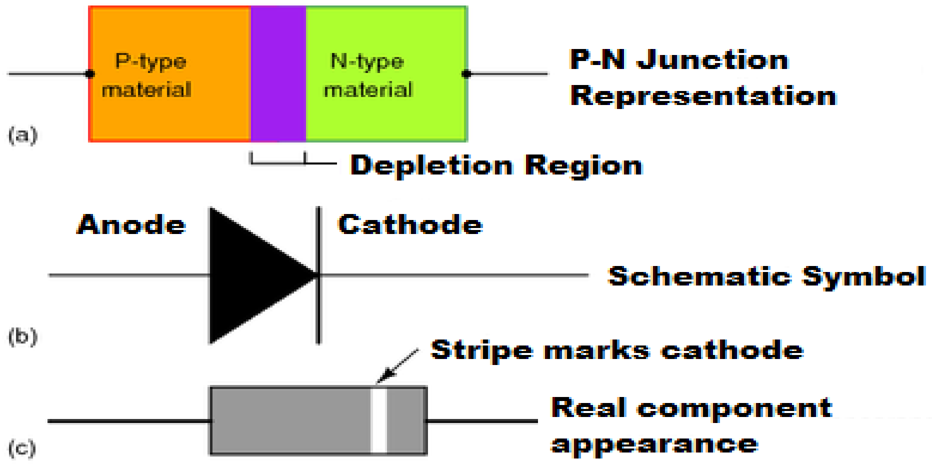
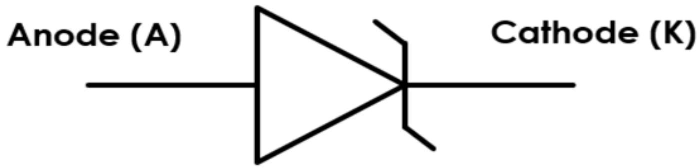
UNIT–IV

Electronic Devices and Circuits:

➢P-N Junction diode and its characteristics.



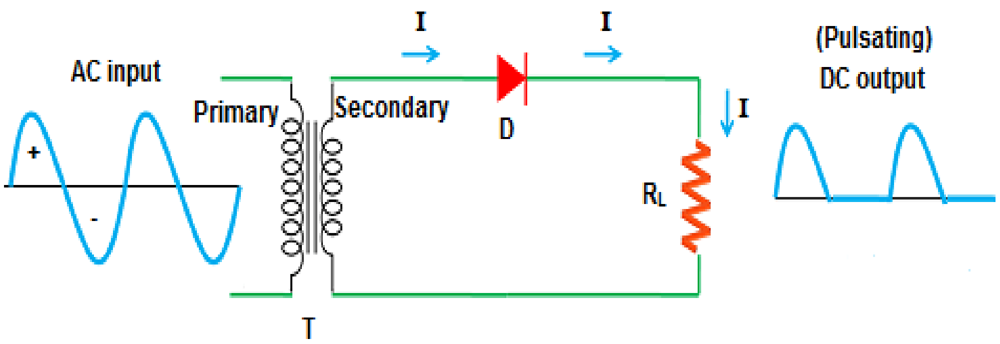
➢Zener diode and its characteristics.



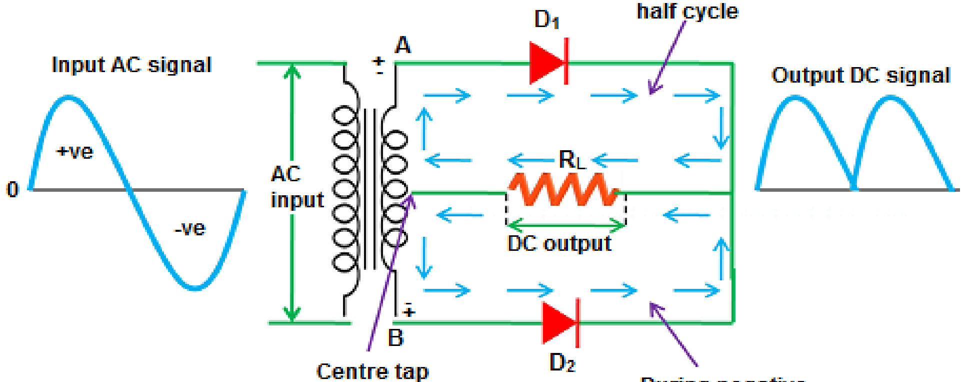
Symbol of zener diode

(Zener diode)

➢P-N junction diode as a rectifier - Half Wave Rectifier, Full Wave Rectifier-ripple factor.

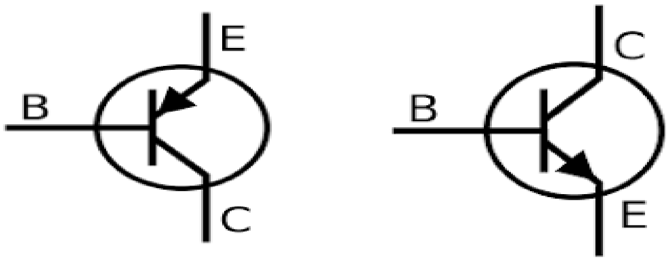


Half wave rectifier



Center tapped full wave rectifier

➢Bipolar Junction transistor- Symbol, Construction and operation.



PNP BJT

NPN BJT

Typical Bipolar Junction Transistor

On the basis of electrical conductivity the solids can be classified into three types as follows:

Conductors

- They allow the maximum portion of the applied electric field to flow through them.
- The electrical conductivity is in the order of $10^6 - 10^8$ ohm^{-1}.

Insulators

- They have low conductivities i.e. they do not practically allow the electric current to flow through them.
- The electrical conductivity is in order $10^{-10} - 10^{-20}$ ohm^{-1} m^{-1}

Semi conductors

- The solids with intermediate conductivities at the room temperature.
- allow a portion of electric current to flow through them.

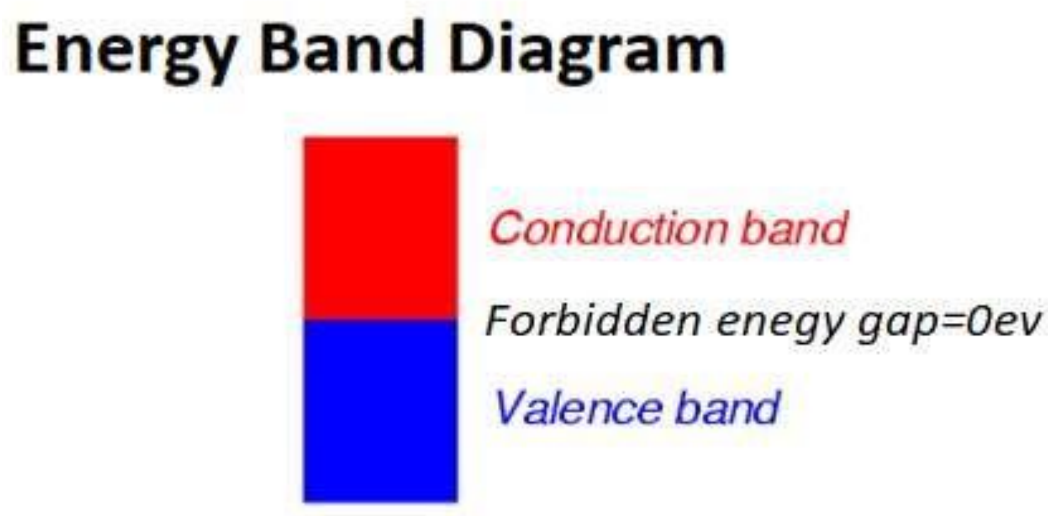
Conductors:

In conductors the conduction band and valence band overlaps each other.

- The forbidden energy gap between the conduction band and valence band is 0ev.
- A conductor is having many number of free electrons.
- **E.g.**

(i) Copper

(ii) Aluminum

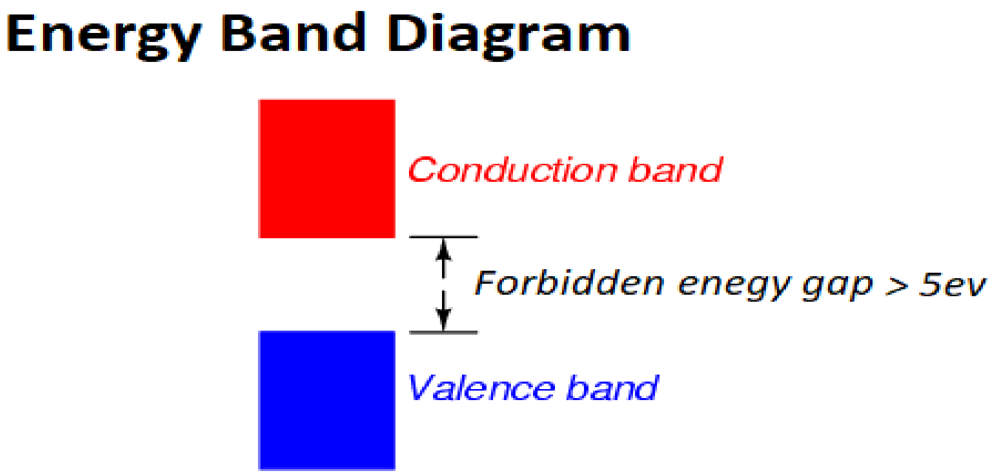


Insulators:

- In insulators ,the forbidden energy gap between the conduction band and valence band is greater than 5ev.
- A insulator is having very few number of free electrons.
- Insulator does not conducts.
- **E.g.**

(i) Wood

(ii) Glass

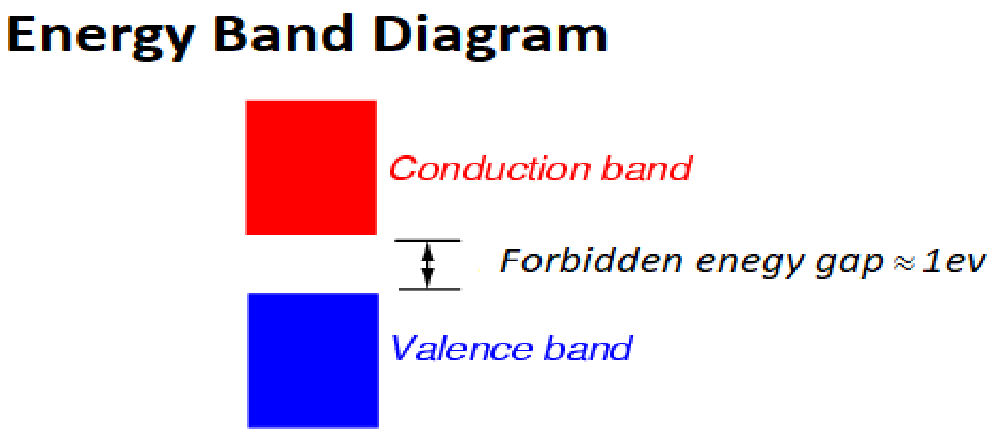


Semiconductors:

- In semiconductors ,the forbidden energy gap between the conduction band and valence band is around 1ev.
- A semiconductor is having few number of free electrons compared to the conductors.
- Semiconductor conducts partially.
- **E.g.**

(i) Germanium

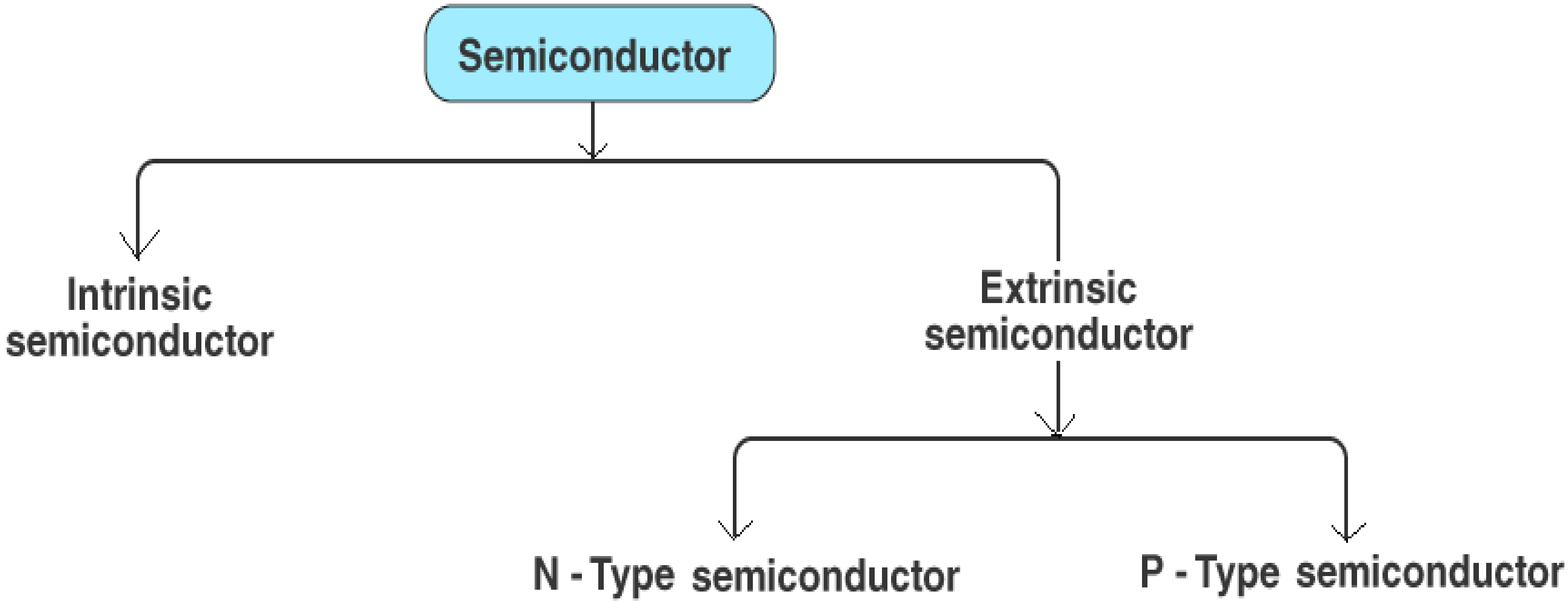
(ii) Silicon



- Silicon and Germanium atoms have 4 valence electrons.

Semiconductors

- SEMICONDUCTORS ARE CLASSIFIED AS FOLLOWS.



- Semiconductor in pure form is kwon as **intrinsic semiconductor.**

  E.g. Silicon and Germanium.

- When the pure semiconductor or intrinsic semiconductor is doped (added) with impurities then it becomes the **extrinsic semiconductor.**

- **Doping**: It is the process of adding the impurities to the semiconductor.
- Doping increases the electrical conductivity of semiconductor.
- Extrinsic semiconductor has high electrical conductivity than intrinsic semiconductor.
- Hence, the extrinsic semiconductors are used for the manufacturing of electronic devices such as diodes, transistors etc.

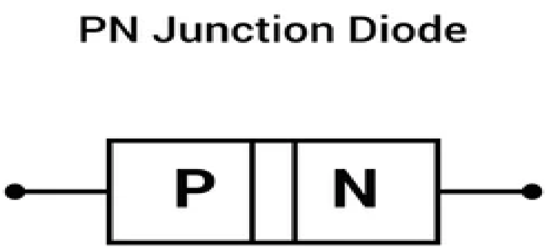
- In extrinsic semiconductors, the number of electrons is not equal to the number of holes.
- It is impure form of semiconductor.
- Extrinsic semiconductors are classified as follows.

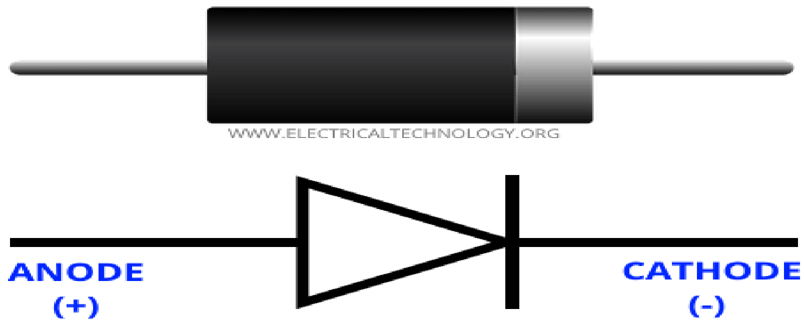
(i) N-Type Semiconductor. Pentavalent impurities are the atoms with five valence electrons used for the doping of semiconductors. i.e. Arsenic (As), Phosphorous (Pi), Antimony (Sb), etc.

(ii) P-Type Semiconductor. Trivalent impurities are the atoms with three valence electrons used for the doping of semiconductors. i.e. Indium , Gallium, Aluminium, Boron , etc.

P-N JUNCTION DIODE

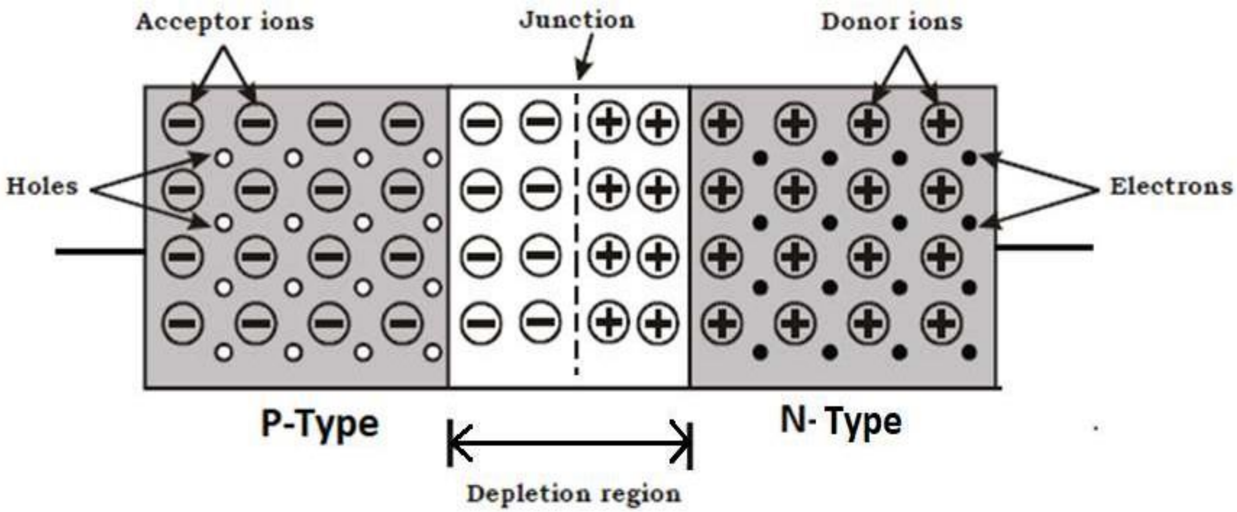
- A P-N junction diode is two-terminal or two- electrode semiconductor device.
- When a P-Type semiconductor is suitably joined to N-Type semiconductor, the contact surface is called as P-N Junction.
- P-N junction diode allows the current in only one direction while blocks the current in opposite or reverse direction.
- If the diode is forward biased, it allows the current flow. On the other hand, if the diode is reverse biased, it blocks the electric current flow.

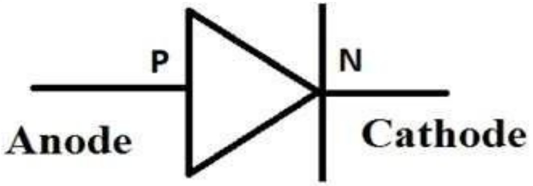




P-N Junction Diode

- **Construction:**





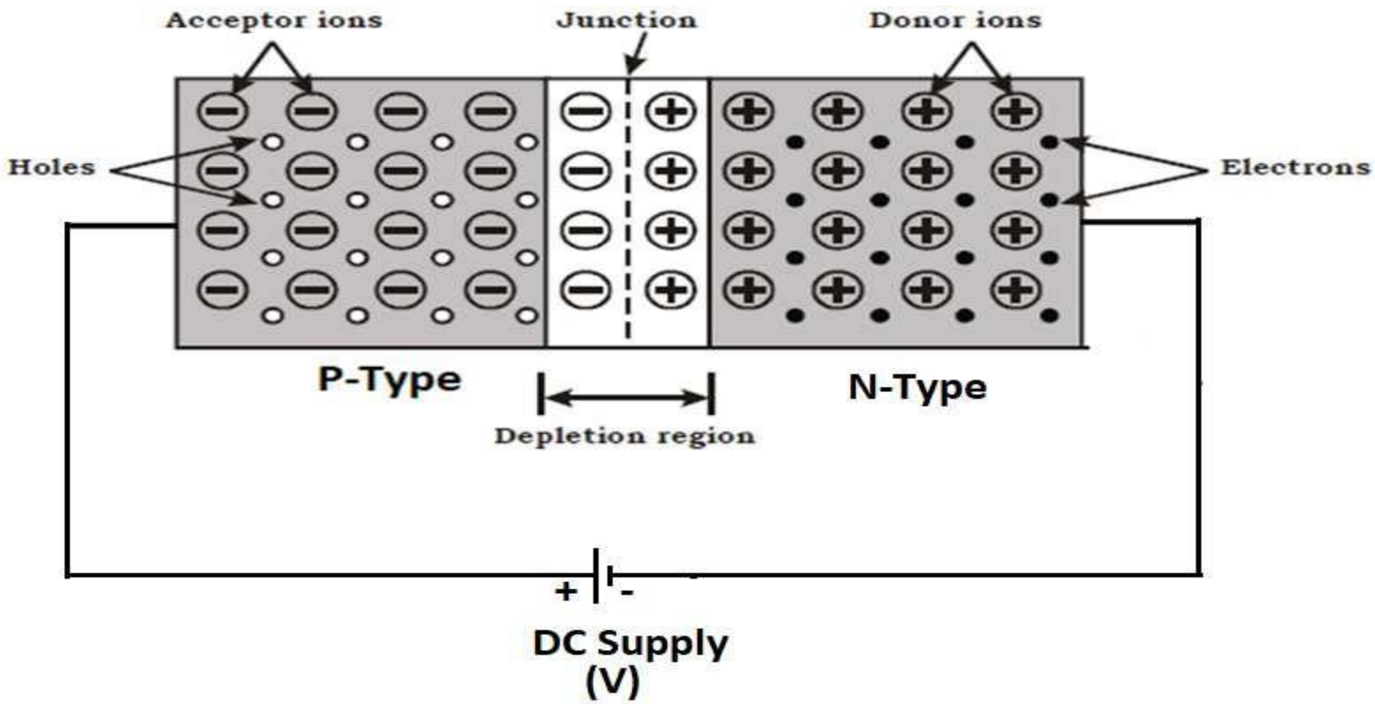
Symbol of Diode

- When the P-Type and N-Type semiconductors are joined, at the junction, there is a tendency for the free electrons to diffuse from N-side to P-side and holes from P-side to N-side.
- Once holes enter into the N-region, they will recombine with donor ions.

- At the same time, donor ions admit additional holes and become positively charged immobile ions.
- The electrons spreading from N-region to P-region recombine with the acceptor ions in P-region.
- At the same time, acceptor ions admit additional electrons and become negatively charged immobile ions.
- As a result, a large number of positively charged ions are produced at the junction on the N-side and a large number of negatively charged ions are produced at the junction on P-side.
- This situation soon prevents the further diffusion due to positive charge on N-side repels the holes to cross the junction and negative charge on P-side repels the electrons to cross the junction.
- Thus a barrier is set up against the further movement of charge carriers i.e., holes and electrons. This is called as potential barrier or depletion region.

Operation of P-N Junction Diode

Forward Bias:

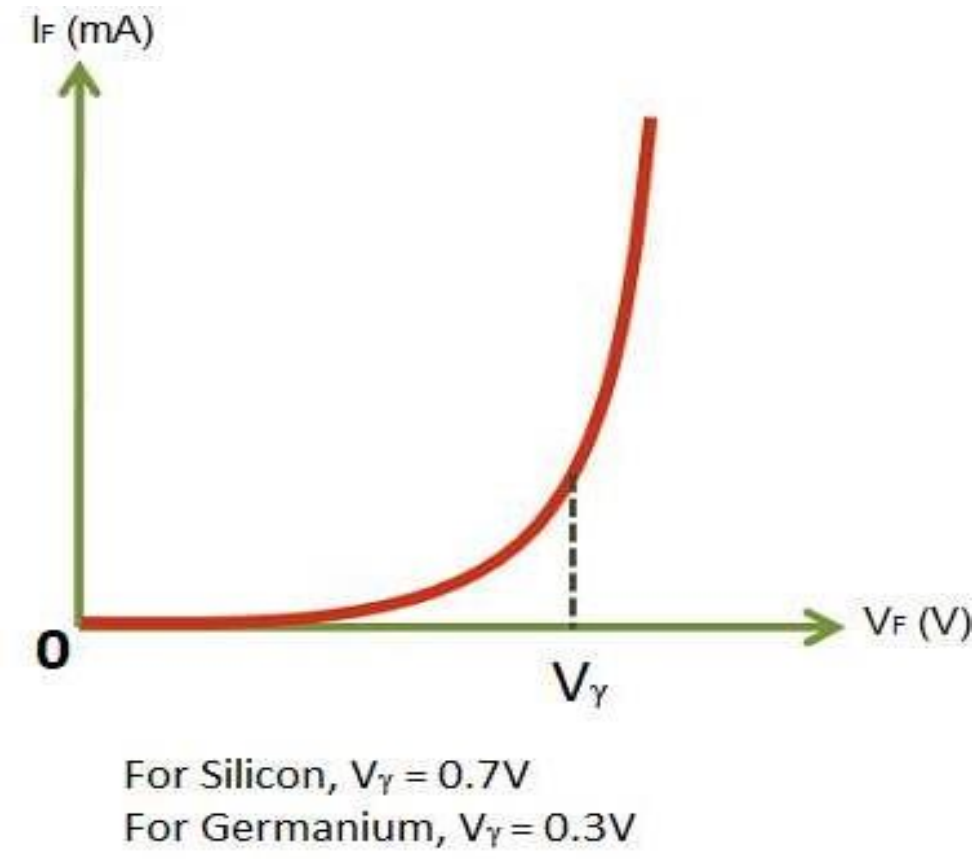


- When the P-type is connected to the positive terminal and N- type is connected to the negative terminal of the supply then that is said to be forward bias.
- Holes are repelled by the positive terminal of the supply and electrons are repelled by the negative terminal of the supply. Hence, the width of the depletion region decreases.

- At certain forward voltage, the width of the depletion region becomes zero, then diode starts conducting. This voltage is called as cut-in voltage.

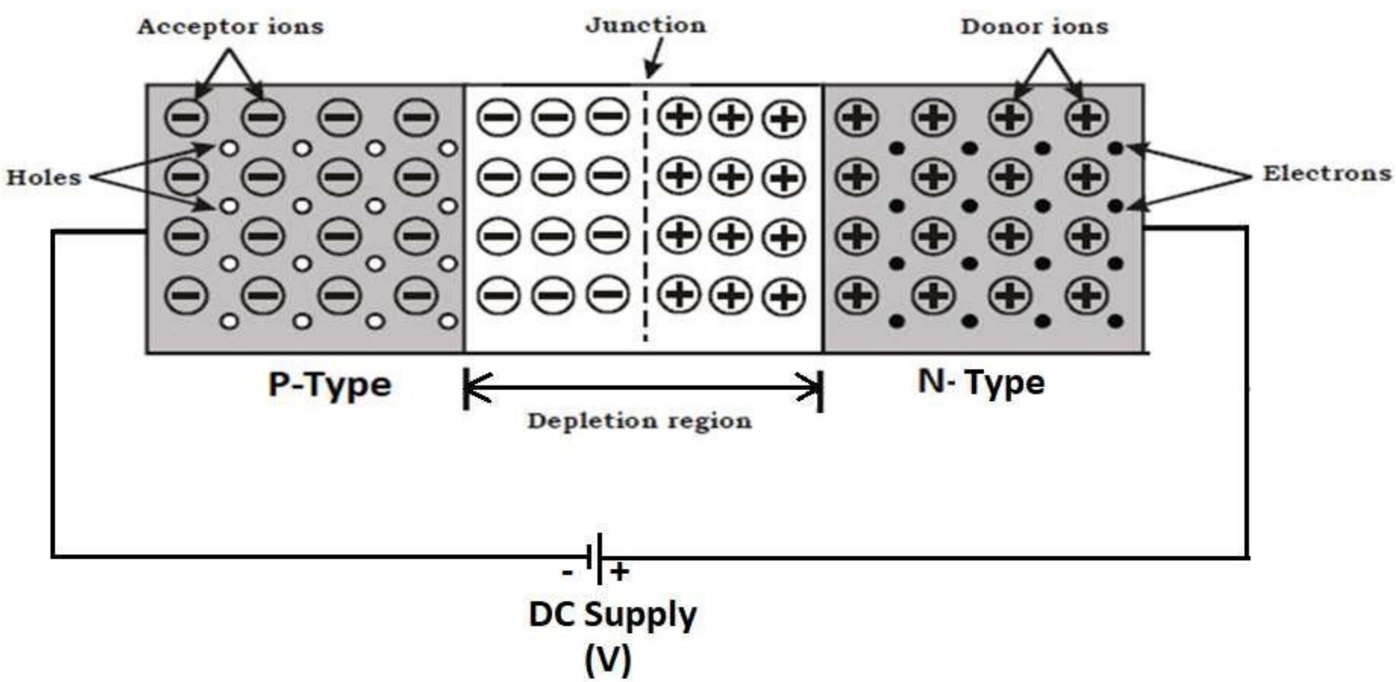
- After cut-in voltage ,the current through the diode increases non-linearly.

- Cut-in voltage or breakdown voltage is 0.7V for silicon and 0.3V for germanium.



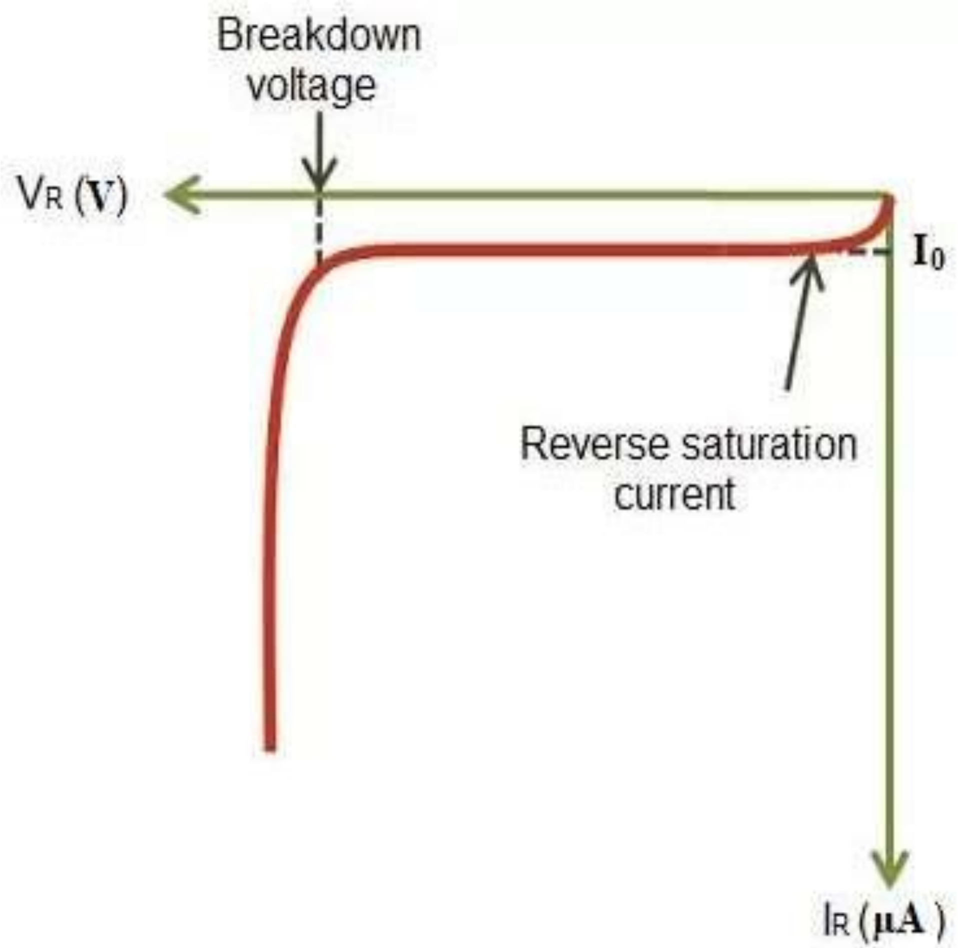
forward bias V-I Characteristics

Reverse Bias:



- When the P-type is connected to the negative terminal and N- type is connected to the positive terminal of the supply then that is said to be reverse bias.
- Holes are attracted by the negative terminal of the supply and electrons are attracted by the positive terminal of the supply. Hence, the width of the depletion region increases.

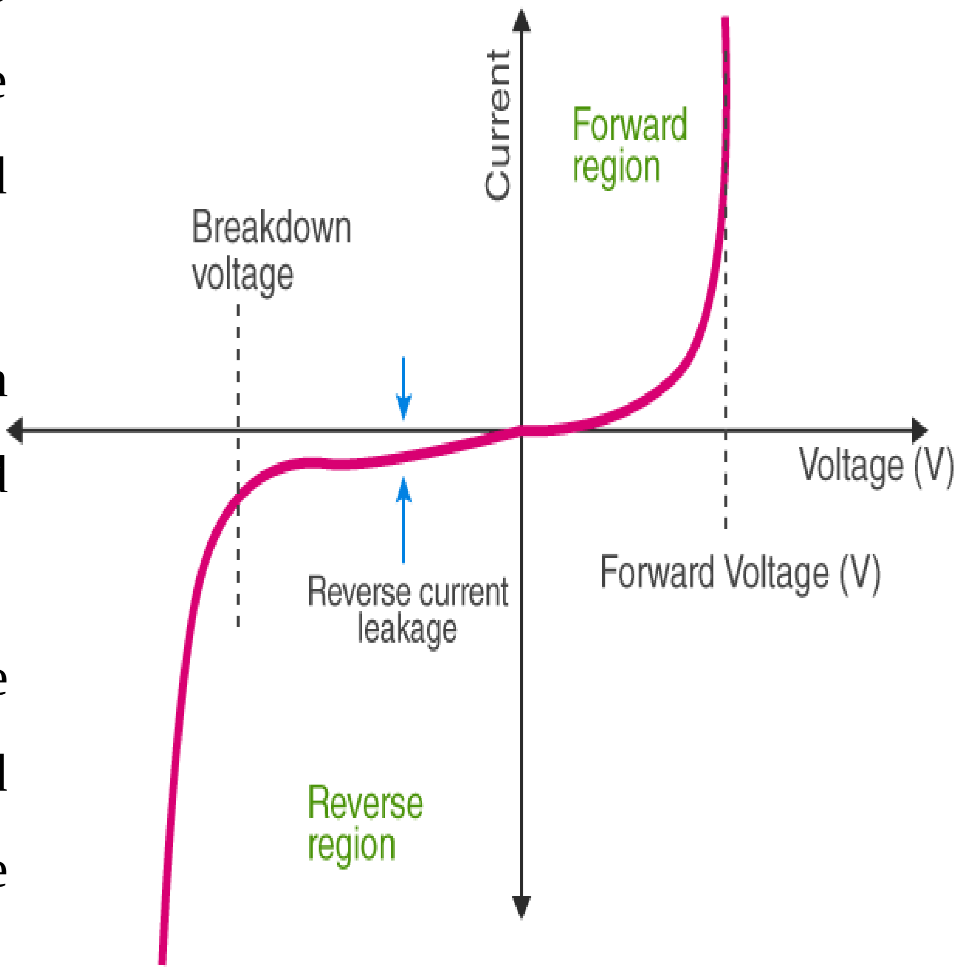
- A small amount of current i.e., reverse saturation current flows through the diode due to flow of minority charge carriers.
- At certain reverse voltage, the reverse breakdown occurs(Avalanche breakdown), the current through the diode increases rapidly.
- This voltage is called as reverse breakdown voltage.



Reverse bias V-I Characteristics

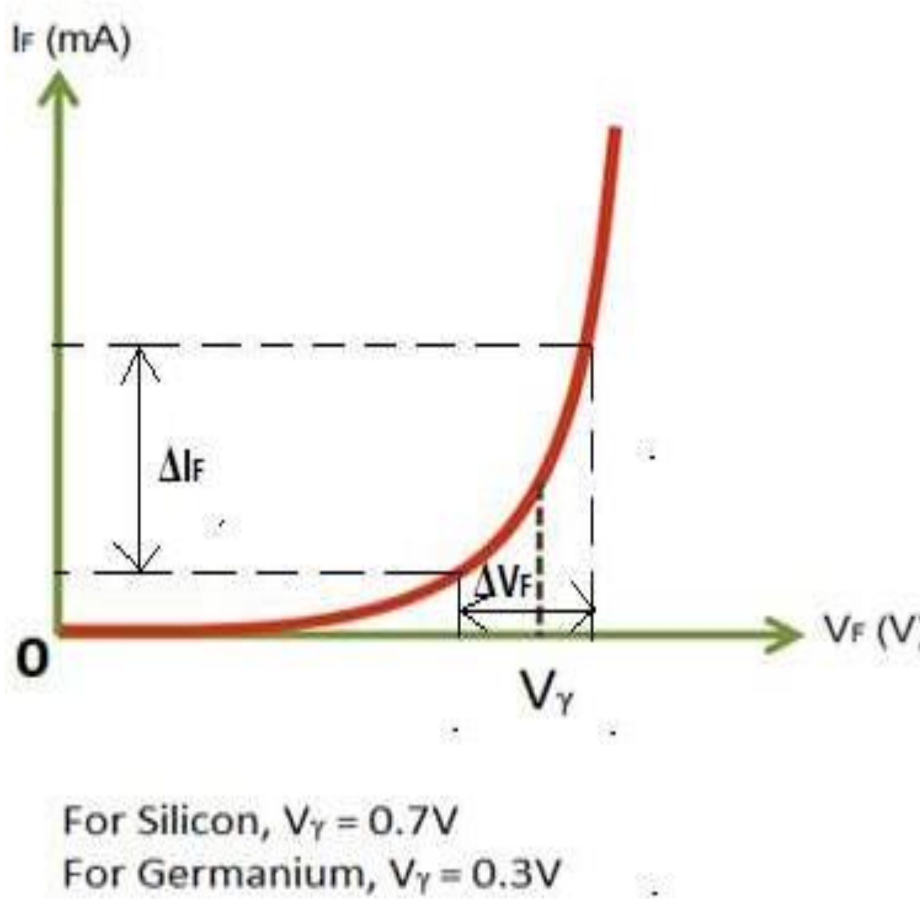
Avalanche Breakdown :

- When a high value of reverse voltage is applied to the P-N junction, the free electrons gain sufficient energy and accelerate at high velocities.
- These free electrons moving at high velocity collides other atoms and knocks off more electrons.
- Due to this continuous collision, a large number of free electrons are generated as a result of electric current in the diode rapidly increases.
- This is called as avalanche breakdown.



Forward Resistance

- It is the resistance offered by the diode in the forward bias to the flow of forward current. It is of two types
- **Static Resistance (DC Resistance):** It is the resistance offered by the diode in the forward bias to the flow of DC current.
- From the forward bias characteristics, the static resistance is given by



$$\text{Static Resistance } (R_s) = \frac{\text{Forward voltage across the diode}}{\text{Forward current through the diode}}$$

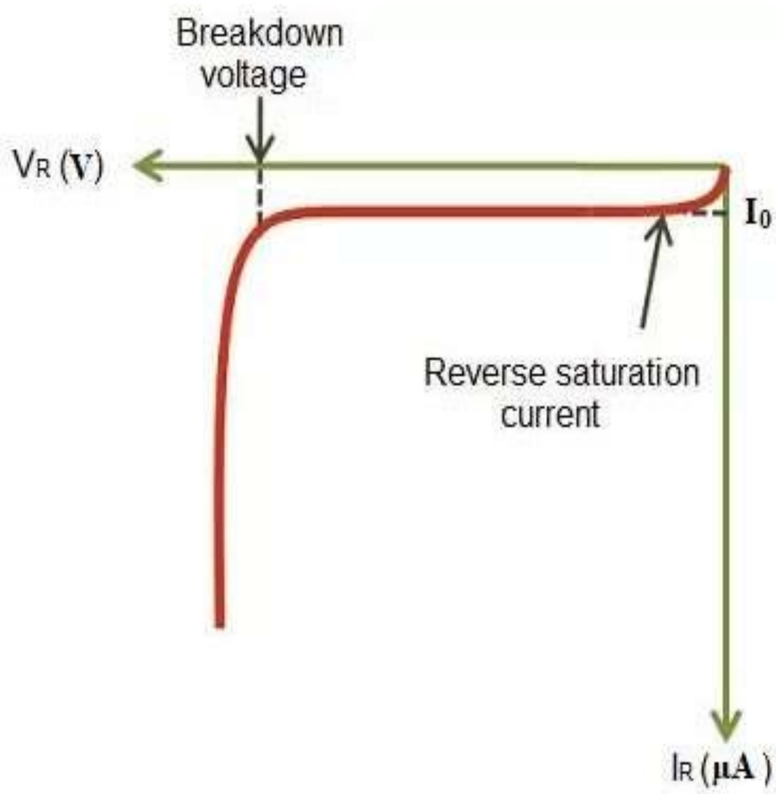
$$R_s = V_F / I_F$$

- **Dynamic resistance (AC Resistance):** It is the resistance offered by the diode in the forward bias to the flow of AC current.
- From the forward bias characteristics the dynamic resistance is given by
- Dynamic resistance (R_D) = Change in forward voltage/Change in forward current.

$$R_D = \Delta V_F / \Delta I_F$$

REVERSE RESISTANCE

- **Reverse resistance:** It is the resistance offered by the diode in the reverse bias to the flow of reverse saturation current.



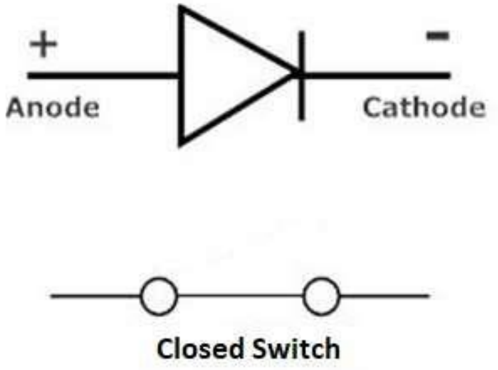
- From the reverse characteristics it is given by

Reverse resistance (Rr) = Reverse voltage across the diode/Reverse saturation current.

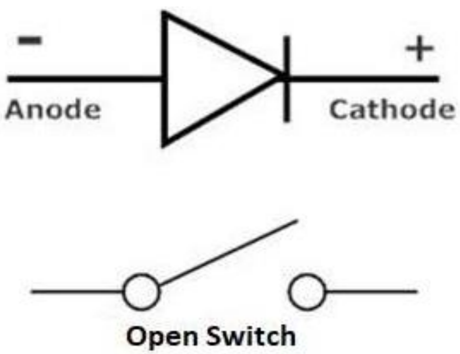
$$Rr = V_R/I_0$$

IDEAL DIODE

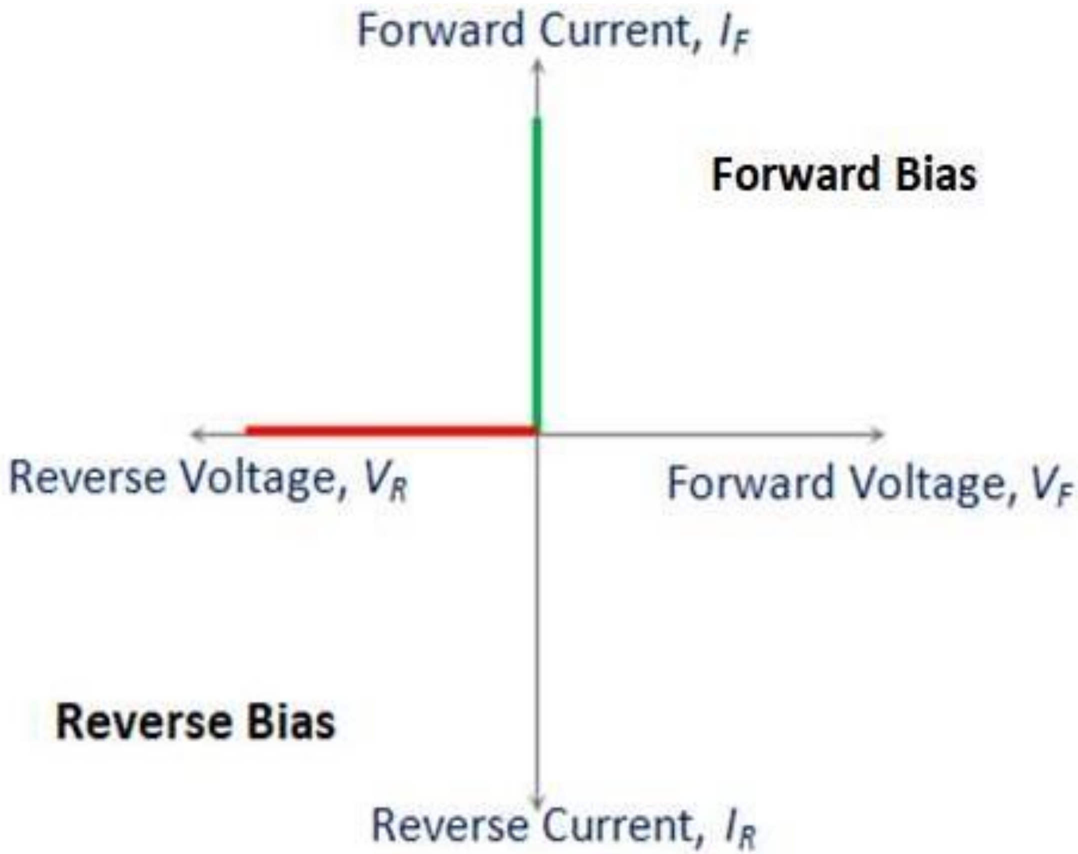
- For Ideal diode, the forward resistance is Zero ohms and the reverse resistance is ∞ ohms.



Forward biased



Reverse biased



Ideal diode V-I Characteristics

Diode Applications

- Diode is used in

(i) Electronic Switch

(ii) Rectifiers

(iii) Clippers

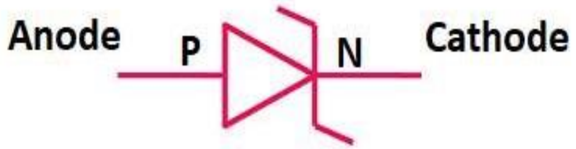
(iv) Clampers

(v) Logic gates

(vi) Voltage multiplier circuits etc.,

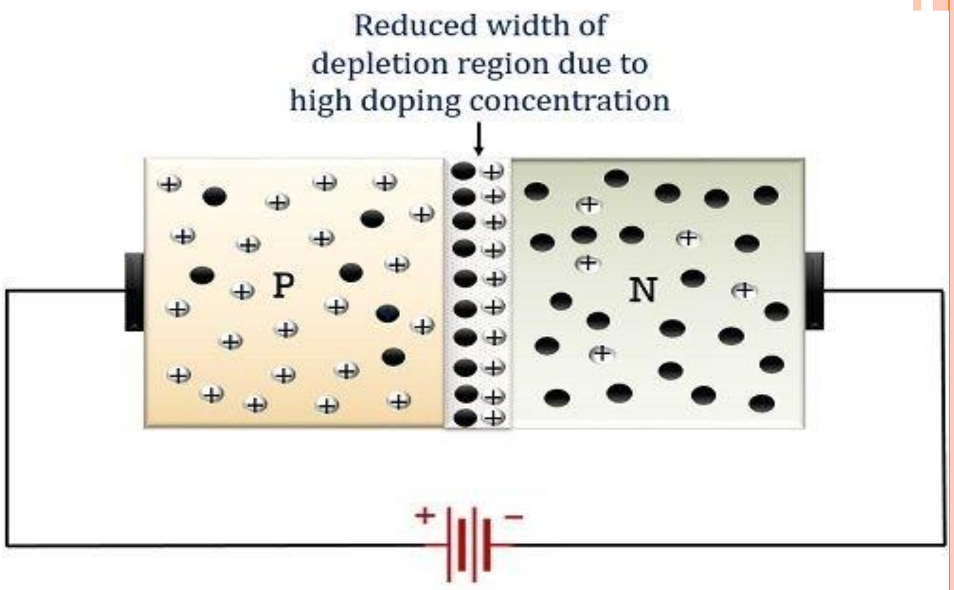
ZENER DIODE

- A Zener diode is a heavily doped P-N junction semiconductor device that is designed to operate in the reverse bias condition.
- Heavily doped means the high level impurities are added to the material for making it more conductive.
- In other words, the diode which is specially designed for optimizing the breakdown region is known as the Zener diode.
- Zener diode acts like normal P-N junction diode under forward biased condition.
- The depletion region of the Zener diode is very thin as it is heavily doped.
- As it is heavily doped the intensity of the electric field across the depletion region is high even for the small reverse voltage.



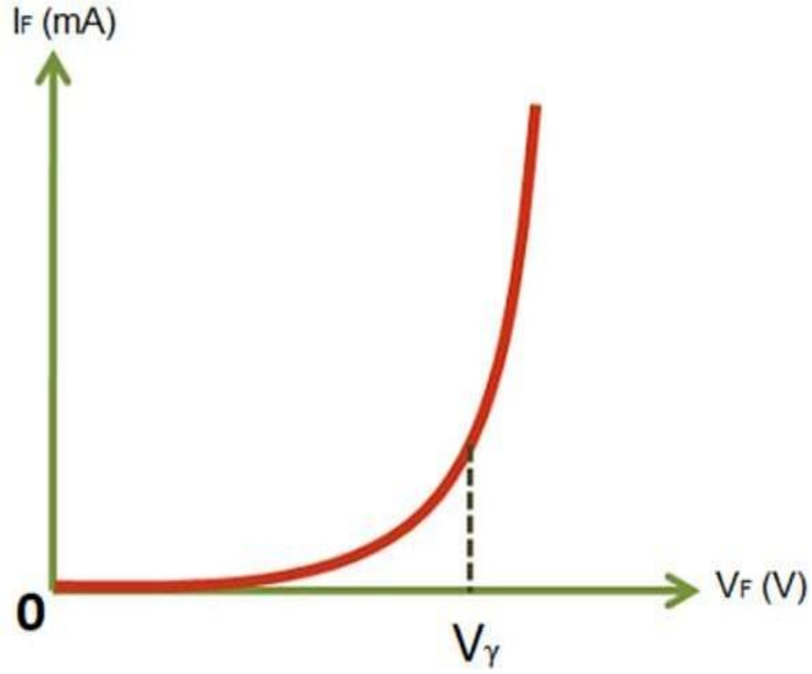
Operation of Zener Diode

Forward Bias:



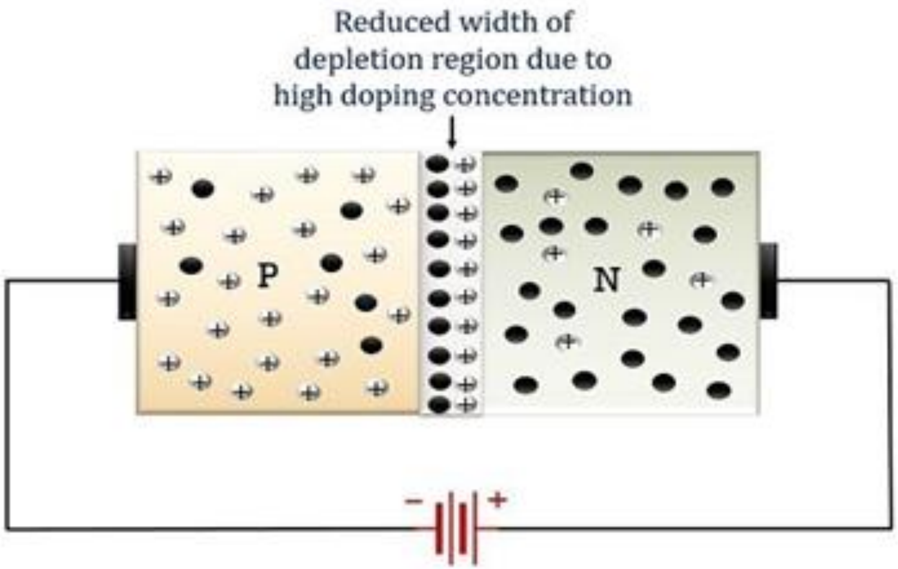
- When the P-type is connected to the positive terminal and N- type is connected to the negative terminal of the supply then that is said to be forward bias.
- Holes are repelled by the positive terminal of the supply and electrons are repelled by the negative terminal of the supply. Hence, the width of the depletion region decreases.
- At certain forward voltage, the width of the depletion region becomes zero, then diode starts conducting. This voltage is called as cut-in voltage which is less than P-N junction diode.
- After cut-in voltage ,the current through the Zener diode increases non-linearly.

Forward Bias V-I Characteristics



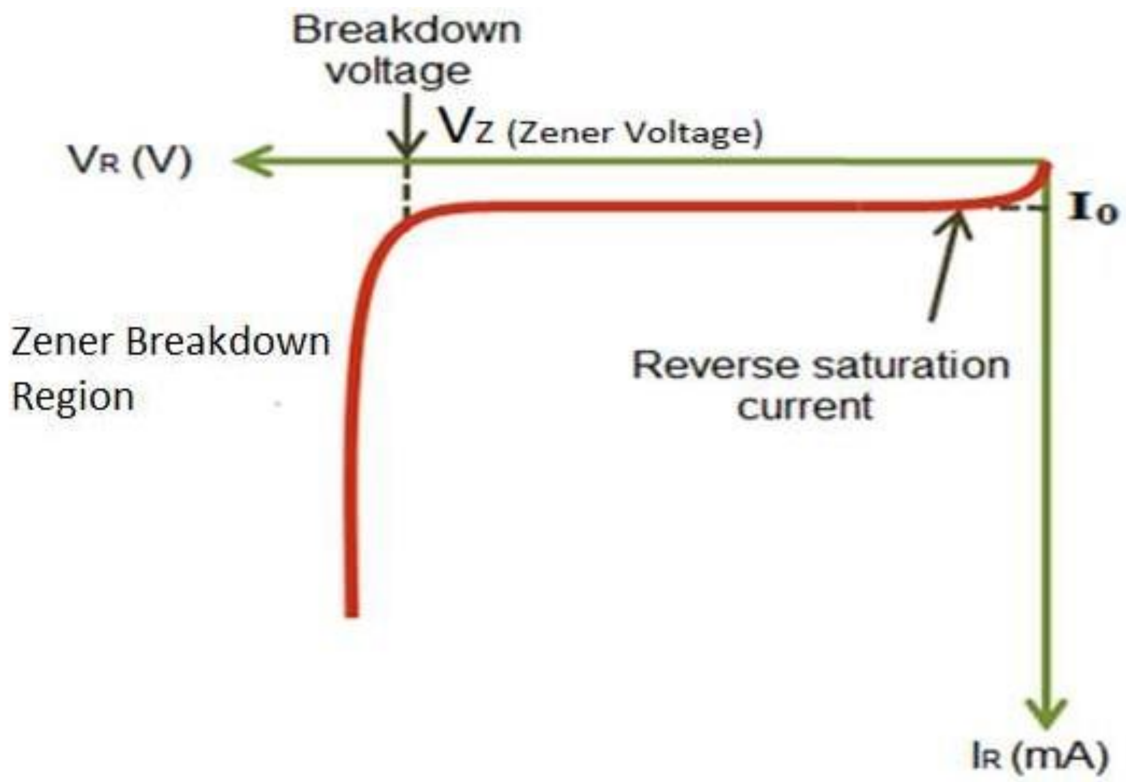
Reverse Bias:

- When the P-type is connected to the negative terminal and N- type is connected to the positive terminal of the supply then that is said to be reverse bias.

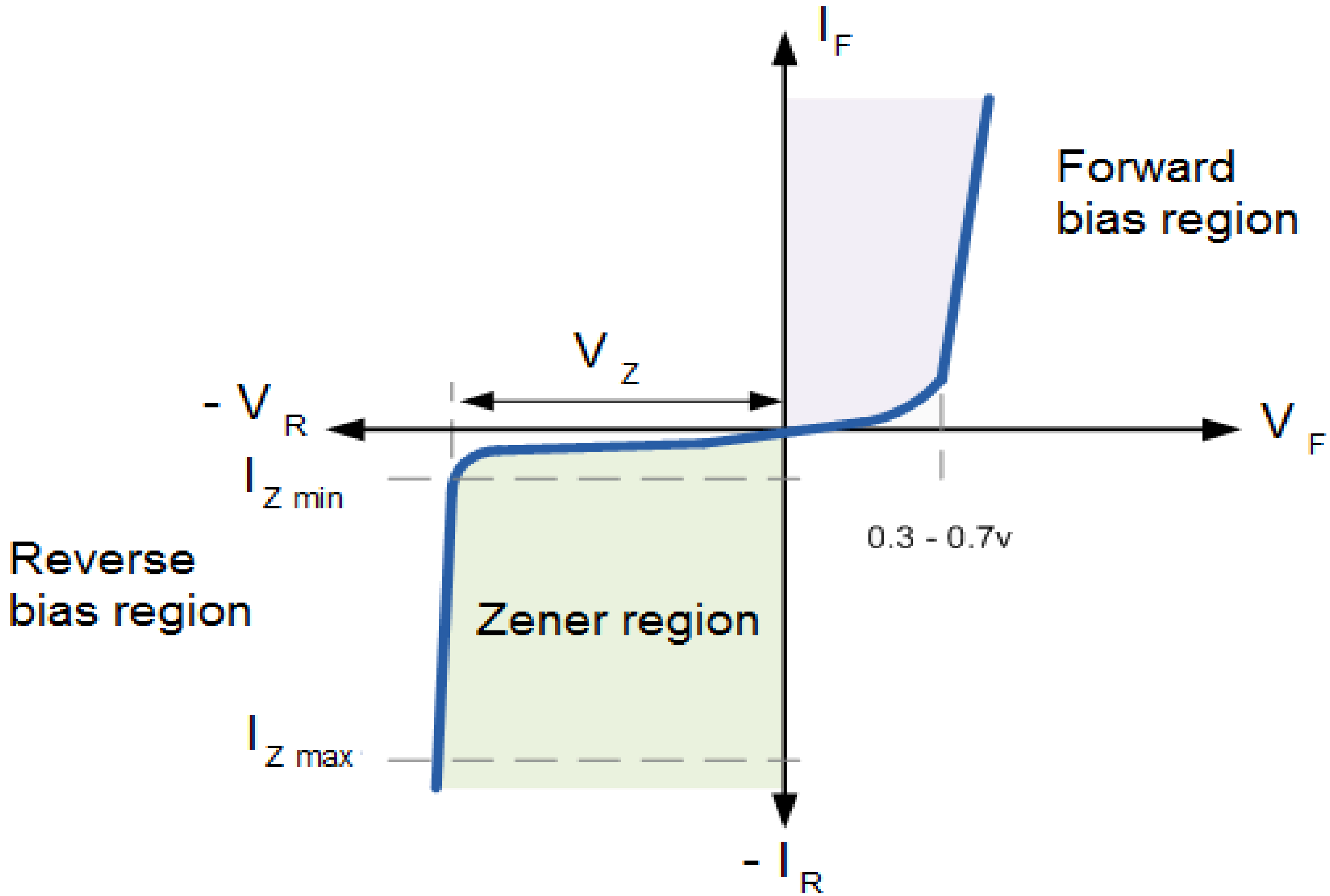


- When reverse biased voltage is applied to the Zener diode, it allows only a small amount of leakage current(reverse saturation current) until the voltage is less than Zener voltage.
- When reverse voltage reaches Zener voltage, Zener breakdown occurs, it starts allowing large amount of electric current.
- At this point, a small increase in reverse voltage will rapidly increase the electric current.

REVERSE BIAS V-I CHARACTERISTICS:



V-I Characteristics of Zener Diode:



There are two types of breakdowns for a Zener Diode:

- Avalanche Breakdown
- Zener Breakdown

Avalanche Breakdown in Zener Diode:

- Avalanche breakdown occurs both in normal diode and Zener Diode at high reverse voltage.
- When a high value of reverse voltage is applied to the PN junction, the free electrons gain sufficient energy and accelerate at high velocities.
- These free electrons moving at high velocity collides other atoms and knocks off more electrons.
- Due to this continuous collision, a large number of free electrons are generated as a result of electric current in the diode rapidly increases.

- This sudden increase in electric current may permanently destroy the normal diode, however, a Zener diode is designed to operate under avalanche breakdown and can sustain the sudden spike of current.
- Avalanche breakdown occurs in Zener diodes with Zener voltage (Vz) greater than 6V.

Zener Breakdown in Zener Diode:

- The Zener breakdown occurs in heavily doped P-N junction diode because of its narrow depletion region.
- When reverse biased voltage applied to the diode is increased, the narrow depletion region generates strong electric field.
- When reverse biased voltage applied to the diode reaches the zener voltage, the electric field in the depletion region is strong enough to pull electrons from their valence band.
- The valence electrons which gains sufficient energy from the strong electric field will break the bonding with the parent atom.
- At the Zener breakdown region, a small increase in the voltage results in the rapid increase of the electric current.
- This is called as zener breakdown.
- Zener breakdown occurs in Zener diode with Zener voltage (V_z) less than 6V.

Zener Diode Applications

Zener Diode is used in

(i) Voltage Regulator

(ii) Waveform Clipper

(iii) Voltage Shifter etc,.

What is rectifier ?

A **rectifier** is an electrical device that converts alternating current (AC) into direct current (DC).

- Based on the type of rectification circuit does, the rectifiers are classified into two categories.

- Half wave rectifier
- Full wave rectifier

TYPES OF RECTIFIERS

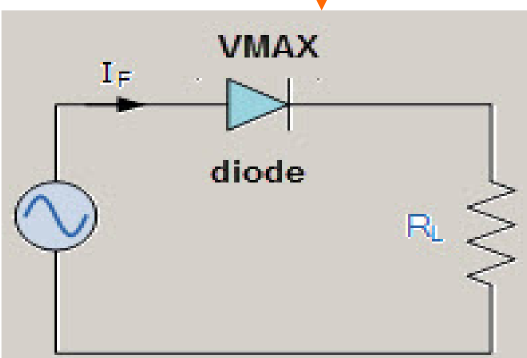
Rectifier

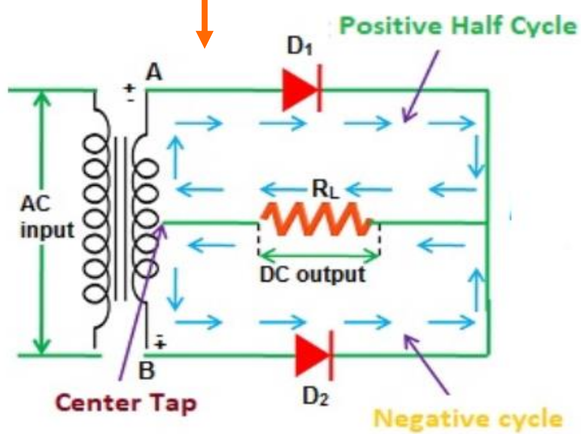
Half-wave Rectifier

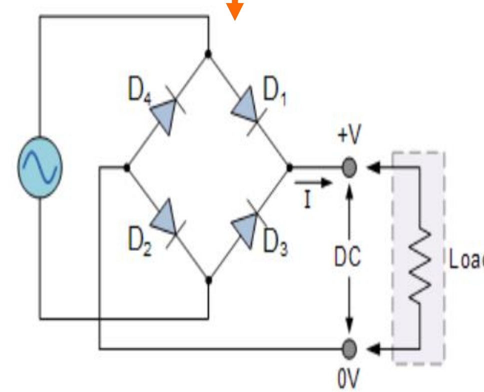
Full-wave Rectifier

Centre-tape full-wave rec.

Full-wave Bridge rec.







Half Wave Rectifier:

- A halfwave rectifier is defined as a type of rectifier that allows only one-half cycle of an AC voltage waveform to pass while blocking the other half cycle.
- A halfwave rectifier circuit uses only one diode for the transformation.

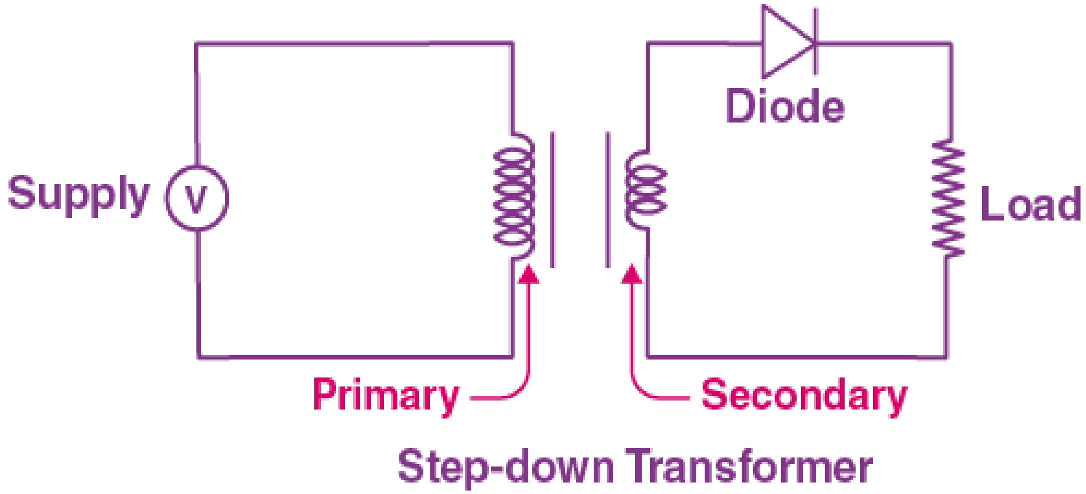
Half Wave Rectifier Circuit:

- A half-wave rectifier is the simplest form of the rectifier and requires only one diode for the construction of a halfwave rectifier circuit.
- A halfwave rectifier circuit consists of three main components as follows:

• A diode

• A transformer

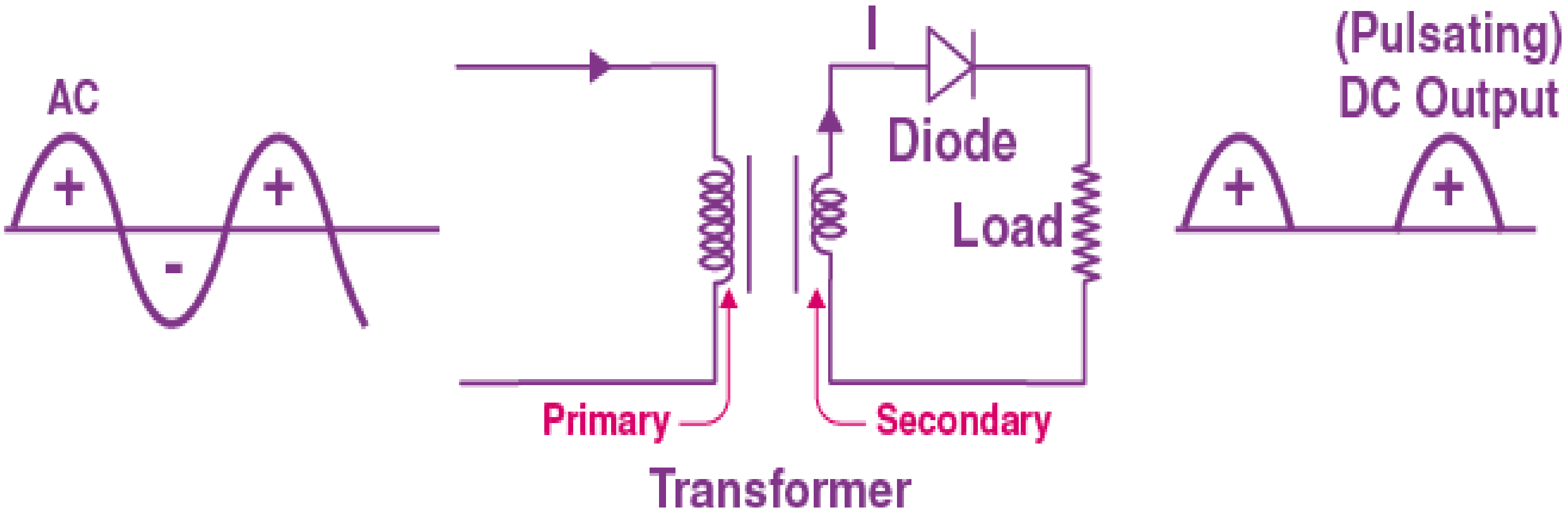
• A resistive load



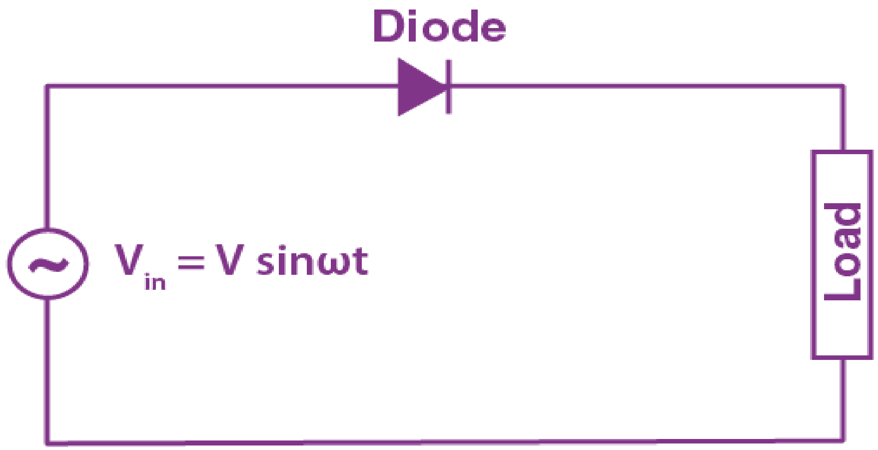
Working of Half Wave Rectifier

In this section, let us understand how a half-wave rectifier transforms AC into DC.

1. A high AC voltage is applied to the primary side of the transformer. The obtained secondary voltage is applied to the diode.
2. The diode is forward biased during the positive half cycle of the AC voltage and reverse biased during the negative half cycle of the AC voltage.
3. The final output voltage waveform is as shown in the figure below:

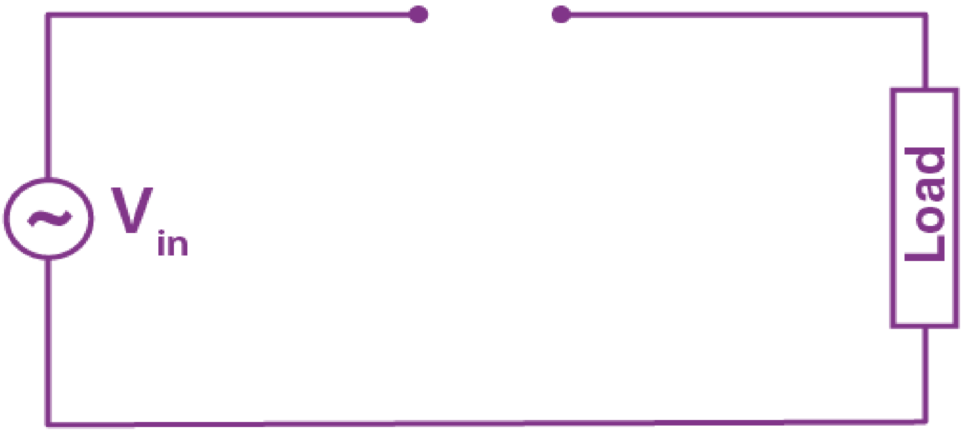


- For better understanding, let us simplify the half-wave circuit by replacing the secondary transformer coils with a voltage source as shown below:



- For the positive half cycle of the AC source voltage, the diode is forward biased, it acts as a closed switch. the circuit effectively becomes as shown below in the diagram:

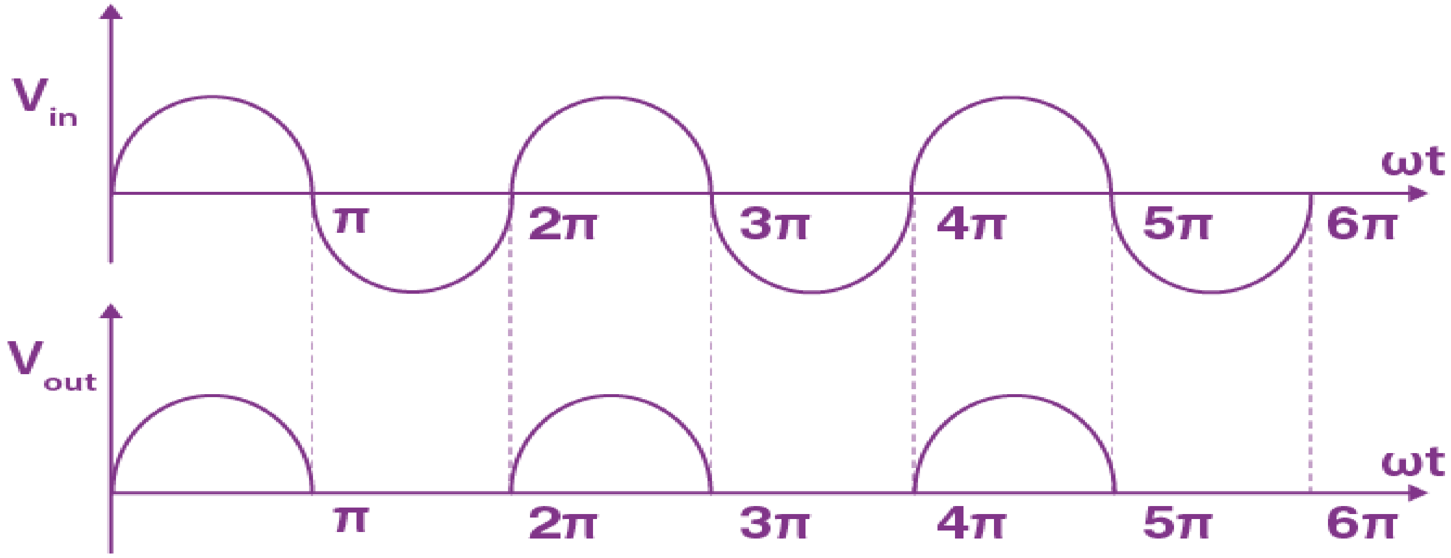
- But, during the negative half cycle of the AC source voltage, the diode is reverse biased, it acts as a open switch. the circuit effectively becomes as shown below in the diagram:



- When a diode is reverse biased, it acts as an open switch. Since no current can flow to the load, the output voltage is equal to zero.

Half Wave Rectifier Waveform

The halfwave rectifier waveform before and after rectification is shown below in the figure.



The average voltage value of output in a half wave rectifier is be derived as follows:

$$v_{avg} = \frac{1}{T}\int_{o}^{T} v_{in}\, \mathrm{d}t$$

$$v_{avg} = \frac{1}{2\pi}\int_{o}^{2\pi} v_m\, sin\omega t\, \mathrm{d}\omega t \qquad \text{(since, } v_{in} = v_m\, sin\omega t\text{)}$$

$$v_{avg} = \frac{v_m}{2\pi}\int_{o}^{\pi} sin\omega t\, \mathrm{d}\omega t$$

$$v_{avg} = \frac{v_m}{2\pi}\left[-cos\omega t\right]_0^{\pi} \mathrm{d}\omega t$$

$$v_{avg} = \frac{v_m}{2\pi}\left[-cos\pi + \cos(0)\right]$$

$$v_{avg} = \frac{v_m}{2\pi}\left[-(-1) + 1\right] = \frac{v_m}{2\pi}(1+1) = \frac{v_m}{2\pi}(2)$$

$$v_{avg}\ (or)\ v_{dc} = \frac{v_m}{\pi} \qquad \text{-------------- (1)}$$

The rms voltage value of output in a half wave rectifier is be derived as follows:

$$v_{rms} = \sqrt{\frac{1}{T}\int_{o}^{T} {v_{in}}^{2}\,\mathrm{d}t}$$

$$v_{rms} = \sqrt{\frac{1}{2\pi}\int_{o}^{\pi} {v_m}^{2}\,sin^{2}\omega t\,\mathrm{d}\omega t}$$

$$v_{rms} = \sqrt{\frac{{v_m}^{2}}{2\pi}\int_{o}^{\pi} \frac{(1 - cos2\omega t)}{2}\,\mathrm{d}\omega t}$$

$$v_{rms} = \sqrt{\frac{{v_m}^{2}}{4\pi}\int_{o}^{\pi} (1 - cos2\omega t)\,\mathrm{d}\omega t}$$

$$v_{rms} = \sqrt{\frac{{v_m}^2}{4\pi}\left[\int_{o}^{\pi} \mathrm{d}\omega t - \int_{o}^{\pi} cos2\omega t \ \mathrm{d}\omega t\right]}$$

$$v_{rms} = \sqrt{\frac{{v_m}^2}{4\pi}[\,(\pi - 0) - (\,sin2\pi \ - sin0)]}$$

$$v_{rms} = \sqrt{\frac{{v_m}^2}{4\pi}(\pi)}$$

$$v_{rms} = \frac{v_m}{2} \quad \text{-----------} \quad (2)$$

The ripple factor is given by:

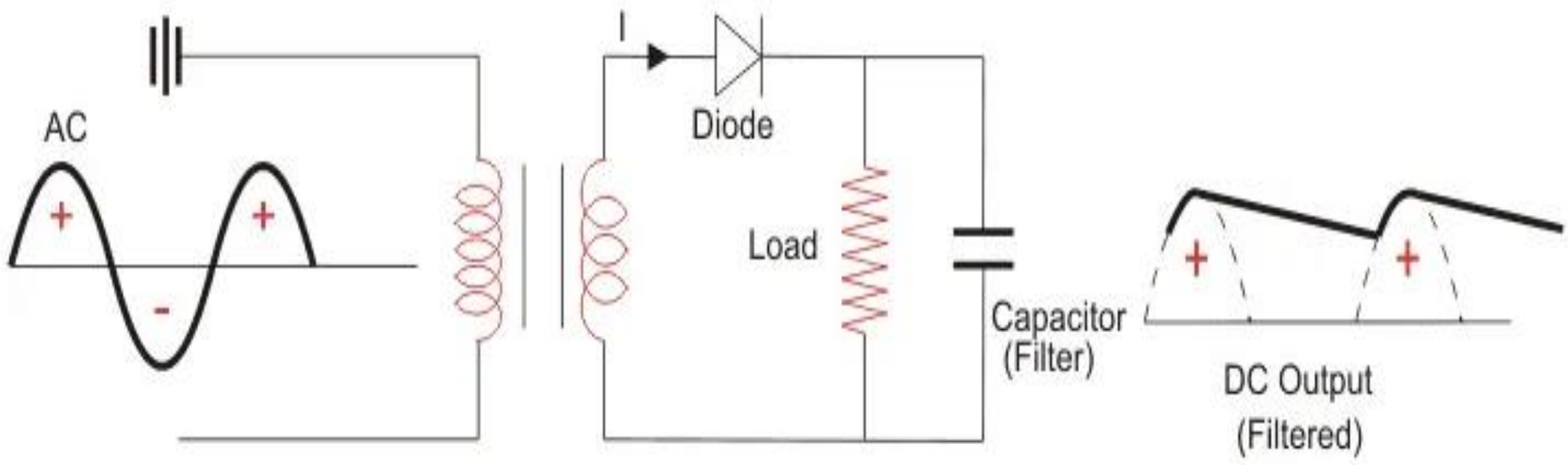
$$\gamma = \sqrt{(\frac{V_{rms}}{V_{dc}})^2 - 1}$$

Half Wave Rectifier with Filter:

The output waveform we have obtained from the theory above is a pulsating DC waveform. This is what is obtained when using a half wave rectifier without a filter.

- Filters are components used to convert (smoothen) pulsating DC waveforms into constant DC waveforms. They achieve this by suppressing the DC ripples in the waveform.
- Although half-wave rectifiers without filters are theoretically possible, they can't be used for any practical applications. As DC equipment requires a constant waveform, we need to 'smooth out' this pulsating waveform for it to be any use in the real world.

- This is why in reality we use half wave rectifiers with a filter. A capacitor or an inductor can be used as a filter – but half wave rectifier with capacitor filter is most commonly used.
- The circuit diagram below shows how a capacitive filter is can be used to smoothen out a pulsating DC waveform into a constant DC waveform.



The ripple factor is given by:

$$\gamma = \frac{1}{2\sqrt{3}\ (fCR)}$$

Where,

f - frequency of supply voltage

C – capacitance

R - resistance

Applications of Half Wave Rectifier:

Half wave rectifiers are not as commonly used as full-wave rectifiers. Despite this, they still have some uses:

- For rectification applications
- For signal demodulation applications
- For signal peak applications

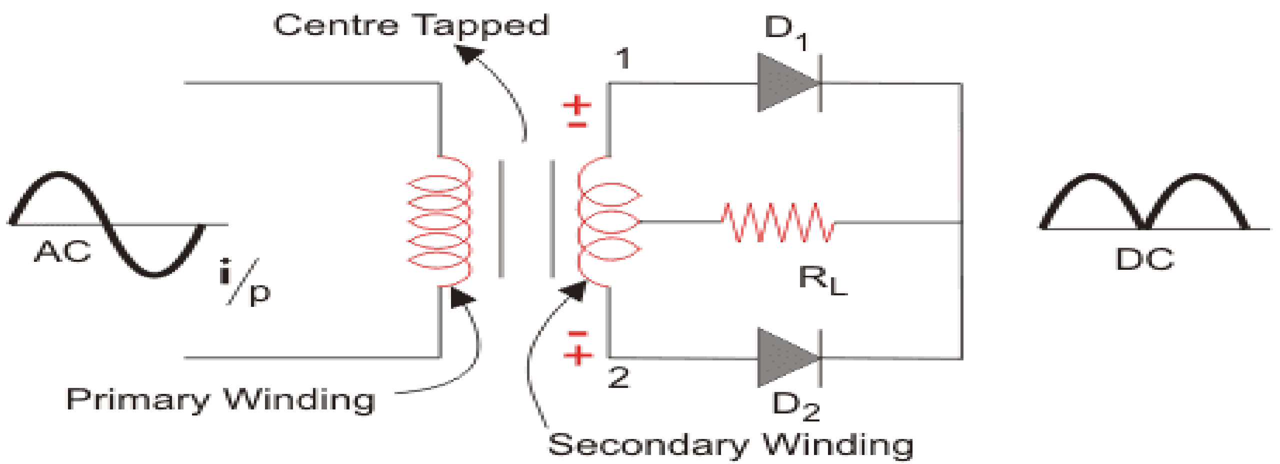
Full Wave Rectifier:

A full wave rectifier is defined as a rectifier that converts the complete cycle of alternating current into pulsating DC.

Full Wave Rectifier Circuit:

The circuit of the full wave rectifier can be constructed in two ways.

- The first method uses a center tapped transformer and two diodes. This arrangement is known as a center tapped full wave rectifier.
- The second method uses a standard transformer with four diodes arranged as a bridge. This is known as a bridge rectifier.
- In the next section, we will restrict the discussion to the center tapped full wave rectifier only.



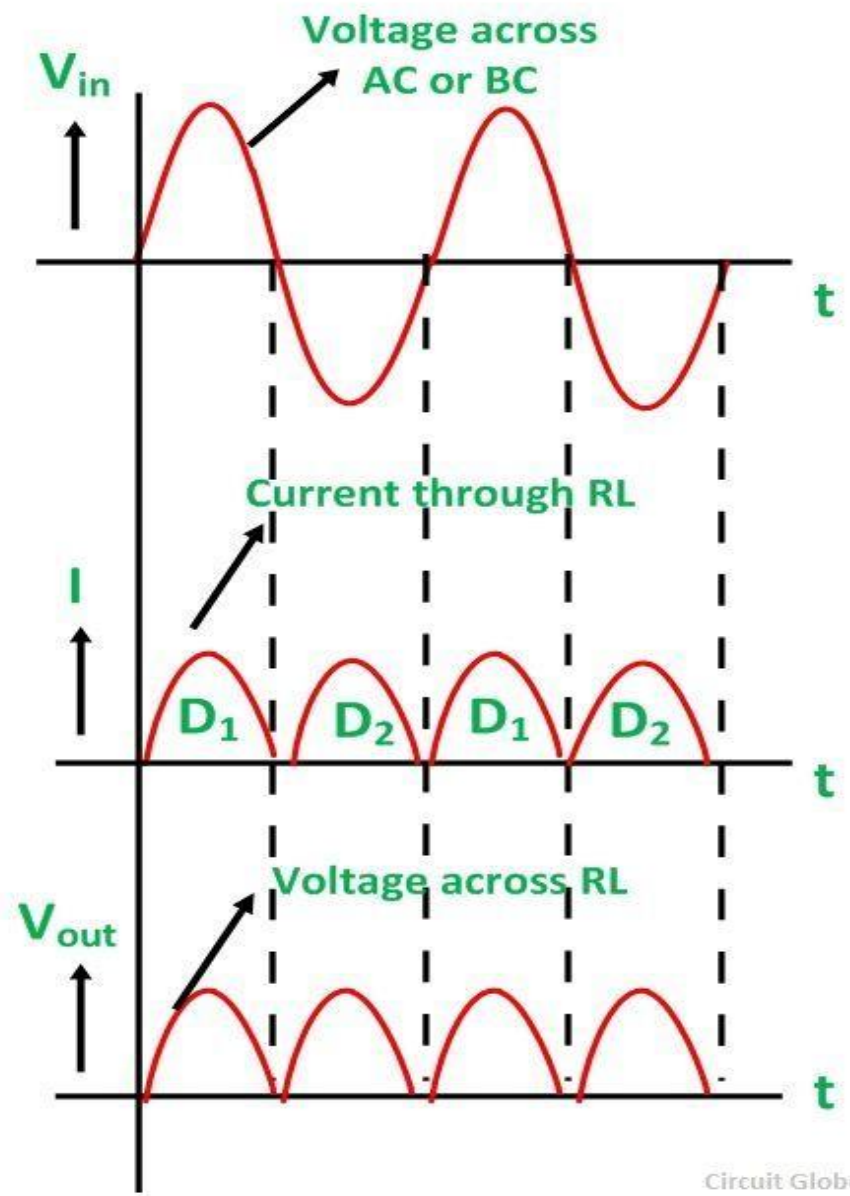
Centre Tapped Full Wave Rectifier
Figure - 1

- The circuit of the full wave rectifier consists of a transformer and two diodes that are connected and center tapped. The output voltage is obtained across the connected load resistor.

Working of Full Wave Rectifier:

- The input AC supply is applied to the full wave rectifier. The step-down transformer in the rectifier circuit converts the high voltage AC into low voltage AC.

- The anode of the center tapped diodes is connected to the transformer's secondary winding and connected to the load resistor.
- During the positive half cycle of the alternating current, the top half of the secondary winding becomes positive while the second half of the secondary winding becomes negative.
- During the positive half cycle, diode D_1 is forward biased as it is connected to the top of the secondary winding while diode D_2 is reverse biased as it is connected to the bottom of the secondary winding.



- Due to this, diode D_1 will conduct acting as a short circuit and D_2 will not conduct acting as an open circuit.
- During the negative half cycle, the top half of the secondary circuit becomes negative and the bottom half of the circuit becomes positive
- During this, the diode D_1 is reverse biased and the diode D_2 is forward biased.
- Thus in a full wave rectifiers, DC voltage is obtained for both positive and negative half cycle.

The average voltage value of output in a full wave rectifier is be derived as follows:

$$v_{avg} = \frac{1}{T}\int_{o}^{T} v_{in}\, \mathrm{d}t$$

$$v_{avg} = \frac{1}{\pi}\int_{o}^{\pi} v_m\, sin\omega t\, \mathrm{d}\omega t \qquad \text{(since, } v_{in} = v_m\, sin\omega t \text{)}$$

$$v_{avg} = \frac{v_m}{\pi}\int_{o}^{\pi} sin\omega t\, \mathrm{d}\omega t$$

$$v_{avg} = \frac{v_m}{\pi}\left[-cos\omega t\right]_0^{\pi} \mathrm{d}\omega t$$

$$v_{avg} = \frac{v_m}{\pi}\left[-cos\pi + \cos(0)\right]$$

$$v_{avg} = \frac{v_m}{\pi}\left[-(-1) + 1\right] = \frac{v_m}{\pi}(1+1) = \frac{v_m}{\pi}(2)$$

$$v_{avg}\ (or)\ v_{dc} = \frac{2v_m}{\pi} \qquad \text{-------------- (1)}$$

The rms voltage value of output in a half wave rectifier is be derived as follows:

$$v_{rms} = \sqrt{\frac{1}{T}\int_{o}^{T} {v_{in}}^2 \, \mathrm{d}t}$$

$$v_{rms} = \sqrt{\frac{1}{\pi}\int_{o}^{\pi} {v_m}^2 \, sin^2\omega t \, \mathrm{d}\omega t}$$

$$v_{rms} = \sqrt{\frac{{v_m}^2}{\pi}\int_{o}^{\pi} \frac{(1 - cos2\omega t)}{2} \, \mathrm{d}\omega t}$$

$$v_{rms} = \sqrt{\frac{{v_m}^2}{2\pi}\int_{o}^{\pi} (1 - cos2\omega t) \, \mathrm{d}\omega t}$$

$$v_{rms} = \sqrt{\frac{{v_m}^2}{2\pi}[\int_o^{\pi} \mathrm{d}\omega t - \int_o^{\pi} cos2\omega t \ \mathrm{d}\omega t]}$$

$$v_{rms} = \sqrt{\frac{{v_m}^2}{2\pi}[\,(\pi - 0) - (\,sin2\pi \ - sin0)]}$$

$$v_{rms} = \sqrt{\frac{{v_m}^2}{2\pi}(\pi)}$$

$$v_{rms} = \frac{v_m}{\sqrt{2}} \quad \text{-----------} \quad (2)$$

The ripple factor is given by:

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

For HWR

$V_{rms} = I_{rms} = \frac{I_m}{2}$ & $I_{dc} = \frac{I_m}{\pi} \Rightarrow V_{dc} = \frac{V_m}{\pi}$

$\therefore \frac{I_{rms}}{I_{dc}} = \frac{\frac{I_m}{2}}{\frac{I_m}{\pi}} = 1.57 = \frac{V_{rms}}{V_{dc}}$

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

$$= \sqrt{(1.57)^2 - 1}$$

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

For FWR:

$V_{dc} = \frac{2V_m}{\pi}$ & $I_{dc} = \frac{2I_m}{\pi}$

$V_{rms} = \frac{V_m}{\sqrt{2}}$ & $I_{rms} = \frac{I_m}{\sqrt{2}}$

$$\frac{V_{rms}}{V_{dc}} = \frac{\frac{V_m}{\sqrt{2}}}{\frac{2V_m}{\pi}}$$

$$\boxed{\gamma = 0.482}$$

Rectification Efficiency $= \eta = \frac{P_{dc}}{P_{ac}} \times 100\%$.

For HWR :- $P_{dc} = I_{dc}^2 R_L = \left(\frac{I_m}{\pi}\right)^2 \cdot R_L$

$P_{ac} = I_{rms}^2 (r_d + R_L) \simeq \left(\frac{I_m}{2}\right)^2 R_L$

$\therefore \eta\% = \frac{\cancel{I_m^2} \cdot \cancel{R_L}}{\pi^2} \times \frac{2^2}{\cancel{I_m^2}}$

$= \frac{2^2}{\pi^2}$

$= \frac{4}{\pi^2} = \frac{4}{9.8596} = 40.6\%$

For FWR : $P_{dc} = I_{dc}^2 R_L = \left(\frac{2I_m}{\pi}\right)^2 \cdot R_L$

$P_{ac} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (r_d + R_L)$

$\simeq \left(\frac{I_m}{\sqrt{2}}\right)^2 \cdot R_L$

$\therefore \eta\% = \frac{(2 \cdot \cancel{I_m})^2}{\pi^2} \times \frac{(\sqrt{2})^2}{\cancel{I_m^2}}$

$= 4 \cdot \frac{2}{\pi^2} = 2 \cdot \frac{4}{\pi^2} = 2 \times 40.6 = 81.2\%$

$\boxed{\eta\% = 81.2\%}$

Table 4.1 COMPARISON BETWEEN DIFFERENT AVERAGE RECTIFIERS

	Half-wave	Full-wave	
		Centre-tap	*Bridge*
Number of diodes	1	2	4
Transformer necessary	No†	Yes	No†
Peak secondary voltage	V_m	V_m^*	V_m
Peak inverse voltage	V_m^{**}	$2\,V_m$	V_m
Peak load current, I_m	$V_m/(r_d+R_L)$	$V_m/(r_d+R_L)$	$V_m/(2r_d+R_L)$
RMS current, I_{rms}	$I_m/2$	$I_m/\sqrt{2}$	$I_m/\sqrt{2}$
DC current, I_{dc}	I_m/π	$2I_m/\pi$	$2I_m/\pi$
Ripple factor, r	1.21	0.482	0.482
Rectification efficiency (max)	40.6 %	81.2 %	81.2 %
Lowest ripple frequency, f_r	f_i	$2f_i$	$2f_i$

*It is the voltage between centre-tap and one of the terminals.

**With a capacitor-input filter, the PIV of a half-wave circuit becomes $2V_m$, as we shall see later.

† Transformer may be used for isolation even if not required for stepping up (or down) the input ac.

BIPOLAR JUNCTION TRANSISTOR (BJT)

BIPOLAR JUNCTION TRANSISTOR (BJT)

- A device which transfers resistance from one channel of the circuit to other is called transistor.
- A bipolar junction transistor (BJT) is a three terminal device.
- The operation depends on the interaction of both majority and minority carriers and hence the name is bipolar.
- It is used as amplifier and oscillator circuits, and as a switch in digital circuits.
- It has wide applications in computers, satellites and other modern communication systems.

CONSTRUCTION:

- The Bipolar Transistor basic construction consists of two P-N junctions producing three connecting terminals.
- These three terminals are known and labeled as the Emitter (E), the Base (B) and the Collector (C) respectively.
- The Emitter is heavily doped region and moderate in size.
- Base is lightly doped region and small in size.
- Collector is moderately doped region and large in size.

TYPES OF BIPOLAR JUNCTION TRANSISTOR:

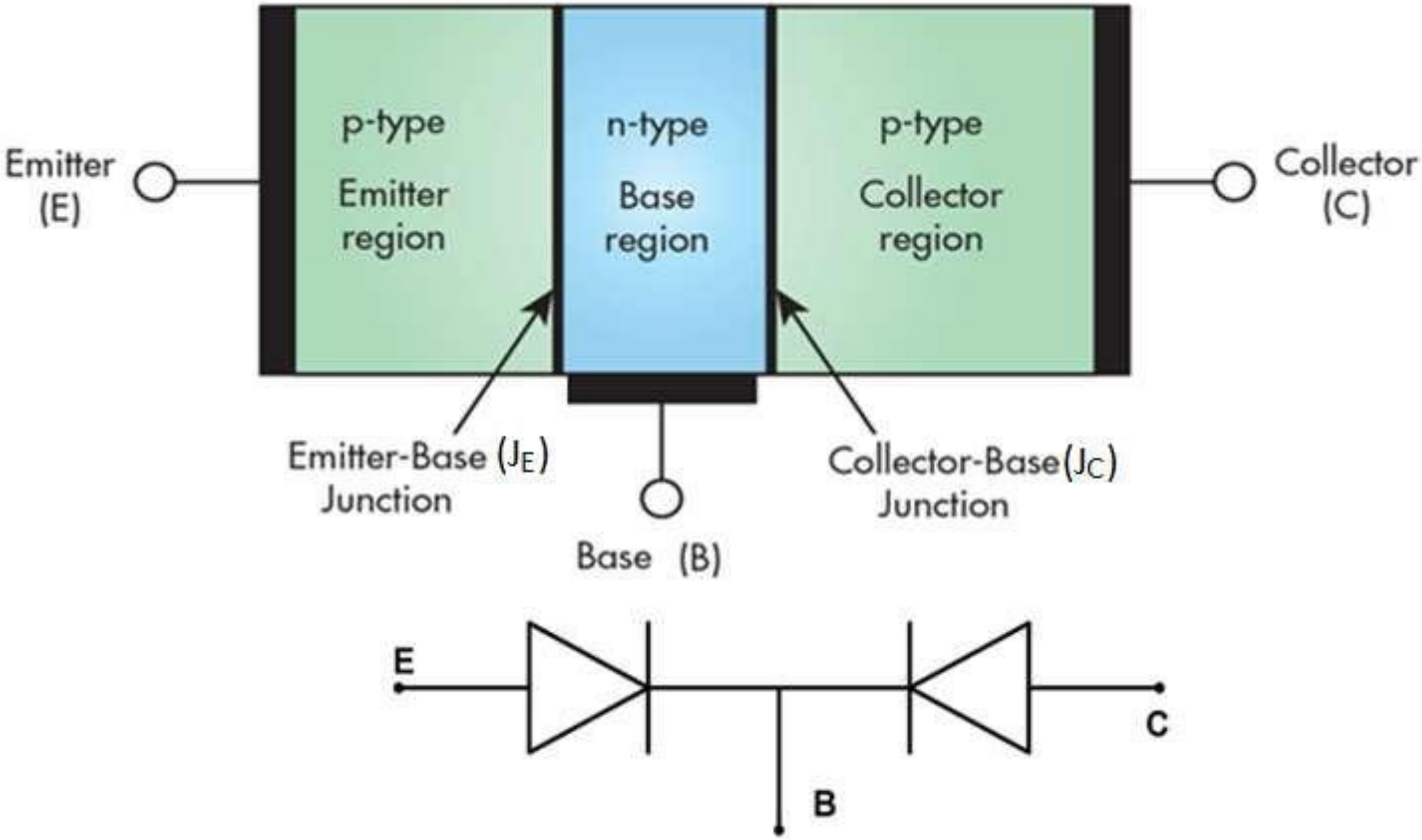
- There are two basic constructions:

(i) PNP Transistor

(ii) NPN Transistor

PNP Transistor

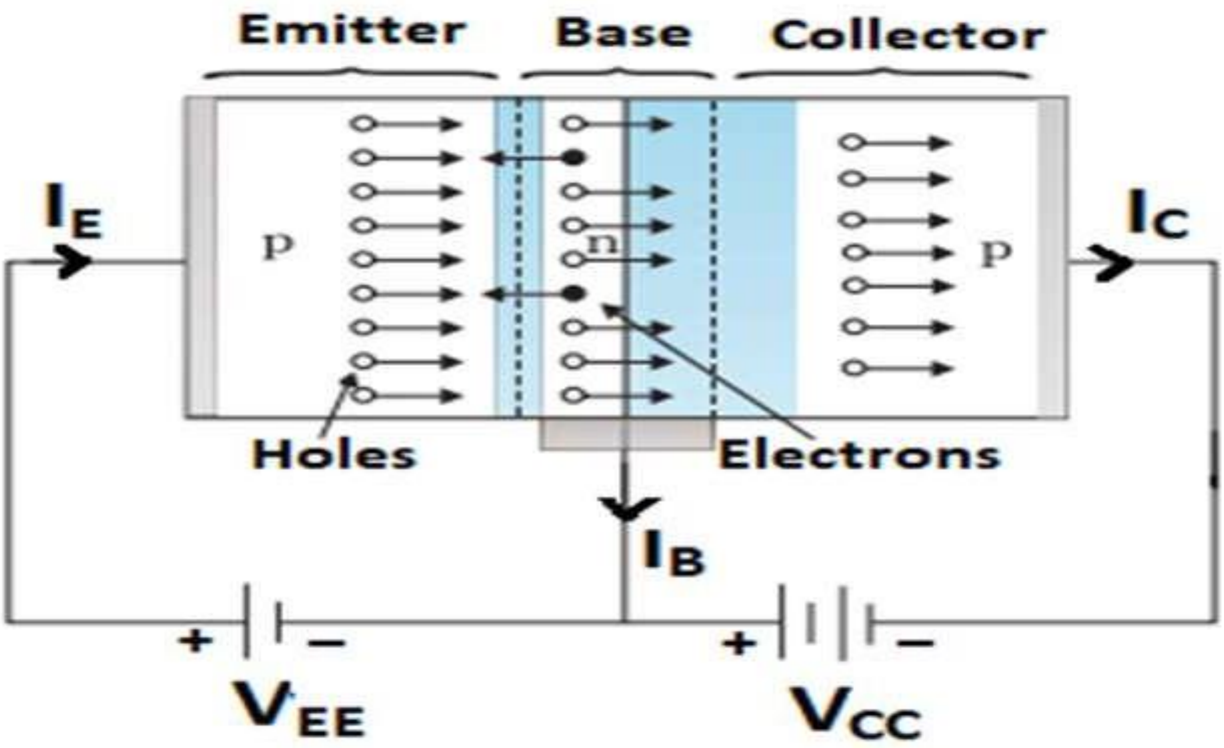
Construction of PNP Transistor:

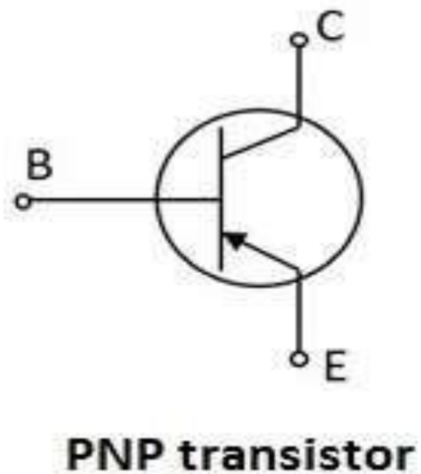


Two-diode Analogy

- A PNP transistor is constructed by sandwiching an N-type semiconductor between two P-type semiconductors.
- The PNP transistor behaves like two PN junctions diodes connected back to back.
- These back to back PN junction diodes are known as the collector-base junction and base-emitter junction.
- The Emitter is heavily doped P-Type region, Base is lightly doped N-Type region and Collector is moderately doped P-type region.
- Therefore, the depletion region at both junctions penetrates more towards the Base region.

Working of PNP Transistor:





Symbol

- The Emitter-Base junction is connected in forward bias and the Collector-Base junction is connected in reverse bias.
- Therefore,the depletion region at Emitter-Base junction is narrow and the depletion region at Collector-Base junction is wide.
- As the Emitter-Base junction is forward biased, a very large number of holes from emitter region will cross the depletion region and enter into the Base region.
- Simultaneously, a very few number of electrons will enter into the emitter region from the base region and these electrons will recombine with the holes.

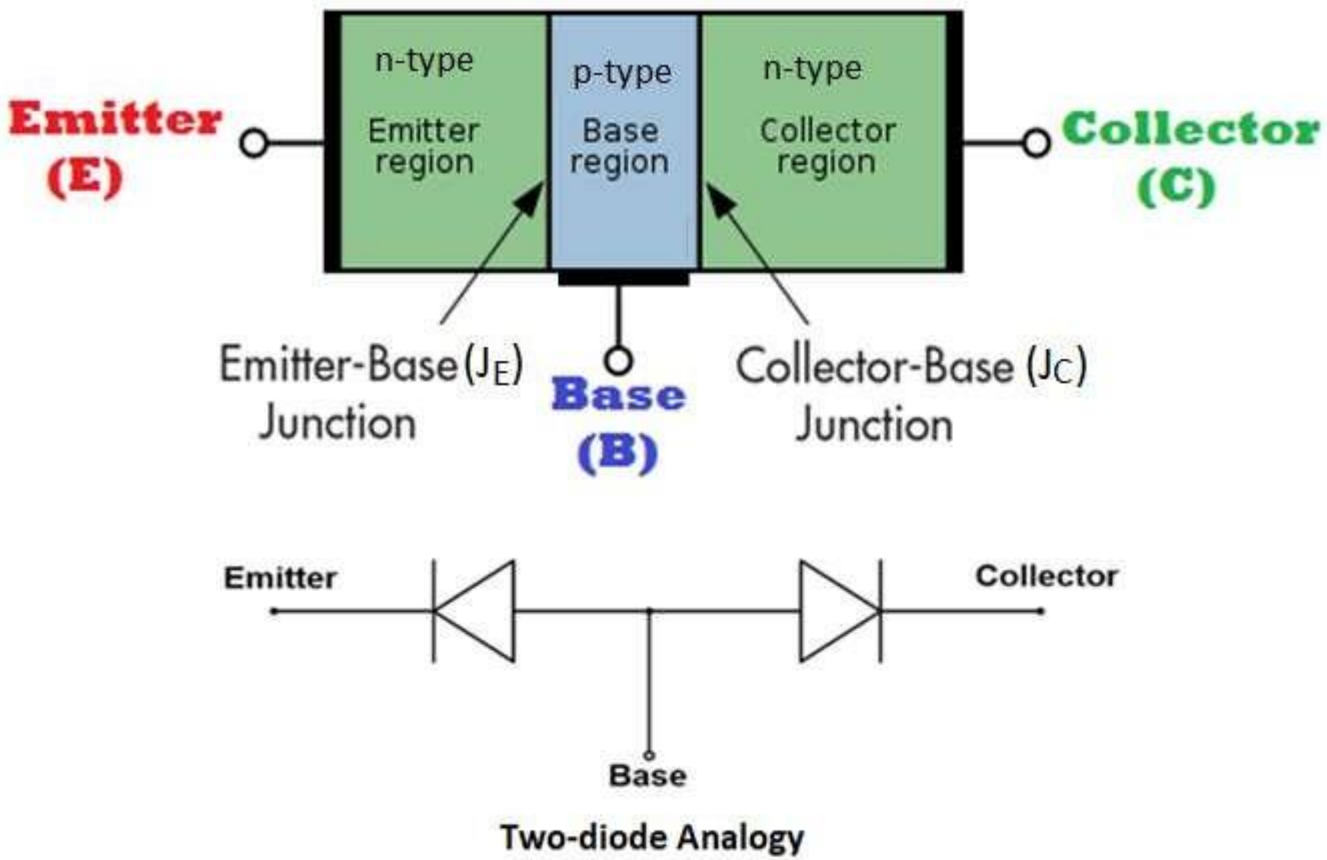
- The loss of holes in the emitter region is equal to the number of electrons present in the base region.
- But the number of electrons in the base region is very small as it is a lightly doped and thin region.
- Therefore, almost all holes of emitter will cross the depletion region and enter into the base region.
- Because of the movement of holes, the current will flow through the Emitter-Base junction. This current is known as emitter current (I_E).
- The holes are majority charge carriers to flow the emitter current.
- The remaining holes which do not recombine with electrons in base region will further travel to the collector.
- The collector current (I_C) flows through the Collector-Base region due to flow of holes.

- Applying Kirchhoff's current law(KCL), the emitter current is given by

$$I_E = I_B + I_C$$

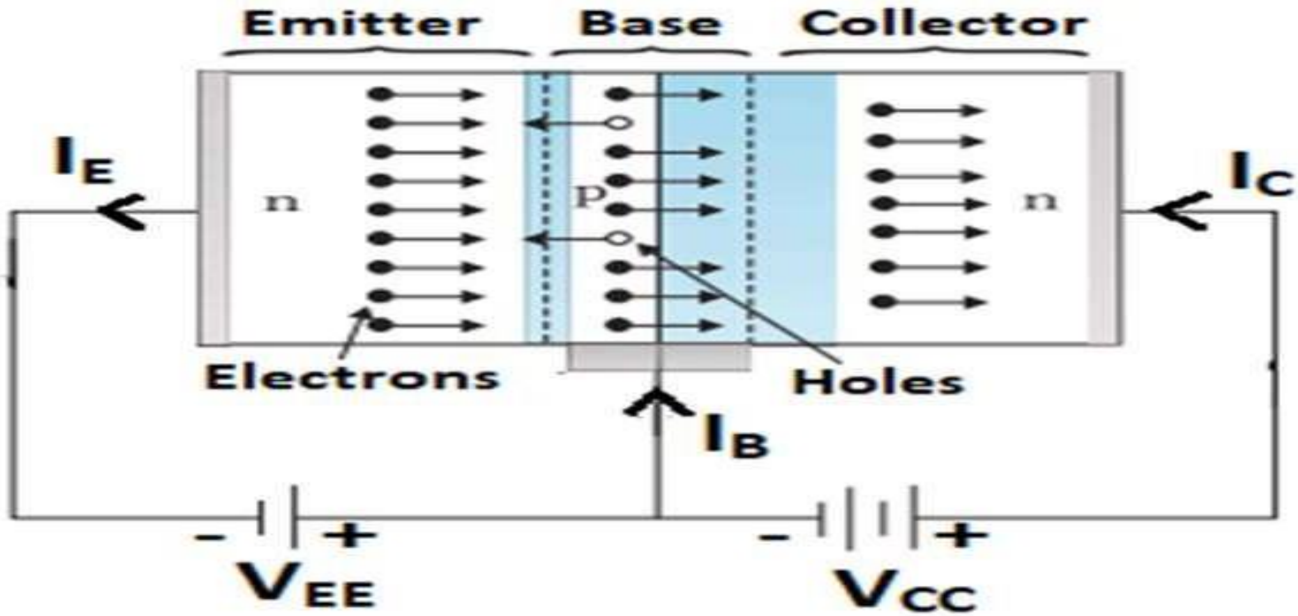
NPN Transistor

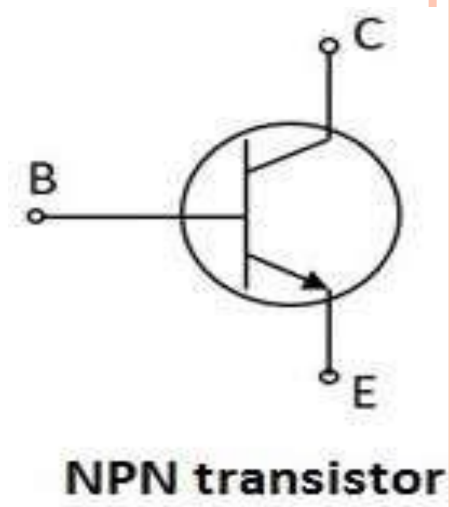
Construction of NPN Transistor:



- A NPN transistor is constructed by sandwiching a P-Type semiconductor between two N-type semiconductors.
- The NPN transistor behaves like two P-N junctions diodes connected back to back.
- These back to back P-N junction diodes are known as the emitter-base junction and collector-base junction.
- The Emitter is heavily doped N-Type region, Base is lightly doped P-Type region and Collector is moderately doped N-type region.
- Therefore, the depletion region at both junctions penetrates more towards the Base region.

WORKING OF NPN TRANSISTOR:





Symbol

- The Emitter-Base junction is connected in forward bias and the Collector-Base junction is connected in reverse bias.
- Therefore,the depletion region at Emitter-Base junction is narrow and the depletion region at Collector-Base junction is wide.
- As the emitter-base junction is forward biased, a very large number of electrons from emitter region will cross the depletion region and enter into the base region.
- Simultaneously, a very few number of holes will enter into the emitter region from the base region and these holes will recombine with the electrons.

- The loss of electrons in the emitter region is equal to the number of holes present in the base region.
- But the number of holes in the base region is very small as it is a lightly doped and thin region.
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- The electrons are majority charge carriers to flow the emitter current.
- The remaining electrons which do not recombine with holes in base region will further travel to the Collector.
- The collector current (I_C) flows through the Collector-Base region due to flow of electrons.

- APPLYING KIRCHHOFF'S CURRENT LAW(KCL), THE EMITTER CURRENT ISGIVEN BY

$$I_E = I_B + I_C$$

Modes(Regions) of operation

Mode (Region)	E-B Junction	C-B Junction
Active	Forward Biased	Reverse Biased
Saturation	Forward Biased	Forward Biased
Cut-off	Reverse Biased	Reverse Biased
Inverse Active	Reverse Biased	Forward Biased

Bipolar Transistor Construction