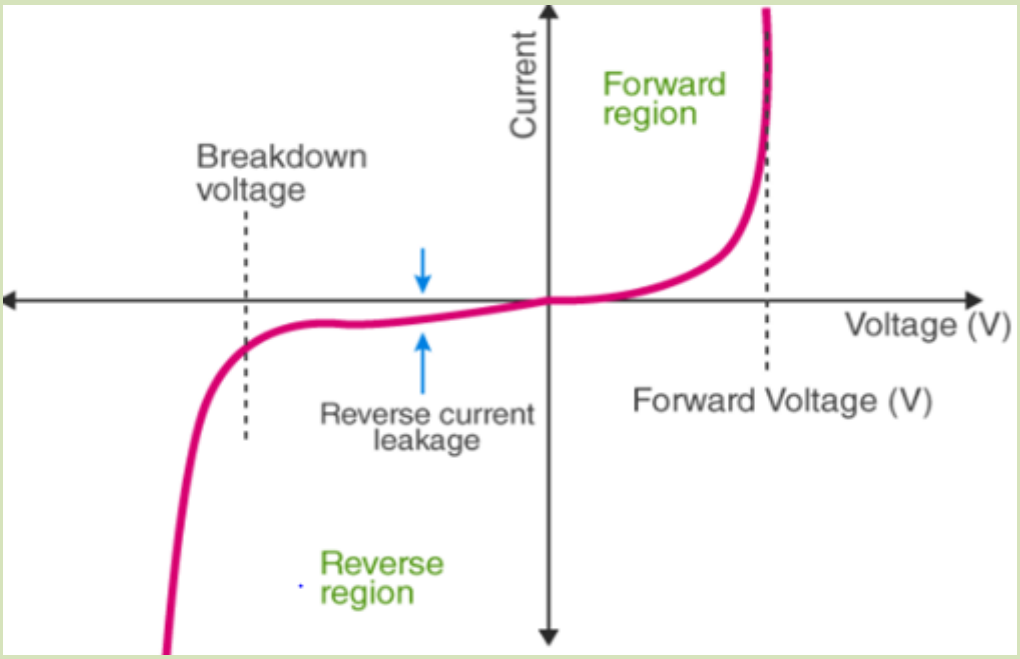
- E_0 is the zero bias junction voltage
- V_T is the thermal voltage of 26mV at room temperature
- N_D and N_A are the impurity concentrations
- n_i is the intrinsic concentration.

How does current flow in PN junction diode?

The flow of electrons from the n-side towards the p-side of the junction takes place when there is an increase in the voltage. Similarly, the flow of holes from the p-side towards the n-side of the junction takes place along with the increase in the voltage. This results in the concentration gradient between both sides of the terminals. Due to the formation of the concentration gradient, there will be a flow of charge carriers from higher concentration regions to lower concentration regions. The movement of charge carriers inside the p-n junction is the reason behind the current flow in the circuit.

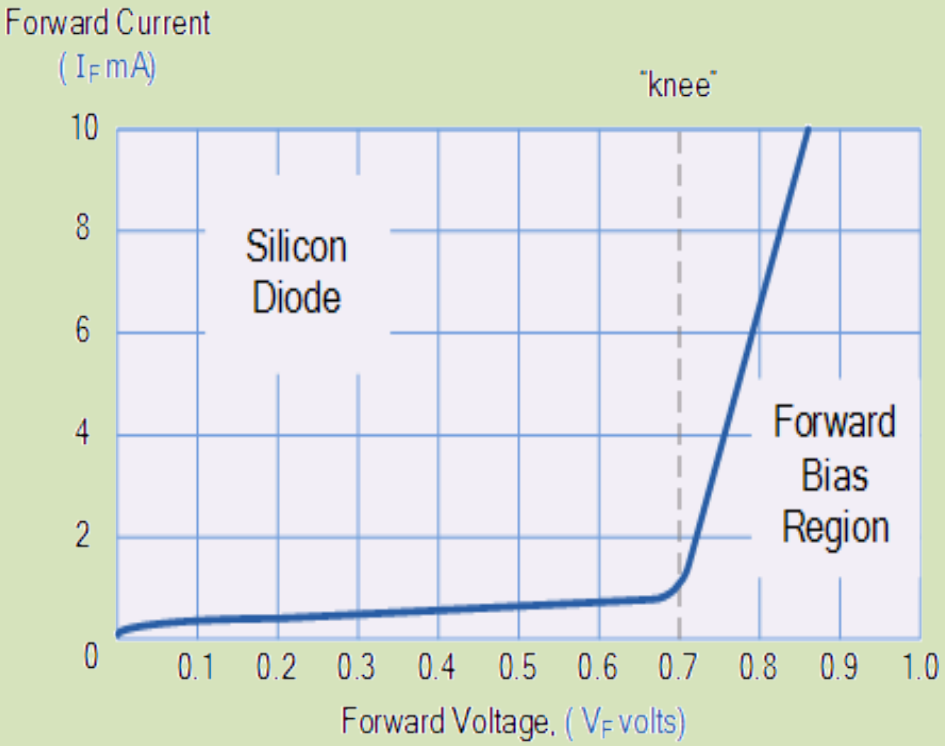
V-I Characteristics of PN Junction Diode

VI characteristics of PN junction diodes is a curve between the voltage and current through the circuit. Voltage is taken along the x-axis while the current is taken along the y-axis. The above graph is the VI characteristics curve of the PN junction diode.



- When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow.

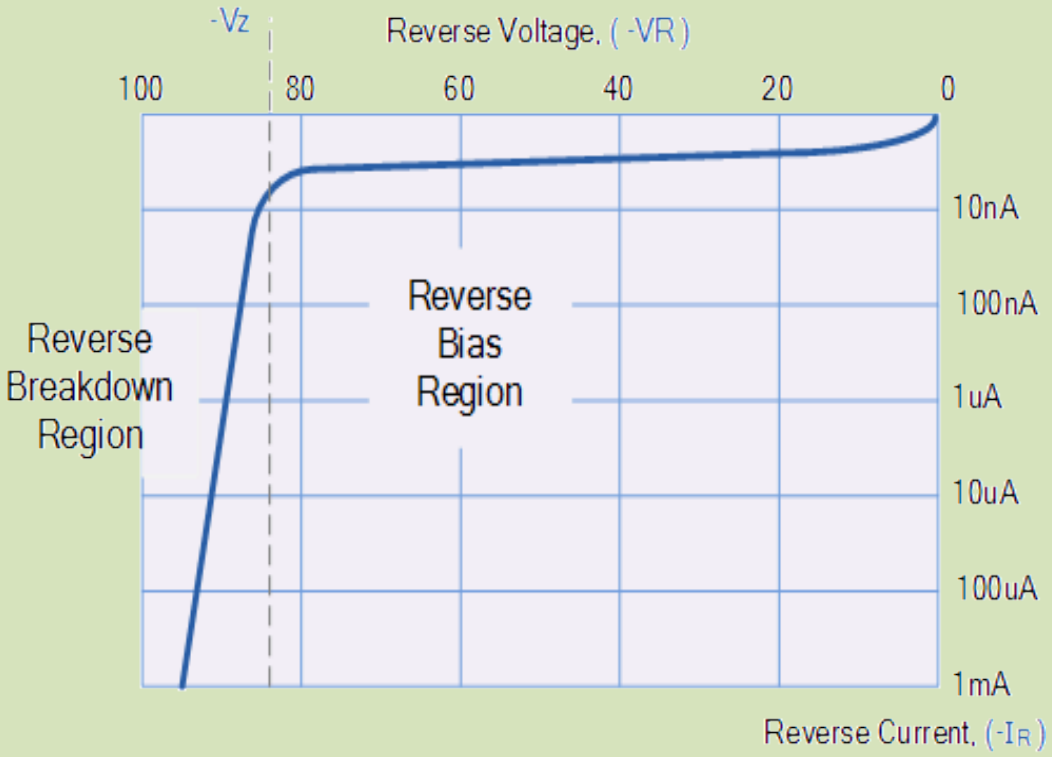
  This is because the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up to this voltage point, called the "**knee**" on the static curves and then a high current flow through the diode with little increase in the external voltage as shown below.



The application of a forward biasing voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the junction thereby allowing high currents to flow. The point at which this sudden increase in current takes place is represented on the static I-V characteristics curve above as the "knee" point.

- When the PN junction diode is under **Reverse bias** condition, the p-type is connected to the negative terminal while the n-type is connected to the positive terminal of the external voltage. This results in an increase in the potential barrier. Reverse saturation current flows in the beginning as minority carriers are present in the junction.

  When the applied voltage is increased, the minority charges will have increased kinetic energy which affects the majority charges. This is the stage when the diode breaks down. This may also destroy the diode.



Applications of PN Junction Diode

- p-n junction diode can be used as a photodiode as the diode is sensitive to the light when the configuration of the diode is reverse-biased.
- It can be used as a solar cell.
- When the diode is forward-biased, it can be used in LED lighting applications.
- It is used as rectifiers in many electric circuits and as a voltage-controlled oscillator in varactors.