SEMICONDUCTOR

ENERGY BANDS IN SOLIDS

In case of a single isolated atom, there are single energy levels in case of solids, the atom is arranged in a systematic space lattice and hence the atom is greatly influenced by neighboring atoms. The closeness of atoms results in the intermixing of electrons of neighboring atoms of course, for the valence electrons in the outermost shells which are not strongly bounded by nucleus. Due to inter-mixing the number of permissible energy levels increases or there are significant changes in the energy levels. Hence in case of a solid, instead of single energy levels associated with the single atom, there will be bands of energy levels.

The range of energy possessed by electron in a solid is called *energy band*.

1. Valence Band
The band formed by a series of energy levels containing the valence electrons is known as valence band. The valence band may be defined as a band which is occupied by the valence electrons or a band having highest occupied band energy. It may be completely or partially filled but never be empty.

2. Conduction Band
The range of energy possessed by electrons that are responsible for conduction is called conduction band. It may be empty or partially filled.

3. Forbidden Band
The separation between conduction band and valence band is known as forbidden energy gap. There is no allowed energy state in this gap and hence no electron can stay in the forbidden energy gap.

Insulators, Semiconductors and Conductors

On the basis of forbidden band, the insulators, semiconductors and conductors are described as follows:

Insulators

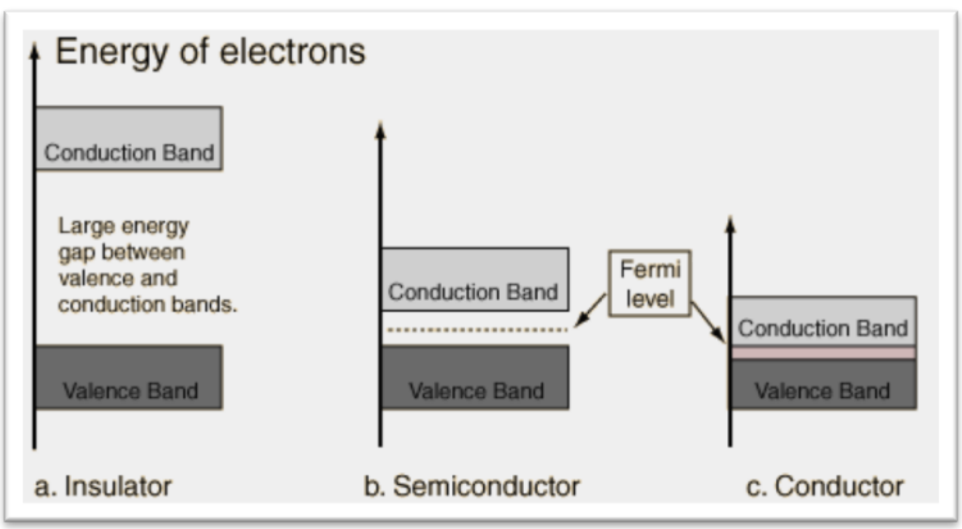
In case of insulators, the forbidden energy band is very wide. Due to this fact electrons cannot jump from valence band to conduction band. In insulators the valence electrons are bond very tightly to their parent atoms. Increase in temperature enables some electrons to go to the conduction band.

Semiconductors

In semiconductors, the forbidden band is very small. Germanium and silicon are the examples of semiconductors. A semiconductor material is one whose electrical properties lie in between insulators and good conductors. When a small amount of energy is supplied, the electrons can easily jump from valence band to conduction band.

Conductors

In case of conductors, there is no forbidden band. The valence band and conduction band overlap each other. Here plenty of free electrons are available for electric conduction. A slight potential difference across the conductor causes the free electrons to constitute electric current. The most important point in conductors is that due to the absence of forbidden band, there is no structure to establish holes. The total current in conductors is simply a flow of electrons.



SEMICONDUCTORS

A substance which has conductivity in between conductors and insulators is known as semiconductor.

Semiconductors have the following properties.

(i) They have resistivity less than insulators and more than conductors.

(ii) The resistance of semiconductor decreases with the increase in temperature and vice versa.

(iii) When suitable metallic impurity like arsenic, gallium etc. is added to a semiconductor, its current conducting properties change appreciably.

Effect of temperature of Semiconductors

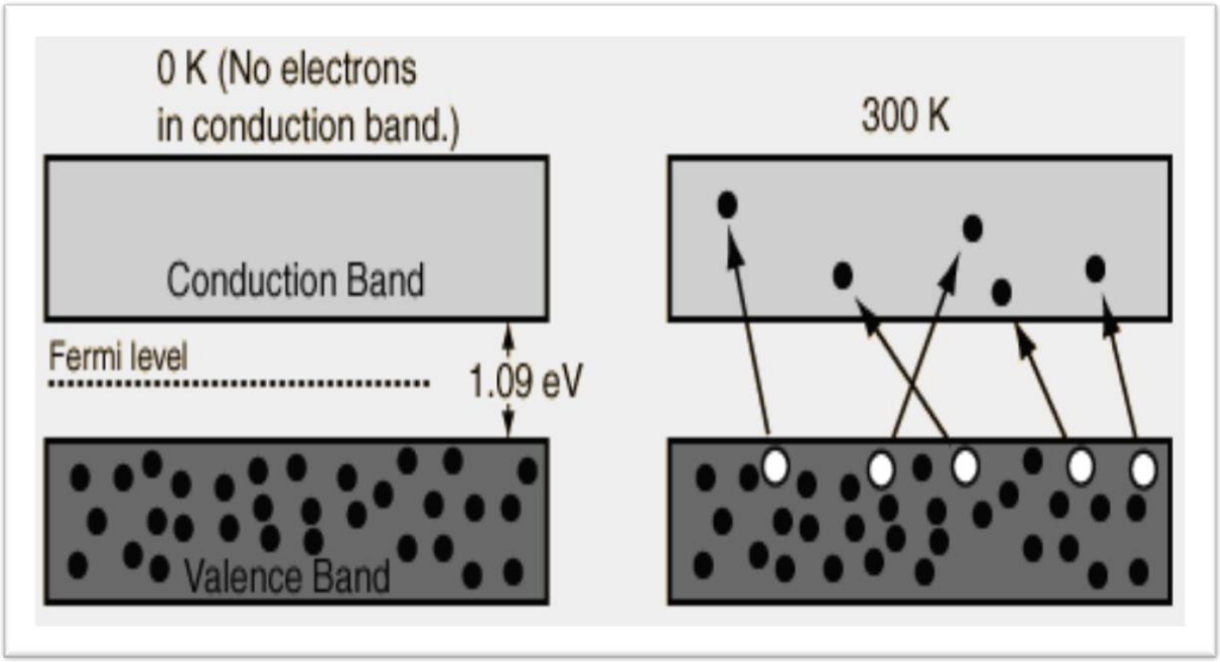
At very low temperature (say 0 K) the semiconductor crystal behaves as a perfect insulator since the covalent bonds are very strong and no free electrons are available. At room temperature some of the covalent bonds are broken due to the thermal energy supplied to the crystal. Due to the breaking of the bonds, some electrons become free which were engaged in the formation of these bonds.

The absence of the electron in the covalent bond is represented by a small circle. This empty place or vacancy left behind in the crystal structure is called a hole. Since an electron has a unit negative charge, the hole carries a unit positive charge.

Mechanism of conduction of Electrons and Holes

When the electrons are liberated on breaking the covalent bonds, they move randomly through the crystal lattice.

When an electric field is applied, these free electrons have a steady drift opposite to the direction of applied field. This constitutes the electric current. When a covalent bond is broken, a hole is created. For one electron set free, one hole is created. This thermal energy creates electron-hole pairs-there being as many holes as free electrons. These holes move through the crystal lattice in a random fashion like liberated electrons. When an external electric field is applied, the holes drift in the direction of applied field. Thus they constitute electric current.



There is a strong tendency of semiconductor crystal to form covalent bonds. Therefore, a hole attracts an electron from the neighboring atom. Now a valence electron from nearby covalent bond comes to fill in the hole at A. This results in a creation of hole at B. The hole has thus effectively shifted from A to B. This hole move from B to C from C to D and so on.

This movement of the hole in the absence of an applied field is random. But when an electric field is applied, the hole drifts along the applied field.

Depending on the type of impurities added, semiconductor is divided into two types:

1) Intrinsic Semiconductor and 2) Extrinsic Semiconductor

Intrinsic Semiconductor

A semiconductor in an extremely pure from is known as intrinsic semiconductor or a semiconductor in which electrons and holes are solely created by thermal excitation is called a pure or intrinsic semiconductor. In intrinsic semiconductor the number of free electrons is always equal to the number of holes.

Extrinsic Semiconductor

The electrical conductivity of intrinsic semiconductor can be increased by adding some impurity in the process of crystallization. The added impurity is very small of the order of one atom per million atoms of the pure semiconductor. Such semiconductor is called impurity or extrinsic semiconductor. The process of adding impurity to a semiconductor is known as doping.

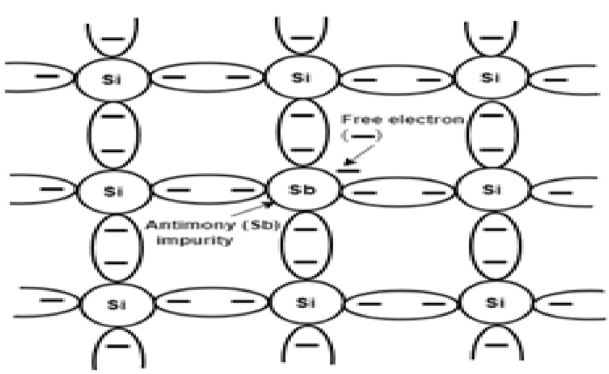
The doping material is either pentavalent atoms (bismuth, antimony, arsenic, phosphorus which have five valence electrons) or trivalent atoms (gallium, indium, aluminium, boron which have three valence electrons). The pentavalent doping atom is known as donor atom because it donates one electron to the conduction band of pure semiconductor.

The doping materials are called impurities because they alter the structure of pure semiconductor crystals.

Depending on the types of impurities added, the extrinsic semiconductor is divided into two types: 1) N- type Semiconductor and 2) P- type semiconductor

N–Type Semiconductor

When a small amount of pentavalent impurity is added to a pure semiconductor crystal during the crystal growth, the resulting crystal is called as N-type extrinsic semiconductor.



In case of N-type semiconductor, the following points should be remembered

(i) In N-type semiconductor, the electrons are the majority carriers while positive holes are minority carriers.

(ii) Although N-type semiconductor has excess of electrons but it is electrically neutral. This is due to the fact that electrons are created by the addition of neutral pentavalent impurity atoms to the semiconductor i.e., there is no addition of either negative changes or positive charges.

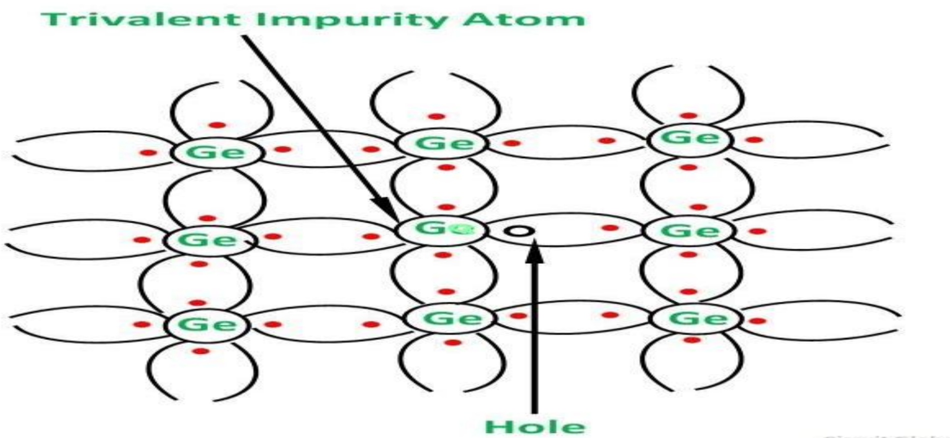
P–Type Semiconductor

When a small amount of trivalent impurity is added to a pure crystal during the crystal growth, the resulting crystal is called a P-type extrinsic semiconductor.

In case of P-type semiconductor, the following points should be remembered

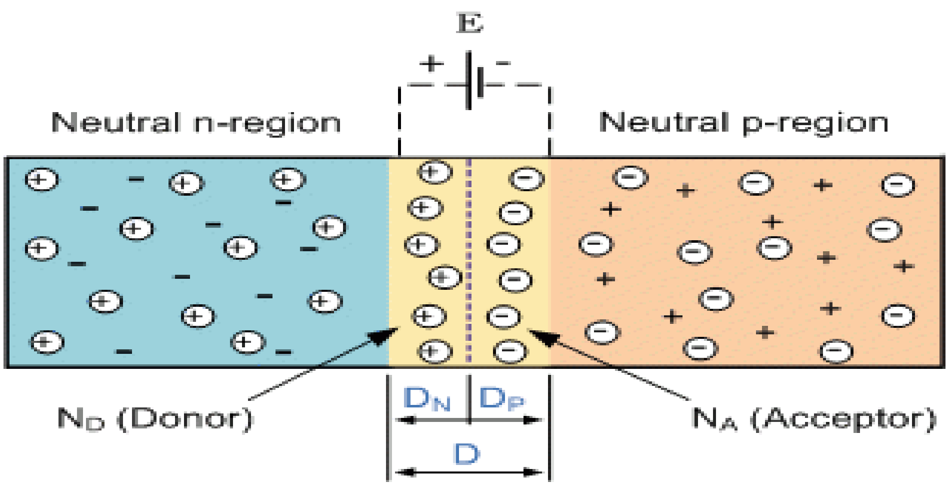
(i) In P-type semiconductor materials, the majority carriers are positive holes while minority carriers are the electrons.

(ii) The P-type semiconductor remains electrically neutral as the number of mobile holes under all conditions remains equal to the number of acceptors.



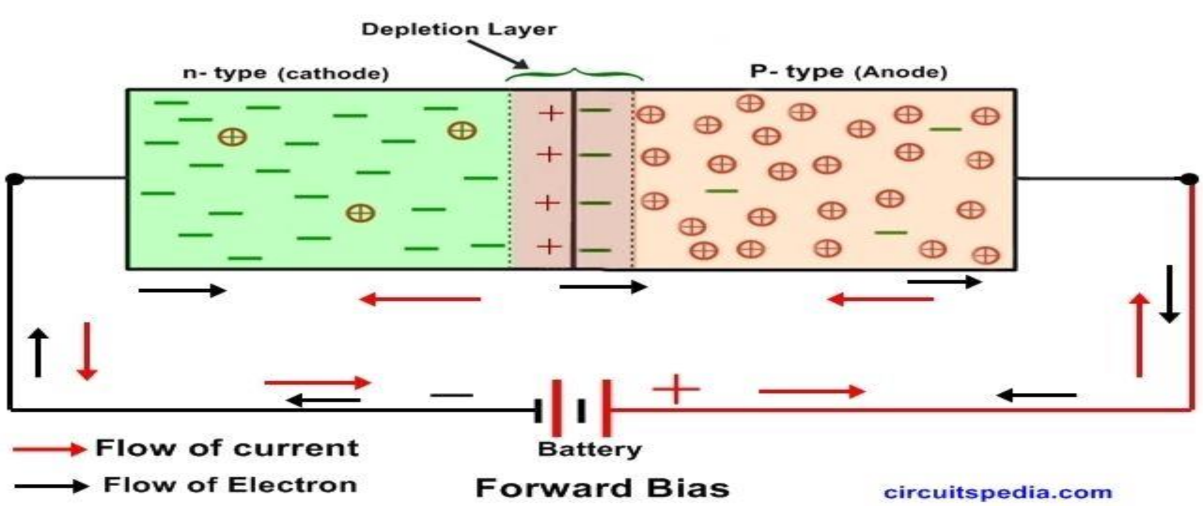
P-N Junction Diode

When a P-type material is intimately joined to N-type, a P-N junction is formed. In fact, merely-joining the two pieces a P-N junction cannot be formed because the surface films and other irregularities produce major discontinuity in the crystal structure. Therefore a P-N junction is formed from a piece of semiconductor (say germanium) by diffusing P-type material to one half side and N-type material to other half side. When P-type crystal is placed in contact with N-type crystal so as to form one piece, the assembly so obtained is called P-N junction diode.



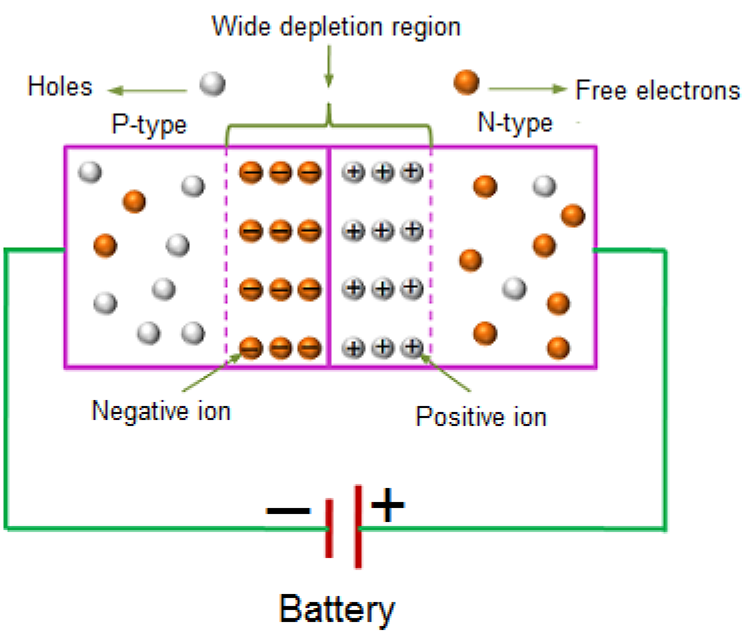
Biasing of a diode

Forward Biased 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.

Reverse Biased PN Junction Diode



Reverse bias

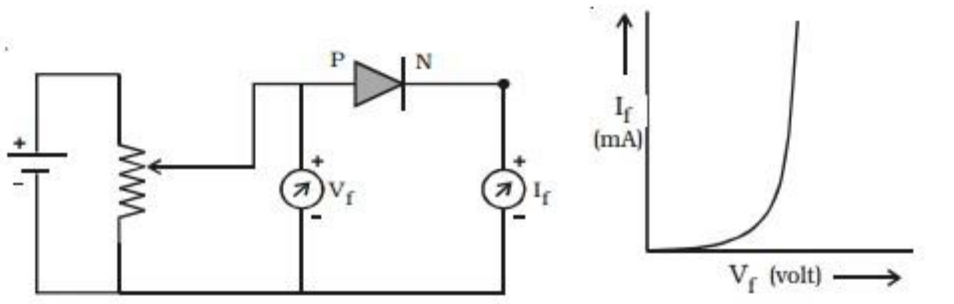
When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.

The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode.

The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator and a high potential barrier is created across the junction thus preventing current from flowing through the semiconductor material.

Characteristics of a diode

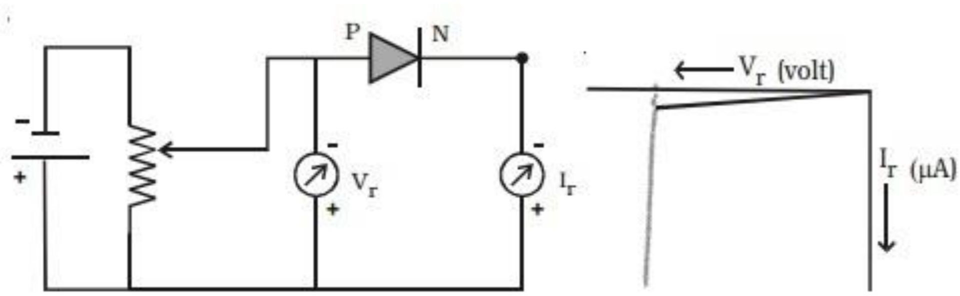
Forward Characteristic for a Junction Diode



(a) Diode circuit–Forward bias *(b) Forward characteristics*

Fig Forward bias characteristics of a diode

Reverse Characteristic for a Junction Diode



(a) Diode circuit–Reverse bias *(b) Reverse characteristics*

Fig Reverse bias characteristics of a diode

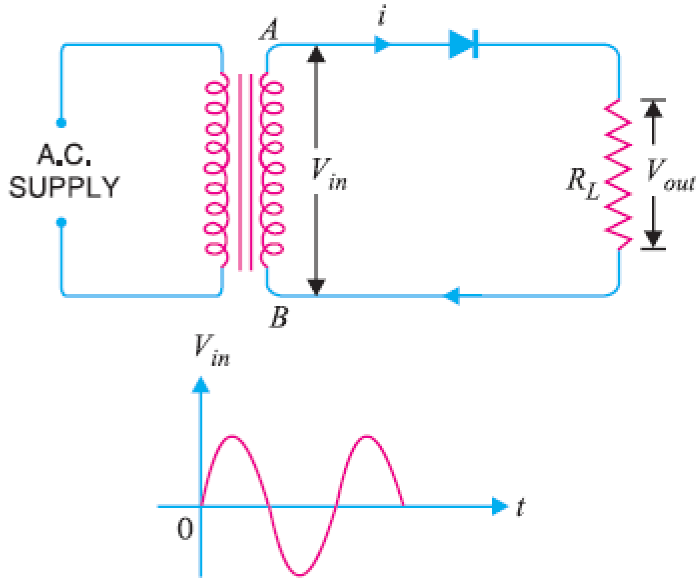
Rectification

The process of converting an ac signal into dc signal is called rectification. An electronic device which converts a.c. power into d.c. power is called a rectifier.

Half wave rectifier

Principle

Junction diode offers low resistive path when forward biased and high resistance when reverse biased.

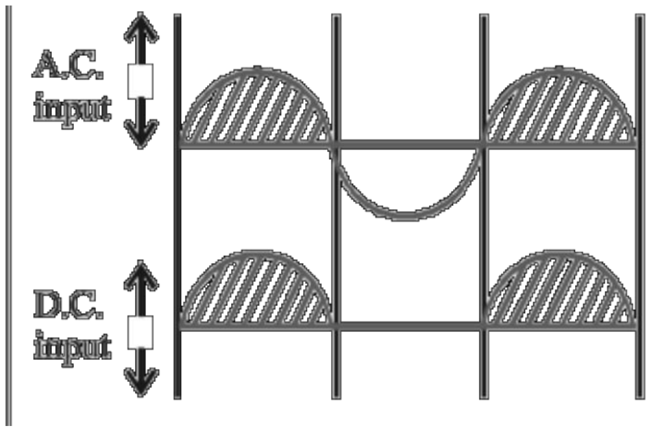


Arrangement

The a.c. supply is fed across the primary coil (P) of step down transformer. The secondary coil ‘S' of transformer is connected to the junction diode and load resistance R_L. The output d.c. voltage is obtained across R_L.

Theory

During first half of a.c. input cycle the junction diode get forward biased. The conventional current will flow in the direction of arrow head. The upper end of R_L will be at +ve potential w.r.t. the lower end. The magnitude of output across R_L during first half at any instant will be proportional to magnitude of current through R_L, which in turn is proportional to magnitude of forward bias and which ultimately depends upon the value of a.c. input at that time.



Full wave rectifier

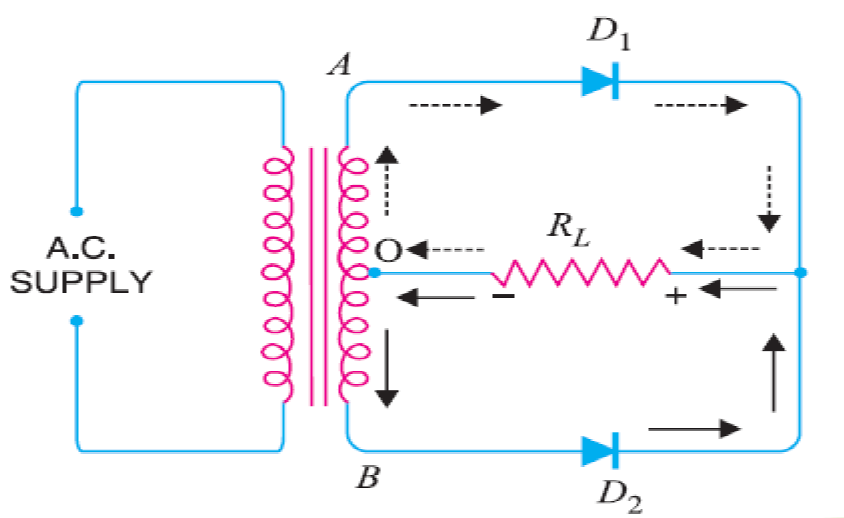
A rectifier which rectifies both halves of a.c. input is called full wave rectifier.

Principle

Junction Diode offers low resistive path when forward biased and high resistive path when reverse biased.

Arrangement

The a.c. supply is fed across the primary coil (P) of step down transformer. The two ends of S–coil (secondary) of transformer are connected to P-section of junction diodes D_1 and D_2. A load resistance RL is connected across the n–sections of two diodes and central tapping of secondary coil. The d.c. output is obtained across R_L.

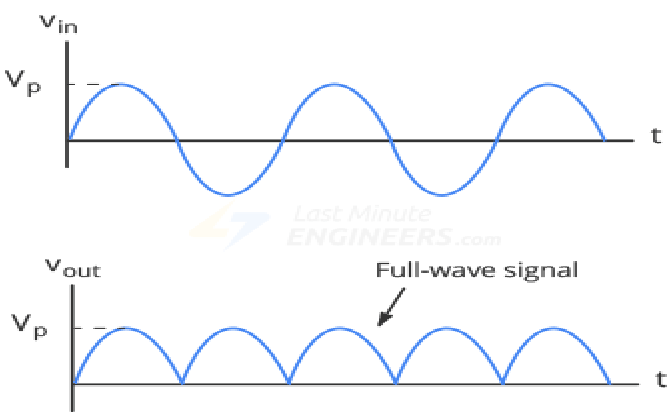


Theory

During first half of input cycle upper end of s-coil is at +ve potential. The junction diode D_1 gets forward biased, while D_2 gets reverse biased. The conventional current due to D_1 will flow along path of full arrows. When second half of input cycle comes, the conditions will be exactly reversed. Now the junction diode D_2 will conduct and the conventional current will flow along path of dotted arrows.

Since current during both the half cycles flows from right to left through load resistance R_L, the output during both the half cycles will be of same nature.

The right end of R_L is at +ve potential w.r.t. left end. Thus in full wave rectifier, the output is continuous.



Zener Diode

A Zener diode is a heavily doped semiconductor device that is designed to operate in the reverse biasing. When the voltage across the terminals of a Zener diode is reversed and the potential reaches the Zener Voltage, the junction breaks down and the current flows in the reverse direction. This effect is known as the Zener Effect.

There are two types of breakdowns for a Zener Diode:

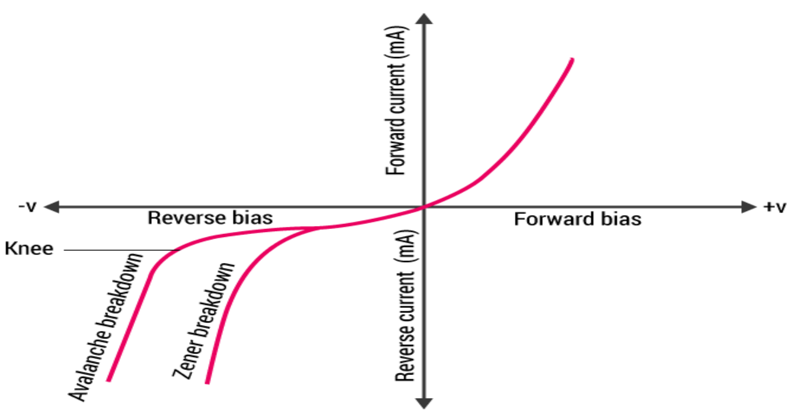
a) Avalanche Breakdown
b) Zener Breakdown

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.

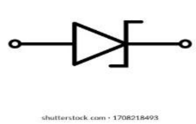
Zener Breakdown in Zener Diode

When the applied reverse bias voltage reaches closer to the Zener voltage, the electric field in the depletion region gets strong enough to pull electrons from their valence band. The valence electrons that gain sufficient energy from the strong electric field of the depletion region break free from the parent atom. At the Zener breakdown region, a small increase in the voltage results in the rapid increase of the electric current.S

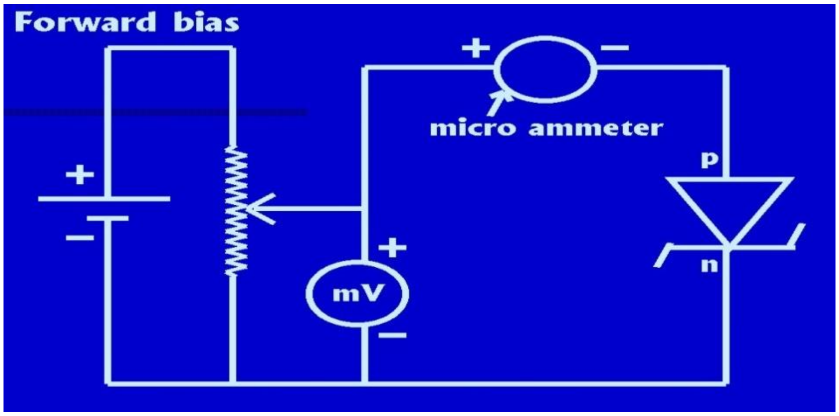


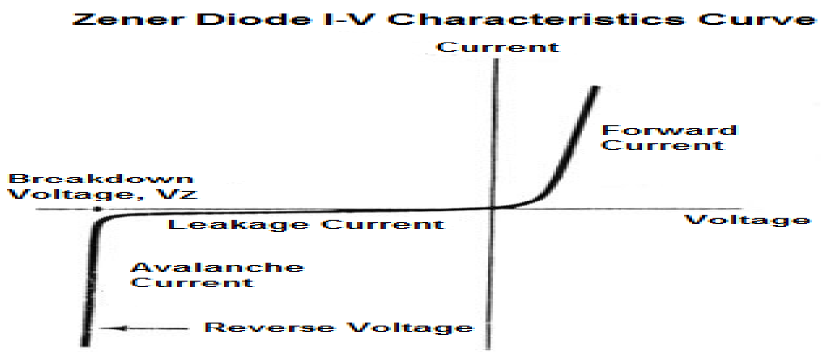
t.

Symbol



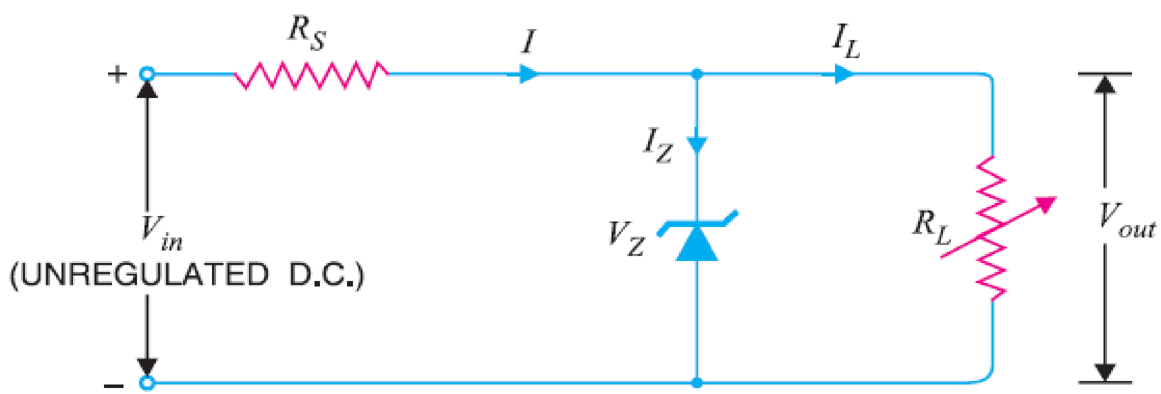
Characteristics of zener diode





Zener diode as a voltage regulator

To maintain a constant voltage across the load, even if the input voltage or load current varies, voltage regulation is to be made. A Zener diode working in the breakdown region can act as a voltage regulator.



The circuit in which a Zener diode is used for maintaining a constant voltage across the load R_L is shown in Fig. The Zener diode in reverse biased condition is connected in parallel with the load RL. Let V_{dc} be the unregulated dc voltage and V_Z be Zener voltage (regulated output voltage). R_S is the current limiting resistor. It is chosen in such a way that the diode operates in the breakdown region.

In spite of changes in the load current or in the input voltage, the Zener diode maintains a constant voltage across the load. The action of the circuit can be explained as given below:

Load current varies, the input voltage is constant: Let us consider that the load current increases. Zener current hence decreases, and the current through the resistance RS is a constant.

The output voltage is $V_Z = V_{dc} - IR_s$, since the total current I remains constant, the output voltage remains constant.

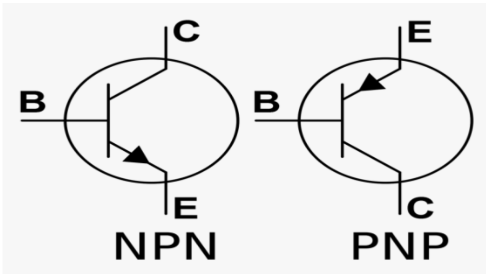
Input voltage varies: Let us consider that the input voltage V_{dc} increases. Now the current through Zener increases and the voltage drop across R_s increases in such a way that the load voltage remains the same. Thus the Zener diode acts as a voltage regulator.

Transistor

It is three sections semiconductor, in which three sections are combined so that the two at extreme ends have the same type of majority carriers, while the section that separates them has the majority carriers in opposite nature. The three sections of transistor are called emitter (E), Base (B), collector (C).

- Emitter- It is heavily doped region. It emits charge carriers.
- Collector- It is moderately doped region. It is largest section. It collects charge carriers.
- Base- It is lightly doped region. It passes charge carriers from emitter to collector. It is smallest section.

Symbol



Biasing of a transistor

- Emitter- Base junction is forward biased.
- Collector-Base junction is reversed biased.

Action of N-P-N Transistor

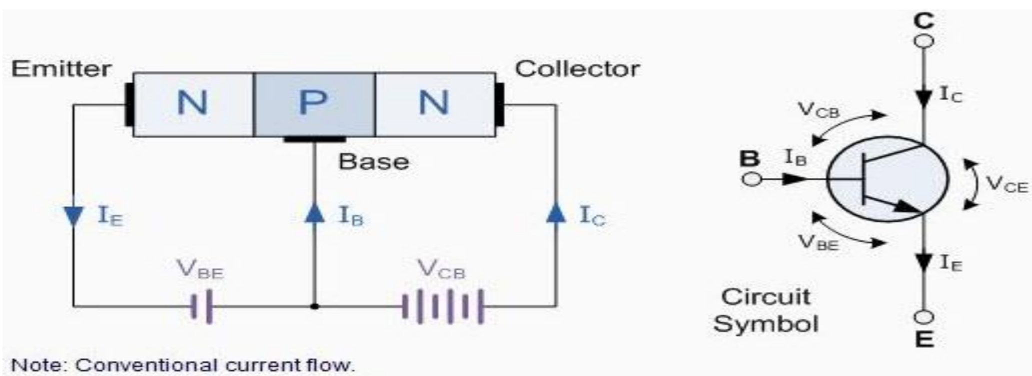


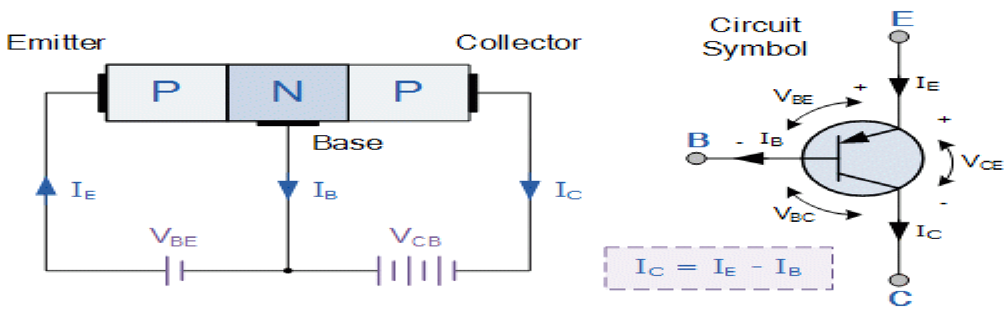
Fig. shows that, the N-type emitter is forward biased by connecting it to -ve pole of V_{BE} (base-emitter battery) and N-type collector is reverse biased by connected it to +ve pole of V_{CB} (collector- base battery).

The majority carriers (e^-) in emitter are repelled towards base due to forward bias. The base contains holes as majority carriers but their number density is small as it is doper very lightly (5%) as compared to emitter and collector. Due to the probability of e^- and hole combination in base is small. Most of e^- (95%) cross into collector region where they are swept away by +ve terminal of battery V_{CB}.

Corresponding to each electron that is swept by collector, an electron enters the emitter from -ve pole of collector - base battery.

If I_e, I_b, I_c be emitter, base and collector current respectively then using Kirchoff first law, $\mathbf{I_e = I_b + I_c}$

Action of P-N-P Transistor



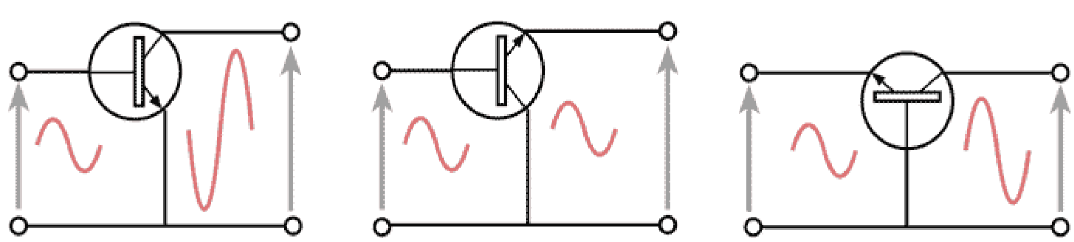
The p–type emitter is forward biased by connecting it to +ve pole of emitter – base battery and p-type collector is reverse biased by connected it to -ve pole of collection - base battery. In this case, majority carrier in emitter i.e. holes are repelled towards base due to forward bias. As base is lightly doped, it has low number density of e^-. When hole enters base region, then only 5% of e^- and hole combination take place. Most of the holes reach the collector and are swept away by -ve pole of V_{CB} battery.

Configuration of transistor

There are three types of configurations of a transistor.

- Common Emitter configuration
- Common Collector configuration
- Common Base configuration

Each has different properties in terms of the gain, and input and output impedance etc and as a result, a particular configuration will be selected during the electronic circuit design process.



TRANSISTOR CONFIGURATION SUMMARY TABL			
TRANSISTOR CONFIGURATION	**COMMON BASE**	**COMMON COLLECTOR (EMITTER FOLLOWER)**	**COMMON EMITTER**
Voltage gain	High	Low	Medium
Current gain	Low	High	Medium
Power gain	Low	Medium	High
Input / output phase relationship	0°	0°	180°
Input resistance	Low	High	Medium
Output resistance	High	Low	Medium

Common Emitter Characteristics

The circuit diagram for common emitter characteristics is shown in figure below.

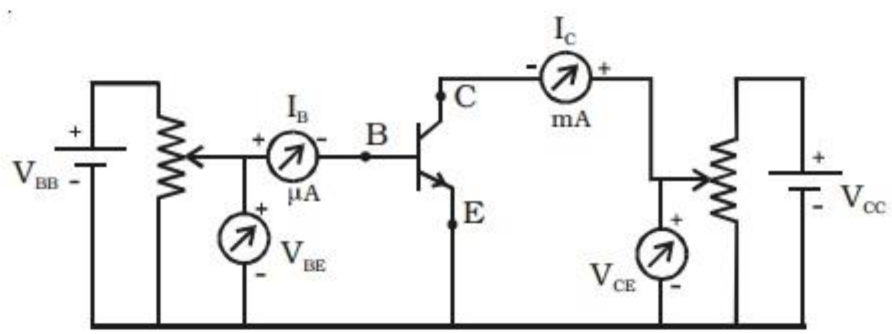


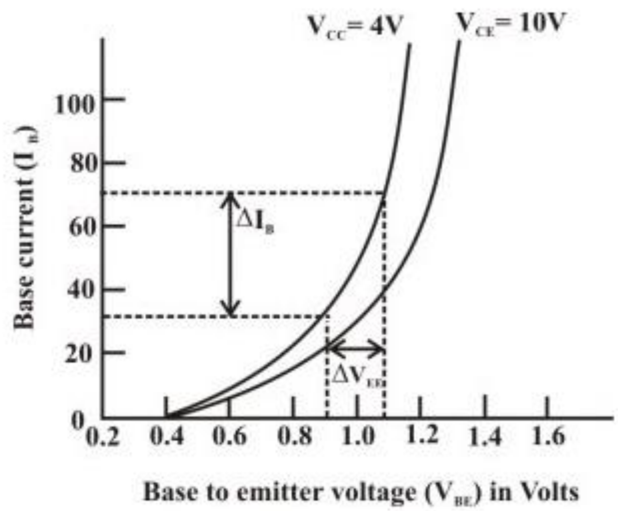
Fig Transistor circuit in CE mode.

The three important characteristics of a transistor in any mode are (i) input characteristics (ii) output characteristics and (iii) transfer characteristics.

(i) Input characteristics

Input characteristic curve is drawn between the base current (I_B) and voltage between base and emitter (V_{BE}), when the voltage between collector and emitter (V_{CE}) is kept constant at a particular value. V_{BE} is increased in suitable equal steps and corresponding base current is noted. The procedure is repeated for different values of V_{CE}.

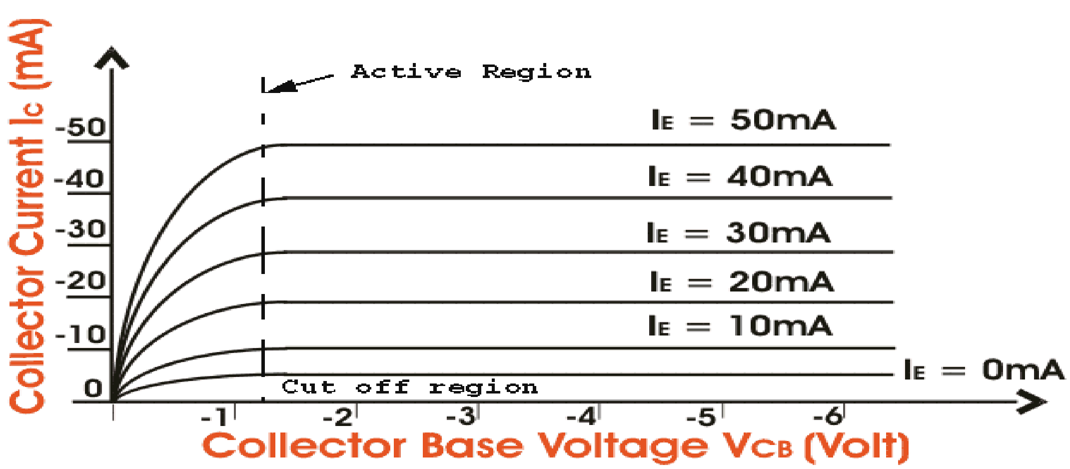
I_B values are plotted against V_{BE} for constant V_{CE}. The input characteristic thus obtained is shown in Fig. The input impedance of the transistor is defined as the ratio of small change in base - emitter voltage to the corresponding change in base current at a given V_{CE}. Input impedance $r_1 = (\Delta V_{BE}/\Delta I_B)$at V_{CE} = constant



(ii) Output characteristics

Output characteristic curves are drawn between I_C and V_{CE}, when I_B is kept constant at a particular value.

The base current I_B is kept at a constant value, by adjusting the base emitter voltage V_{BE}. V_{CE} is increased in suitable equal steps and the corresponding collector current is noted. The procedure is repeated for different values of I_B. Now, I_c versus V_{CE} curves are drawn for different values of I_B. Output impedence, $r_o = (\Delta V_{CE}/ \Delta I_C)$at I_B=constant



(iii) Transfer characteristics

The transfer characteric curve is drawn between I_C and I_B, when V_{CE} is kept constant at a particular value. The base current I_B is increased in suitable steps and the collector current I_C is noted down for each value of I_B. The transfer characteristic curve is shown in Fig.

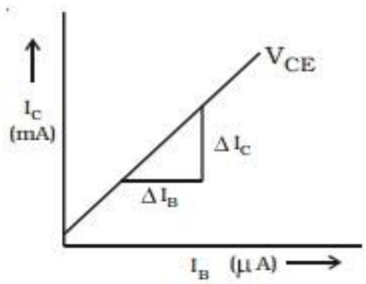


Fig Transfer characteristic curve

The current gain is defined as the ratio of a small change in the collector current to the corresponding change in the base current at a constant V_{CE}.

current gain, $\beta = (\Delta I_C / \Delta I_B)V_{CE}$

The common emitter configuration has high input impedance, low output impedance and higher current gain when compared with common base configuration.

Alpha(α) and (β) parameter of a transistor.

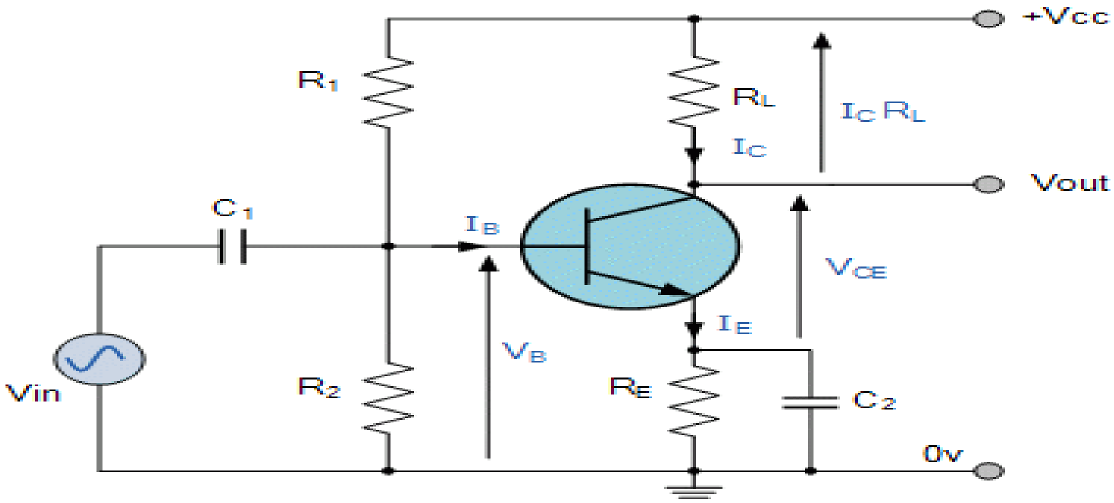
$$\text{Alpha}, (\alpha) = \frac{I_C}{I_E} \quad \text{and} \quad \text{Beta}, (\beta) = \frac{I_C}{I_B}$$

$$\therefore I_C = \alpha . I_E = \beta . I_B$$

$$\text{as: } \alpha = \frac{\beta}{\beta + 1} \qquad \beta = \frac{\alpha}{1 - \alpha}$$

This is relation between α and β.

CE Amplifier



Circuit diagram for CE amplifier is shown in figure above. From figure,

$\mathbf{I_E = I_B + I_C}$ and

$\mathbf{V_{CE} = V_{CC} - I_C R_C}$

When the positive half cycle of input a.c. signal voltage comes, it supports the forward biasing of the emitter-base circuit. Due to this, the emitter current increases and consequently the collector current increases. As a result of which, the collector voltage V_c decreases.

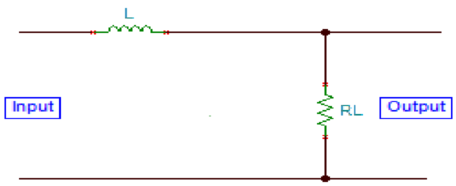
Since the collector is connected to the positive terminal of V_{CE} battery, therefore decreases in collector voltage means the collector will become less positive which means negative w.r. to initial value. This indicates that during positive half cycle of input a.c. signal voltage, the output signal voltage at the collector varies through a negative half cycle.

When negative half cycle of input a.c. signal voltage comes, it opposes the forward biasing of emitter-base circuit, due to this the emitter current decreases and hence collector current decreases; consequently the collector voltage V_c increases i.e., the collector becomes more positive. This indicate that during the negative half cycle of input a.c. signal voltage, the output signal voltage varies through positive half cycle.

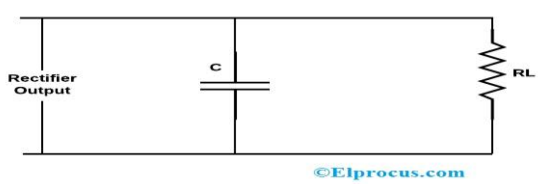
Filter Circuit

The filter is a device that allows passing the dc component to the load and blocks the ac component of the rectifier output. Thus the output of the filter circuit will be a steady dc voltage. The filter circuit can be constructed by the combination of components like capacitors, resistors, and inductors. Some of commonly used filter circuits are: i)Induction filter ii) Capacitor filter iii) LC filter iv) π – filter etc.

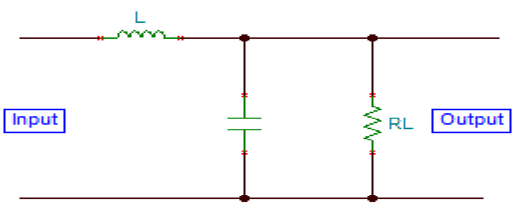
Inductor filter



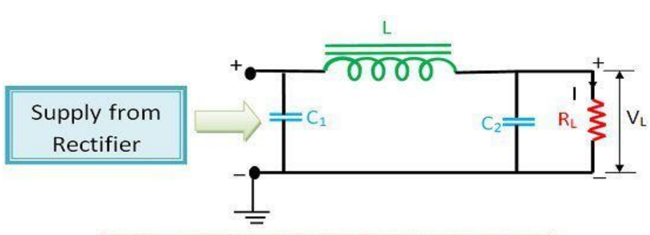
Capacitor filter



LC – filter



π- filter



Capacitor Input Filter or Pi Filter