PART – B: BASIC ELECTRONICS ENGINEERING

UNIT I

Semiconductor Devices

Semiconductor Devices Introduction – Types of semiconductor devices – Operation and Characteristics of PN Junction Diode, Zener Effect, Zener Diode and its Characteristics. Bipolar Junction Transistor -Principle of operation and CB, CE, CC Configurations— Elementary Treatment of Small Signal CE Amplifier.

Introduction to semiconductor

- A semiconductor material is one whose electrical properties (resistivity) lie in between those of insulators and conductors. **Ex: germanium (Ge) and silicon (Si).**
- Semiconductors have **negative temperature co-efficient of resistance** i.e. the resistance of a semiconductor decreases with the increase in temperature and vice-versa.
- When a suitable metallic impurity (e.g. arsenic, gallium etc.) is added to a semiconductor, its current conducting properties change appreciably.
- In terms of energy bands as shown in Fig.1, semiconductors can be defined as those materials which have almost an empty conduction band and almost filled valence band with a very narrow energy gap (of the order of ≈1 eV) separating the two.

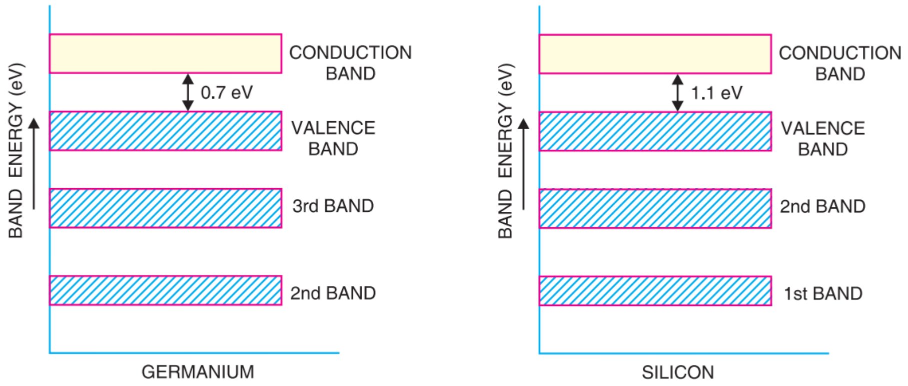


Fig. 1 Energy band diagrams of germanium (Ge) and silicon (Si) atoms

Therefore, relatively small energy is needed by their valence electrons to cross over to the conduction band. Even at room temperature, some of the valence electrons may acquire sufficient energy to enter into the conduction band and thus become free electrons. However, at this temperature, the number of free electrons available is very small. Therefore, at room temperature, a piece of germanium or silicon is neither a good conductor nor an insulator. For this reason, such substances are called semi - conductors.

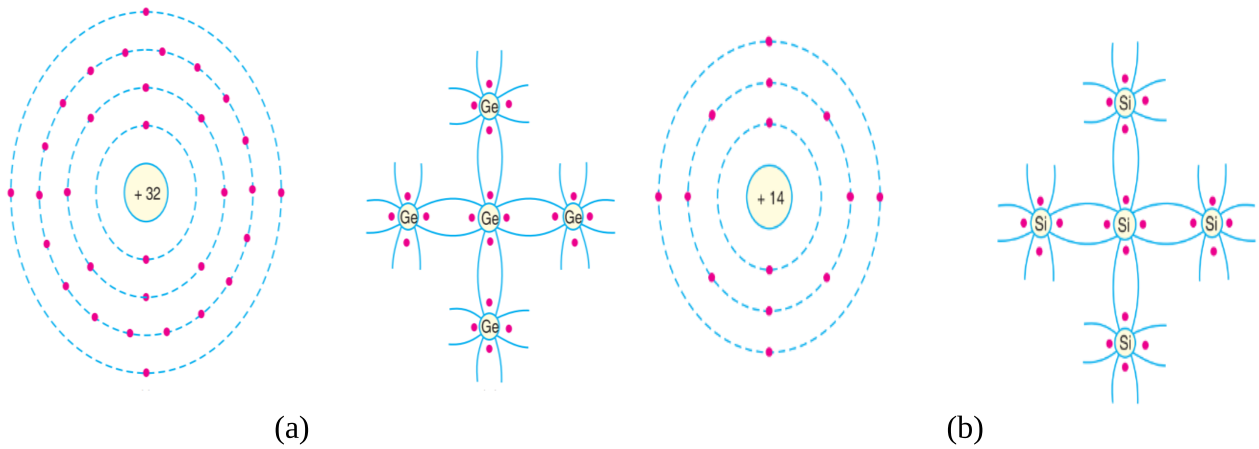


Fig. 2 Formation of Covalent Bonds in a) Ge b) Si atoms

Effect of Temperature on Semiconductors

i) At absolute zero

At absolute zero temperature, all the electrons are tightly held by the semiconductor atoms. The inner orbit electrons are bound whereas the valence electrons are engaged in co-valent bonding as shown in Fig.2. At this temperature, the co-valent bonds are very strong and there are no free electrons. Therefore, no valence electron can reach the conduction band to become free electron as shown in Fig.3. Therefore, the semiconductor crystal behaves as a perfect insulator.

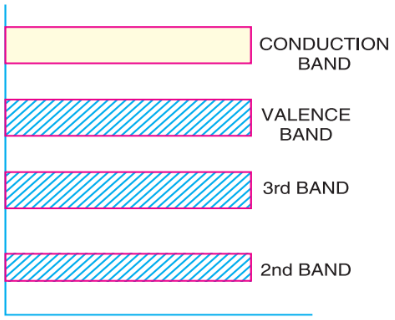


Fig. 3 Energy band diagram at absolute zero

ii) At above absolute zero

When the temperature is raised, some of the covalent bonds in the semiconductor break due to the thermal energy supplied. The breaking of bonds sets those electrons free which are engaged in the formation of these bonds. The result is that a few free electrons exist in the semiconductor. These free electrons can constitute a tiny electric current if potential difference is applied across the semiconductor crystal. This shows that the resistance of a semi-conductor decreases with the rise in temperature i.e. it has **negative temperature coefficient of resistance**. It may be added that at room temperature, current through a semiconductor is too small to be of any practical value.

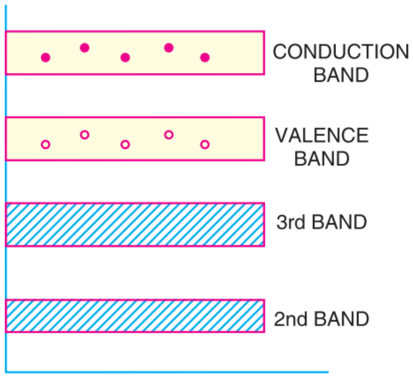


Fig. 4 Energy band diagram at above absolute zero

As the temperature is raised, some of the valence electrons acquire sufficient energy to enter into the conduction band and thus become free electrons as shown in Fig.4. Under the influence of electric field, these free electrons will constitute electric current, i.e., **electron current.**

It may be noted that each time a valence electron enters into the conduction band, a hole is created in the valence band i.e. a missing electron in the covalent bond. This missing electron is called a hole which acts as a positive charge, this constitutes **hole current** due to the movement of valence electrons from one covalent bond to another bond. For one electron set free, one hole is created. Therefore, thermal energy creates hole-electron pairs; there being as many holes as the free electrons.

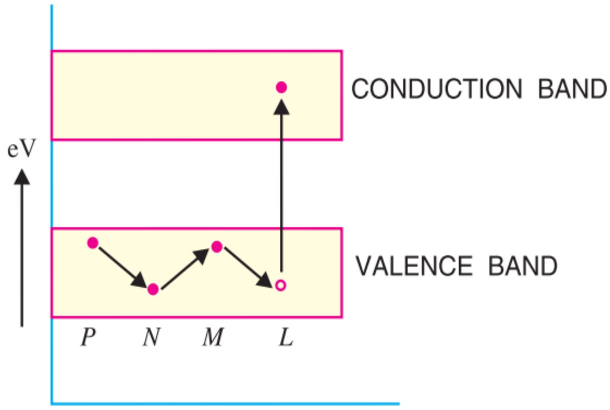
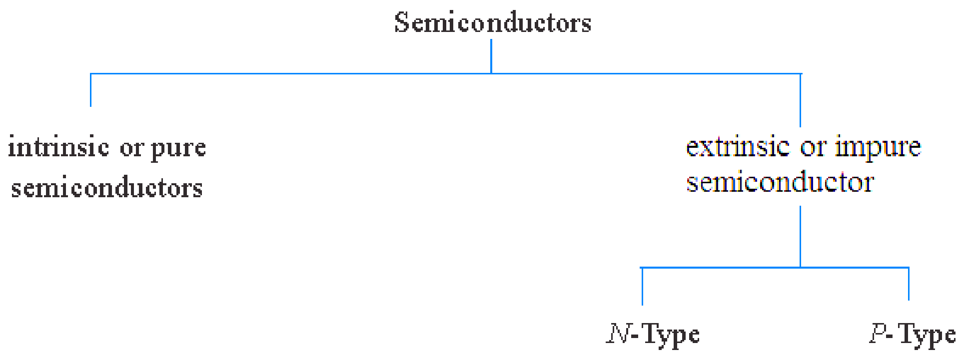


Fig. 5 Energy band diagram for Hole Current

From Fig.5, due to thermal energy, an electron leaves the valence band to enter into the conduction band, this leaves a vacancy at L. Now the valence electron at M comes to fill the hole at L. The result is that hole disappears at L and appears at M. Next, the valence electron at N moves into the hole at M. Consequently, hole is created at N. It is clear that valence electrons move along the path PNML whereas holes move in the opposite direction i.e. along the path LMNP.

<u>**Types of Semiconductors**</u>

Semiconductor may be classified as under:



Intrinsic Semiconductors:

An intrinsic semiconductor is one which is made of the semiconductor material in its extremely pure form.

Examples of such semiconductors are: pure germanium and silicon which have forbidden energy gaps of 0.72 eV and 1.1 eV respectively. The energy gap is so small that even at ordinary room temperature; there are many electrons which possess sufficient energy to jump across the small energy gap between the valence and the conduction bands.

In an intrinsic semiconductor, even at room temperature, hole-electron pairs are created. When electric field is applied across an intrinsic semiconductor, the current conduction takes place by two processes, namely; by free electrons and holes as shown in Fig.6. The free electrons are produced due to the breaking up of some covalent bonds by thermal energy. At the same time, holes are created in the covalent bonds as shown in Fig.7. Under the influence of electric field, conduction through the semi-conductor is by both free electrons and holes. Therefore, the **total current inside the semiconductor is the sum of currents due to free electrons and holes.**

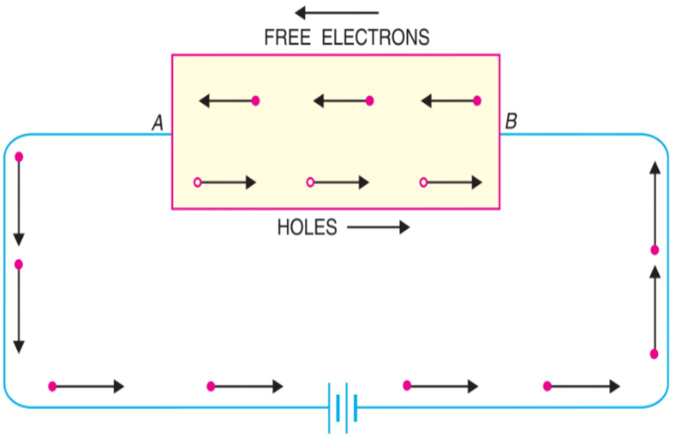


Fig. 6 Current distribution

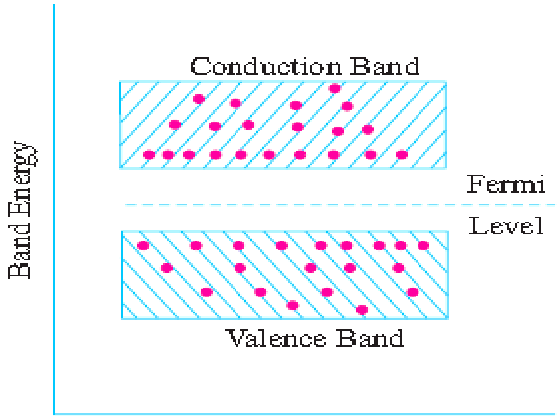


Fig. 7 Energy Band description

It may be noted that current in the external wires is fully electronic i.e. by electrons. Referring to Fig.6, holes being positively charged move towards the negative terminal of supply. As the holes reach the negative terminal B, electrons enter the semiconductor crystal near the terminal and combine with holes, thus cancelling them. At the same time, the loosely held electrons near the positive terminal A are attracted away from their atoms into the positive terminal. This creates new holes near the positive terminal which again drift towards the negative terminal.

Extrinsic Semiconductors:

The intrinsic semiconductor has little current conduction capability at room temperature. To be useful in electronic devices, the pure semiconductor must be altered so as to significantly increase its conducting properties. This is achieved by adding a small amount of suitable impurity to a semi-conductor. It is then called **impurity or extrinsic semiconductor**. The process of adding impurities to a semiconductor is known as **doping**. Depending on the type of doping material used, extrinsic semiconductors can be sub-divided into two classes:

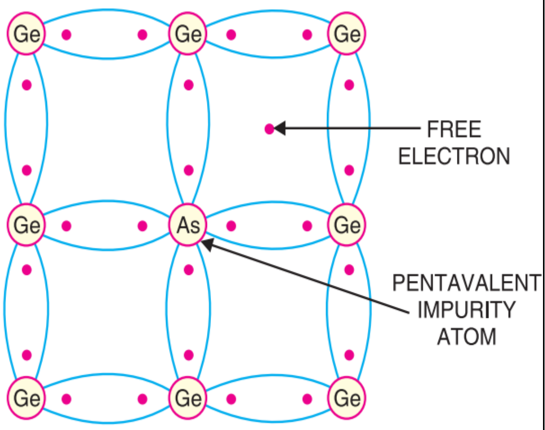
(i) N-type semiconductors and

(ii) P-type semiconductors.

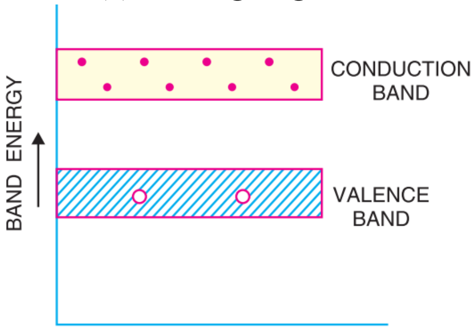
(i) N-type Semiconductor:

When a small amount of **pentavalent impurity** is added to a pure semiconductor, it is known as n-type semiconductor. Such impurities which produce n-type semiconductor are known as **donor impurities** because they donate or provide free electrons to the semi-conductor crystal.

When a small amount of pentavalent impurity like **arsenic** (Atomic. No. 33) is added to germanium crystal, a large number of free electrons become available in the crystal. Arsenic is pentavalent i.e. its atom has five valence electrons. An arsenic atom fits in the germanium crystal in such a way that its four valence electrons form covalent bonds with four germanium atoms. The fifth valence electron of arsenic atom finds no place in co-valent bonds and travels to the conduction band, i.e., as a free electron as shown in Fig.8.



(a) Bonding diagram



(b) Energy Band diagram

Fig.8

Therefore, for each arsenic atom added, one free electron will be available in the germanium crystal. Though each arsenic atom provides one free electron, yet an extremely small amount of arsenic impurity provides enough atoms to supply millions of free electrons.

Thermal energy of room temperature still generates a few hole-electron pairs. However, the number of free electrons provided by the pentavalent impurity far exceeds the number of holes. It is due to this predominance of electrons over holes that it is called n-type semiconductor (n stands for negative).

(ii) P-type Extrinsic Semiconductor:

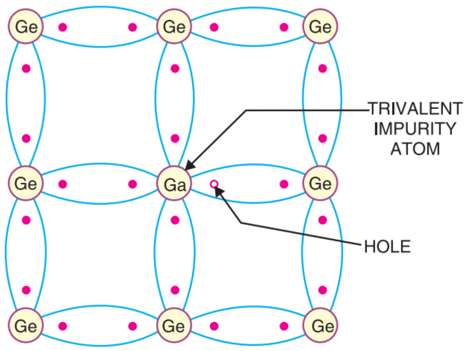
When a small amount of trivalent impurity is added to a pure semiconductor, it is called p-type semiconductor. Such impurities which produce p-type semiconductor are known as **acceptor impurities** because the holes created can accept the electrons.

When a small amount of trivalent impurity like gallium (Atomic no. 31) is added to germanium crystal, there exists a large number of holes in the crystal. Gallium is trivalent i.e. its atom has three valence electrons. Each atom of gallium fits into the germanium crystal but now only three co-valent bonds can be formed as shown in Fig.9. It is because three valence electrons of gallium atom can form only three single co-valent bonds with three germanium atoms as shown in Fig. In the fourth co-valent bond, only germanium atom contributes one valence electron while gallium has no valence electron to contribute as all its three valence electrons are already engaged in the co-valent bonds with neighboring germanium atoms. In other words, fourth bond is incomplete; being short of one electron.

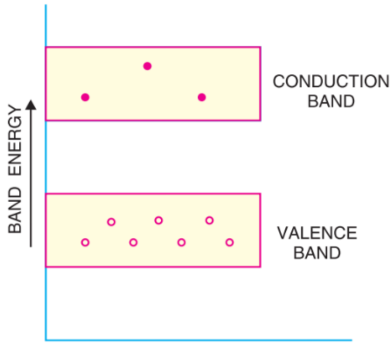
This missing electron is called a hole. Therefore, for each gallium atom added, one hole is created. A small amount of gallium provides millions of holes. The addition of trivalent impurity has produced a large number of holes.

However, there are a few conduction band electrons due to thermal energy associated with room temperature. But the holes far outnumber the conduction band electrons.

It is due to the predominance of holes over free electrons that it is called p-type semiconductor (p stands for positive).



(a) Bonding diagram

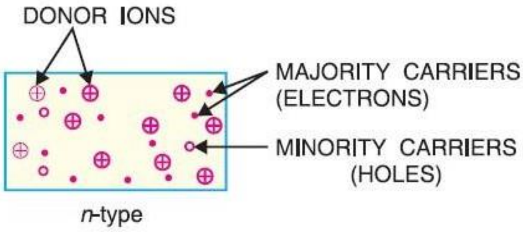


(b) Energy Band diagram

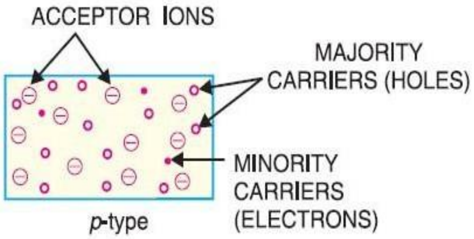
Fig.9

Majority and Minority Carriers:

N-type material has a large number of free electrons whereas p-type material has a large number of holes. However, it may be recalled that even at room temperature, some of the co-valent bonds break, thus releasing an equal number of free electrons and holes. An n-type material has its share of electron-hole pairs (released due to breaking of bonds at room temperature) but in addition has a much larger quantity of free electrons due to the effect of impurity. These impurity-caused free electrons are not associated with holes. Consequently, an n-type material has a large number of free electrons and a small number of holes as shown in Fig.10(i). The free electrons in this case are considered **majority carriers** — since the majority portion of current in n-type material is by the flow of free electrons — and the holes are the **minority carriers.** Similarly, in a p-type material, holes outnumber the free electrons as shown in Fig.10(ii). Therefore, holes are the majority carriers and free electrons are the minority carriers.



(i)

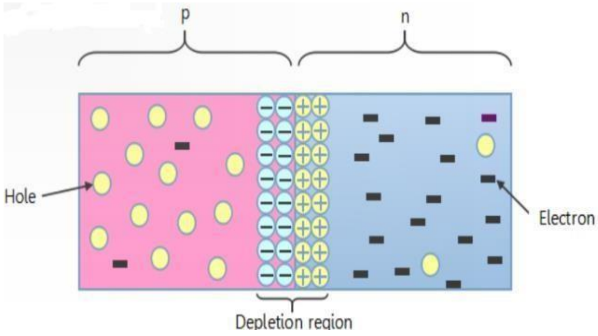


(ii)

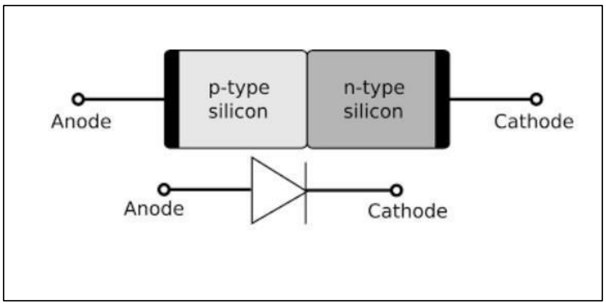
Fig.10

Semiconductor Diode

When a p-type semiconductor is suitably joined to n-type semiconductor, the contact surface is called pn junction as shown in Fig.11a. **A pn junction is known as a semi-conductor or crystal diode.** A crystal diode is usually represented by the schematic symbol shown in Fig.11b.



a) Pn Junction



b) Schematic Symbol

Fig.11

Properties of pn Junction:

At the instant of pn-junction formation, the free electrons near the junction in the n region begin to diffuse across the junction into the p region where they combine with holes near the junction. The result is that n region loses free electrons as they diffuse into the junction. This creates a layer of positive charges (pentavalent ions) near the junction. As the electrons move across the junction, the p-region loses holes as the electrons and holes combine. The result is that there is a layer of negative charges (trivalent ions) near the junction. These two layers of positive and negative charges form the depletion region (or depletion layer) as shown in Fig.12(i). The term depletion is due to the fact that near the junction, the region is depleted (i.e. emptied) of charge carries (free electrons and holes) due to diffusion across the junction. The depletion layer is formed very quickly and is very thin compared to the n-region and the p region.

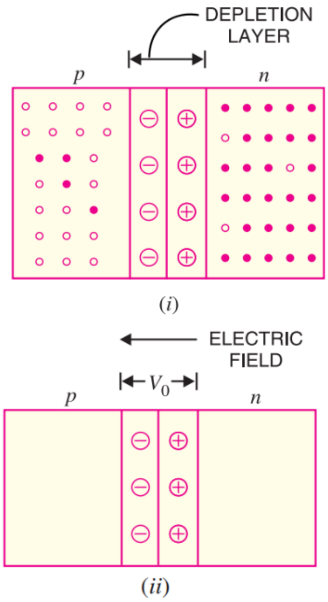


Fig.12

Once pn junction is formed and depletion layer created, the diffusion of free electrons stops. In other words, the depletion region acts as a barrier to the further movement of free electrons across the junction. The positive and negative charges set up an electric field as shown by a black arrow in Fig.12 (ii). The electric field is a barrier to the free electrons in the *n*-region. There exists a potential difference across the depletion layer and is called **barrier potential** (V_0). The barrier potential of a pn junction depends upon several factors including the type of semiconductor material, the amount of doping and temperature.

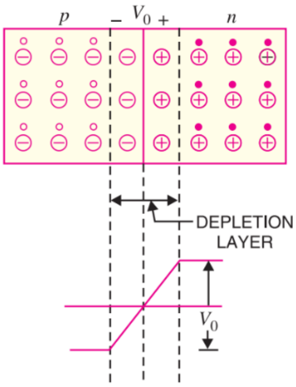


Fig.13

The typical barrier potential is approximately: For silicon, V_0 = 0.7 V; for germanium, V_0 = 0.3 V; shows the potential (V_0) distribution curve in Fig.13.

Operation of pn junction diode

Biasing:

In electronics, the term bias refers to the use of d.c. voltage or applying d.c voltage across pn junction to establish certain operating conditions for an electronic device. In relation to a pn junction, there are following two bias conditions:

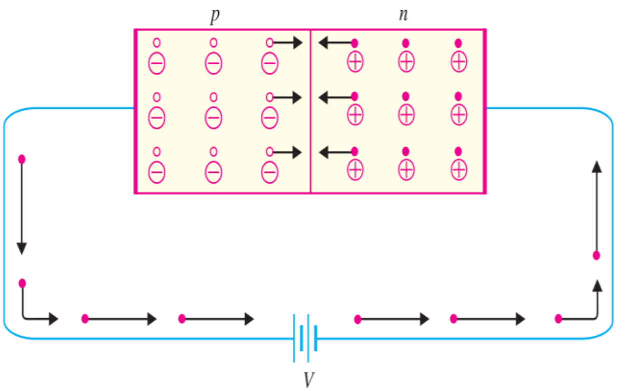
1. Forward biasing

2. Reverse biasing

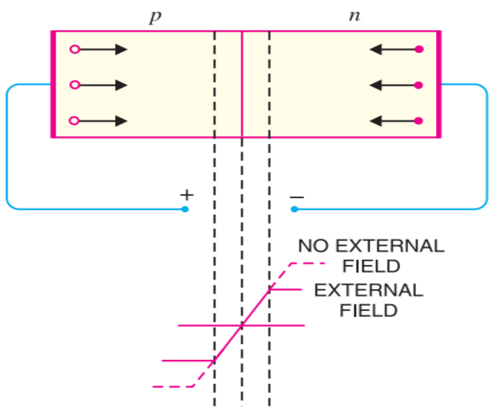
1. Forward biasing:

When external D.C. voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow, it is called **forward biasing.**

To apply forward bias, connect positive terminal of the battery to *p*-type and negative terminal to *n*-type as shown in Fig.14(i). The applied forward potential establishes an electric field which acts against the field due to potential barrier. Therefore, the resultant field is weakened and the barrier height is reduced at the junction as shown in Fig.14(ii).



(i)



(ii)

Fig.14

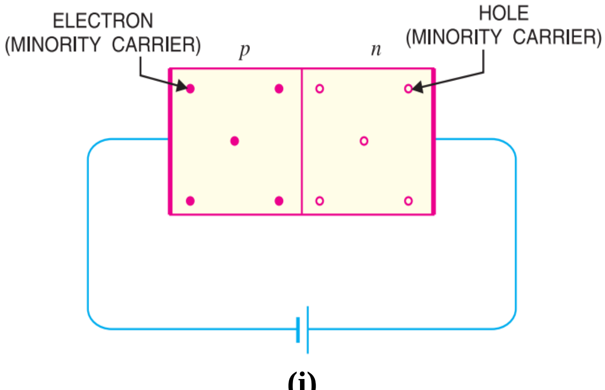
As potential barrier voltage is very small (0.1 - 0.3 V), therefore, a small **forward voltage (V_F)** is sufficient to completely eliminate the barrier. Once the potential barrier is eliminated by the forward voltage, junction resistance becomes almost zero and a **low resistance** (called forward resistance, R_f) path is established for the entire circuit and the **diode acts as a closed switch.**

Under the influence of forward voltage (V), the free electrons in n-type move towards the junction, leaving behind positively charged atoms i.e., **current in n-region is by free electrons**. However, more electrons arrive from the negative battery terminal and enter the n-region to take up their places. As the free electrons reach the junction, they become valence electrons (A hole is in the co-valent bond. When a free electron combines with a hole, it becomes a valence electron). As valence electrons, they move through the holes in the p-region i.e., **current in the p-region is by holes.** The valence electrons move towards left in the p-region which is equivalent to the holes moving to right. When the valence electrons reach the left end of the crystal, they flow into the positive terminal of the battery. However, in the external connecting wires, the current is carried by free electrons. This is called **forward current** and its magnitude depends upon the applied forward voltage.

2.Reverse biasing:

When the external d.c. voltage applied to the junction is in such a direction that potential barrier is increased, it is called **reverse biasing.**

To apply reverse bias, connect negative terminal of the battery to *p*-type and positive terminal to *n*-type as shown in Fig.15(i). The applied **reverse voltage (V_R)** establishes an electric field which acts in the same direction as the field due to potential barrier. Therefore, the resultant field at the junction is strengthened and the barrier height is increased as shown in Fig.15 (ii).



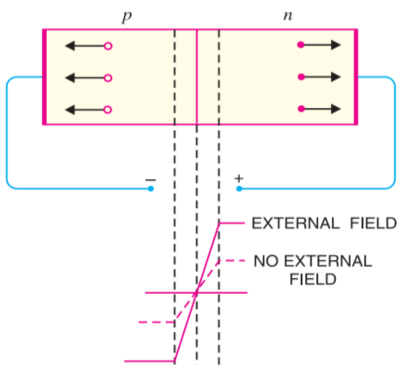


Fig.15

The increased potential barrier prevents the flow of charge carriers across the junction. Thus, a high resistance (called reverse resistance, R_r) path is established for the entire circuit and hence the current does not flow. Therefore, **the diode acts as an open switch.**

Volt-Ampere (V-I) Characteristics of pn Junction diode:

Volt-ampere or V-I characteristic of a pn junction (also called a crystal or semiconductor diode) is the curve between voltage across the junction and the circuit current. Usually, voltage is taken along x- axis and current along y-axis. The characteristics are analyzed in 3 conditions, namely - **zero external voltage, forward bias and reverse bias.**

i) Zero external voltage (no bias): When the external voltage is zero, the potential barrier at the junction does not permit current flow. Therefore, the circuit current is zero as indicated by point O in Fig. 16.

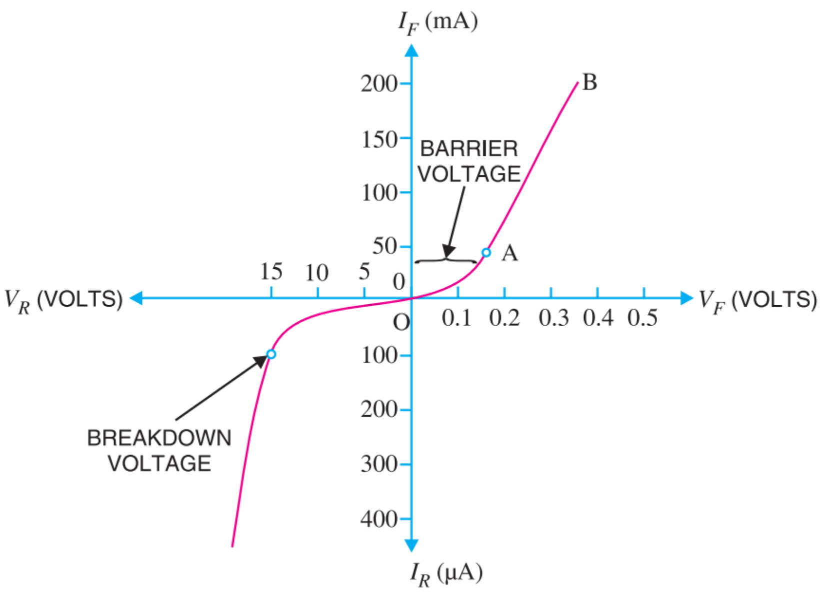


Fig.16

ii) Forward bias:

At some forward voltage (0.7V - Si and 0.3V - for Ge), the potential barrier is altogether eliminated and current starts flowing in the circuit. This forward voltage at which the current through the junction starts to increase rapidly is known as **Knee voltage**. Therefore, the knee voltage for silicon diode is 0.7 V and 0.3 V for germanium diode as shown in Fig.17.

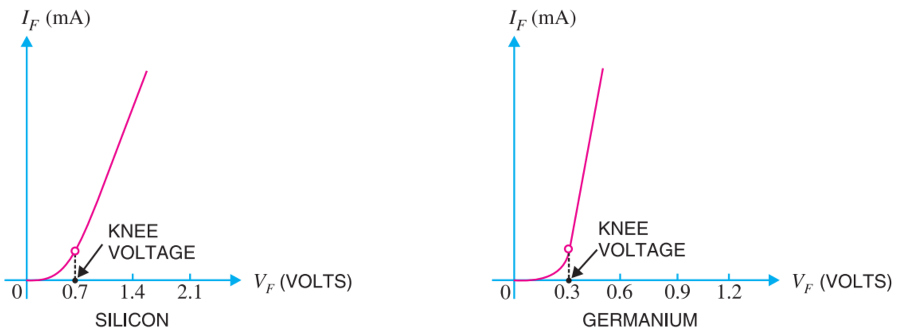


Fig.17

From the forward characteristic, it is seen that at first (region OA), the current increases very slowly and the curve is non-linear. It is because the external applied voltage is used up in overcoming the potential barrier. However, Once the applied forward voltage exceeds the knee voltage, the current starts increasing rapidly in linear manner. Thus, a rising curve AB is obtained with forward bias as shown in Fig. 16. and the pn junction behaves like an ordinary conductor.

iii) Reverse bias:

With reverse bias to the pn junction potential barrier at the junction is increased. Therefore, the junction resistance becomes very high and practically no current flows through the circuit. However, in practice, a very small current (of the order of μA) flows in the circuit with reverse bias as shown in the reverse characteristic in Fig. 16. This is called **reverse saturation current (I_s)** and is due to the minority carriers (few free electrons in p-type material and a few holes in n-type material) produced due to breaking of some co-valent bonds at room temperature as shown in Fig. 15(i).

If reverse voltage is increased continuously, the kinetic energy of electrons (minority carriers) may become high enough to knock out electrons from the semiconductor atoms. At this stage breakdown of the junction occurs, characterized by a sudden rise of reverse current and a sudden fall of the resistance of barrier region. This may destroy the junction permanently. The minimum reverse voltage at which pn junction breaks down with sudden rise in reverse current is called as **Breakdown Voltage**.

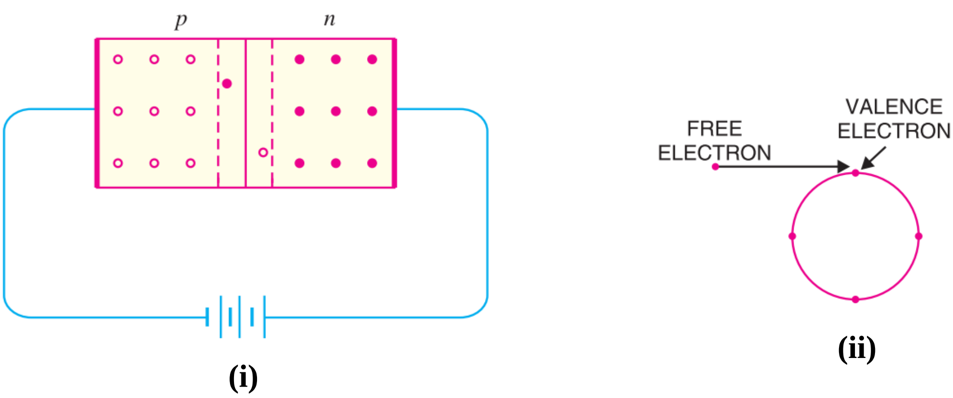


Fig.18 Avalanche Breakdown

Avalanche breakdown

Avalanche breakdown occurs in a pn junction diode which is **moderately doped** and has a thick junction (means its depletion layer width is high). Avalanche breakdown usually occurs when apply a high reverse voltage across the diode.

If applied reverse voltage is V_a and the depletion layer width is d; then the generated electric field can be $\mathbf{E_a = V_a / d}$.

Even at room temperature, some hole-electron pairs (minority carriers) are produced in the depletion layer as shown in Fig. 18(i). The generated electric field exerts a force on the electrons at junction and it frees them from covalent bonds. These free electrons will gain acceleration and it will start moving across the junction with high velocity. This results in collision with other neighboring atoms. These collisions in high velocity will generate further free electrons as shown in Fig. 18(ii). In this way, an avalanche of free electrons is occurred. These electrons will start drifting and electron-hole pair recombination occurs across the junction. This results in net current that rapidly increases. Therefore, the pn junction conducts a very large reverse current. Once the breakdown voltage is reached, the high reverse current may damage the junction. Therefore, care should be taken that reverse voltage across a pn junction is always less than the breakdown voltage.

<u>Zener Diode</u>

A properly doped crystal diode which has a sharp breakdown voltage is known as a **zener diode.** The breakdown or Zener voltage depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin and consequently the breakdown of the junction will occur at a lower reverse voltage compared to pn junction diode. On the other hand, a lightly doped diode has a higher breakdown voltage.

Fig. 19 (i) shows the symbol of a zener diode. It is just like an ordinary diode except that the bar is turned into z-shape.

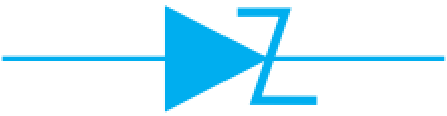
From Fig. 19(ii), the following points may be noted about the zener diode:

(i) A zener diode is like an ordinary diode except that it is properly doped so as to have a sharp breakdown voltage.

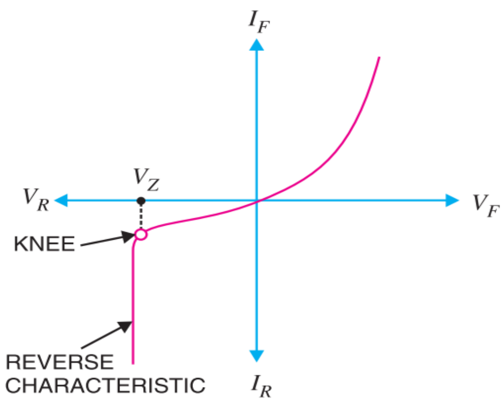
(ii) A zener diode is always reverse connected i.e. it is always reverse biased.

(iii) A zener diode has sharp breakdown voltage, called zener voltage $\mathbf{V_Z}$.

(iv) When forward biased, its characteristics are just those of ordinary diode.



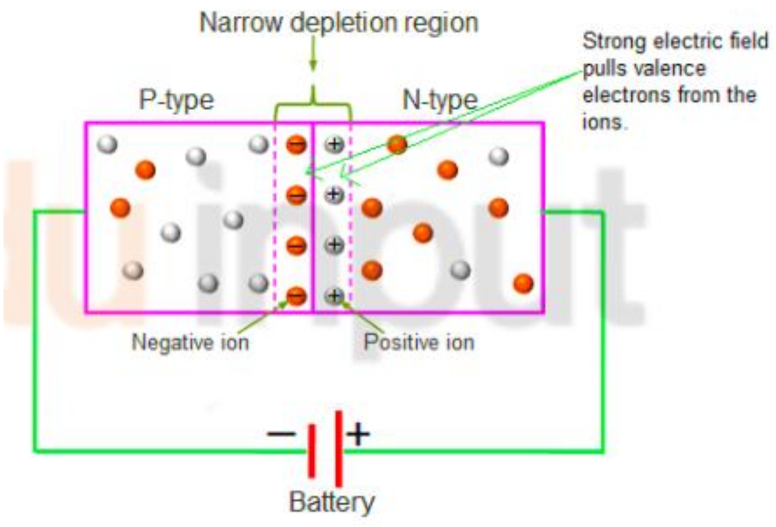
(i)

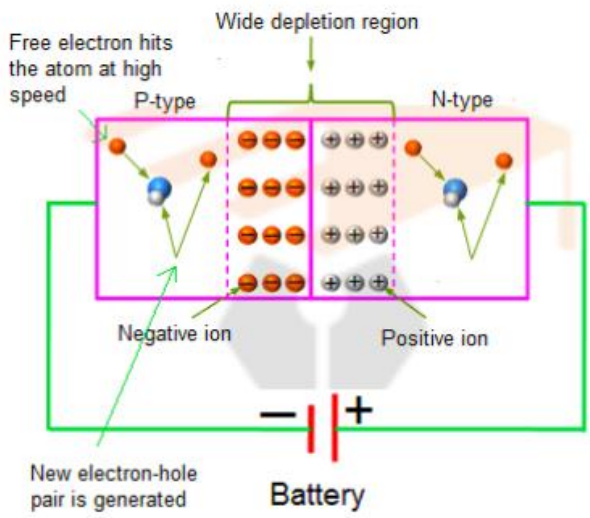


(ii)

Fig.19 Zener Diode

Comparison between Zener Breakdown vs Avalanche Breakdown:





Zener Breakdown **Avalanche Breakdown**

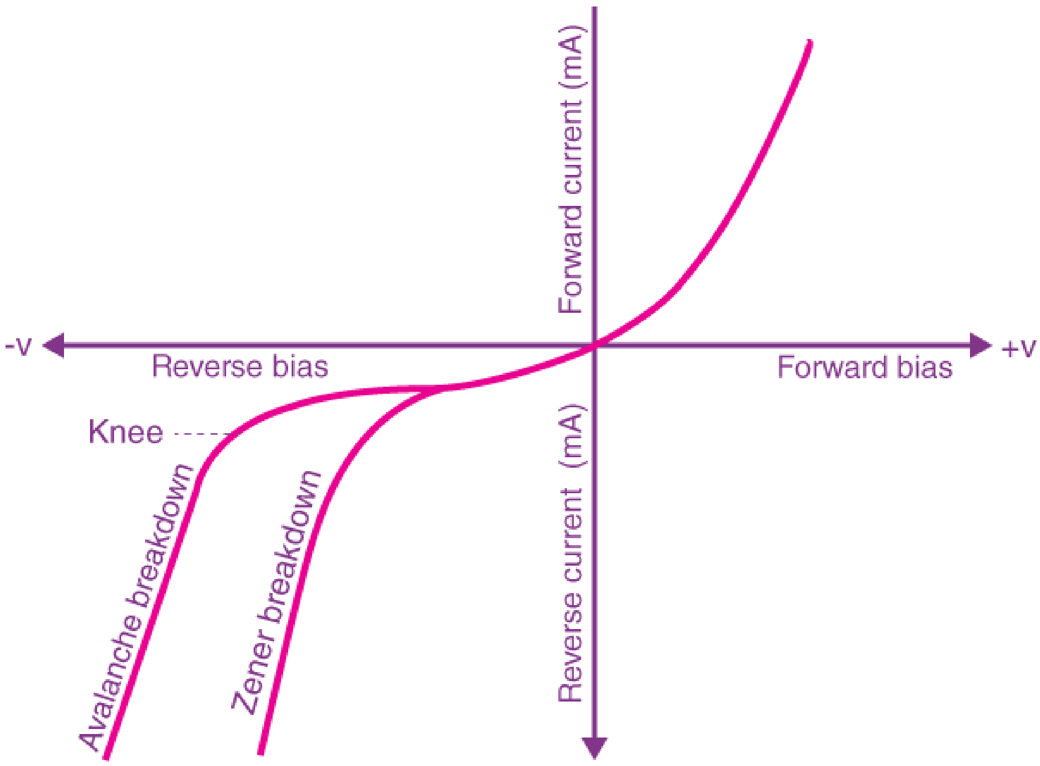


Fig. 20

Zener Breakdown	Avalanche Breakdown
Zener breakdown occurs in p-n junction diodes because of their narrow depletion region. When reverse-biased voltage is increased in the diode, the narrow depletion region starts generating a strong electric field. When the applied voltage reaches closer to the Zener voltage, the **electric field becomes strong enough to pull electrons from their valence band.** The valence electrons break bonding with the parent atom and become free electrons. These free electrons carrying electric current from one place to another.When the Zener voltage is reached, a huge number of free charge carriers are generated and a large current is able to flow through the diode. In Zener breakdown, the electric field becomes substantially strong, but remains narrow, thus restricting many charge carriers to accelerate.	Avalanche breakdown occurs in a PN junction diode which is reasonably doped and has a thick depletion layer. It usually occurs when a high reverse voltage is applied across the diode. As we keep on increasing the reverse voltage, the electric field also keeps increasing. This **electric field exerts a force on the electrons and frees them from a covalent bond.** These free electrons moving across the junction and collide with other neighbouring atoms. This results in the generation of more free electrons. The drifting of these electrons increases the net current across the junction.
This is observed in Zener diodes having a Zener breakdown voltage V_z of **5 to 8 volts.**	This is observed in Zener diode having a Zener breakdown voltage V_z **greater than 8 volts.**
The valence electrons are pulled into conduction due to the high electric field in the narrow depletion region.	The valence electrons are pushed to conduction due to the energy imparted by accelerated electrons, which gain their velocity due to their collision with other atoms.
The increase in temperature decreases the breakdown voltage.	The increase in temperature increases the breakdown voltage.
The V-I characteristics of a Zener breakdown has a sharp curve.	The V-I characteristic curve of the avalanche breakdown is not as sharp as the Zener breakdown.
It occurs in diodes that are highly doped.	It occurs in diodes that are lightly doped.

TRANSISTOR

Transistor: A **transistor** consists of two pn junctions formed by sandwiching either p-type or n-type semiconductor between a pair of opposite types.

There are two types of transistors, are (i) n-p-n transistor (ii) p-n-p transistor

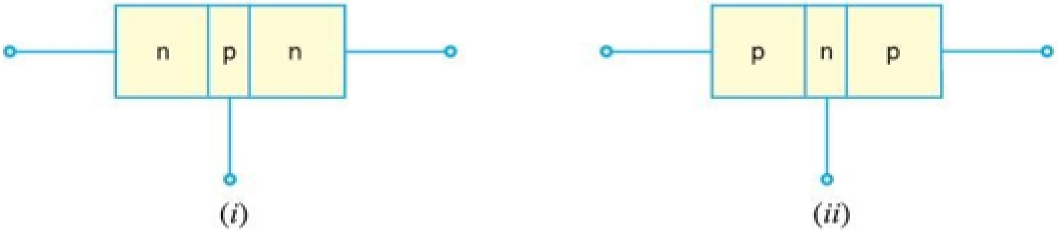


Fig. 21

In each type of transistor:

(i) These are two pn junctions. Therefore, a transistor may be regarded as a combination of **two diodes connected back-to-back.**

(ii) There are three terminals, one taken from each type of semiconductor.

(iii) The middle section is a very thin layer. This is the most important factor in the function of a transistor.

A transistor (pnp or npn) has three sections of doped semiconductors. The section on one side is the **emitter** and the section on the opposite side is the **collector**. The middle section is called the **base** and forms two junctions between the emitter and collector.

(i) **Emitter (E):** The section on one side that **emits or supplies charge carriers** (electrons or holes) is called the emitter. The emitter is always forward biased w.r.t. base so that it can supply a large number of majority carriers.

In Fig. 22 (i), the emitter (p-type) of pnp transistor is forward biased and supplies holes to its junction with the base. Similarly, in Fig. 22 (ii), the emitter (n-type) of npn transistor has a forward bias and supplies free electrons to its junction with the base.

(ii) **Collector (C):** The section on the other side that **collects the charges carriers** is called the collector. The Collector is always reverse biased. Its function is to remove charges from its junction with the base.

In Fig. 22 (i), the collector (p-type) of pnp transistor has a reverse bias and receives holes that flow in the output circuit. Similarly, in Fig. 22 (ii), the collector (n-type) of npn transistor has reverse bias and receives electrons.

(iii) **Base (B):** The middle section which forms two pn-junctions between the emitter and collector is called the base. The base-emitter junction is forward biased, allowing **low resistance** for the **emitter circuit.** The base-collector junction is reverse biased and provides **high resistance** in the **collector circuit.**

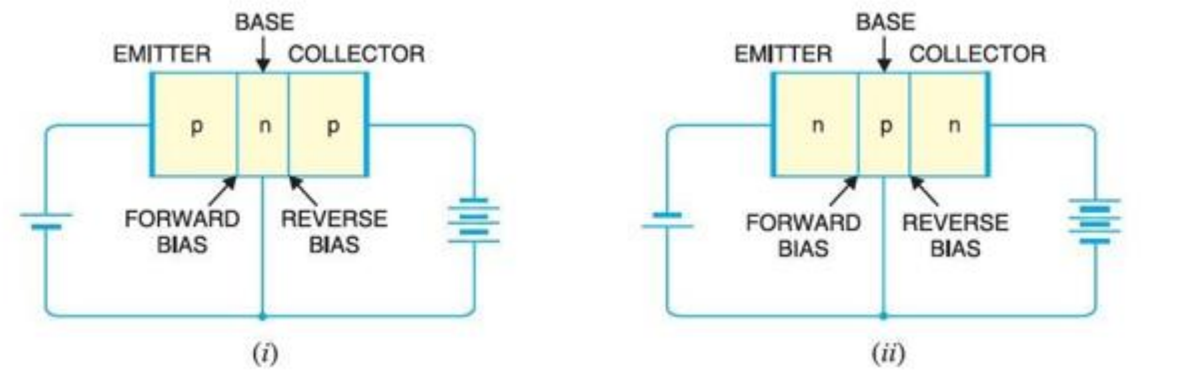


Fig. 22

1. The **base is much thinner than the emitter while collector is wider than both** (During transistor operation, much heat is produced at the collector junction. The collector is made larger to dissipate the heat) as shown in Fig.22. However, for the sake of convenience, it is customary to show emitter and collector to be of equal size.

2. The **emitter is heavily doped** so that it can inject a large number of charge carriers (electrons or holes) into the base. The **base is lightly doped** and very thin; it passes most of the emitter injected charge carriers to the collector. The **collector is moderately doped**.

3. The transistor has two pn junctions i.e. it is like two diodes. The junction between emitter and base may be called **emitter-base diode** or simply the **emitter diode**. The junction between the base and collector may be called **collector-base diode or simply collector diode**. The emitter diode is always forward biased (low resistance), whereas collector diode is always reverse biased (high resistance).

Working of Bipolar Junction Transistor (BJT):

A transistor or Bipolar Junction Transistor (BJT) is a three terminal (E, B & C) semiconductor device in which the conduction depends on both majority and minority charge carriers and hence the name bipolar. A BJT operates based on the control of current flow between the emitter and collector by manipulating the flow of charge carriers through the base (B) region.

npn Transistor:

Fig. 23 Shows the npn transistor with forward bias to emitter-base junction and reverse bias to collector-base junction. The forward bias causes the electrons in the n-type emitter to flow towards the base. This constitutes the emitter current I_E, as these electrons flow through the p-type base, they tend to combine with holes. As the base is lightly doped and very thin, therefore only a few electrons combine with holes to constitute base current I_B. The remainder more than 95 % cross over into the collector region to constitute collector current I_C. In this way almost the entire emitter current flows in the collector circuit. It is clear that emitter current is the sum of collector and base currents. i.e., $\mathbf{I_E=I_B+I_C}$

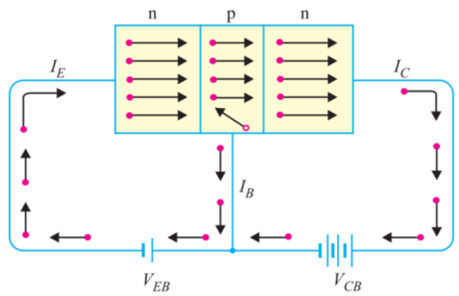


Fig. 23 npn transistor

pnp Transistor:

Fig. 24 shows that the basic connection of a pnp transistor. The forward bias causes the holes in the p-type emitter to flow towards the base. The constitutes the emitter current I_E. As these holes cross into n-type base, they tend to combine with the electrons. As the base is lightly doped and very thin therefore only a few holes (less than 5%) combine with the electrons. The remainder (more than 95%) cross into the collector region to constitute collector current I_C. In this way, almost the entire emitter current flows in the collector circuit. It may be noted that current conduction within pnp transistor is by holes. However, in the external connecting wires, the current is still by electrons.

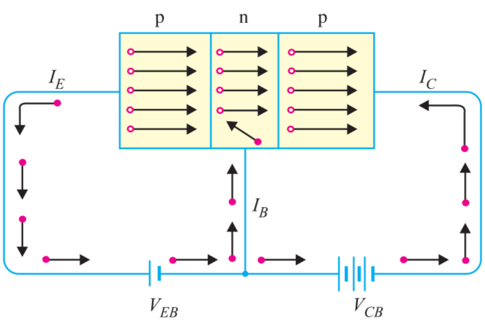


Fig. 24 pnp transistor

Transistor Symbols:

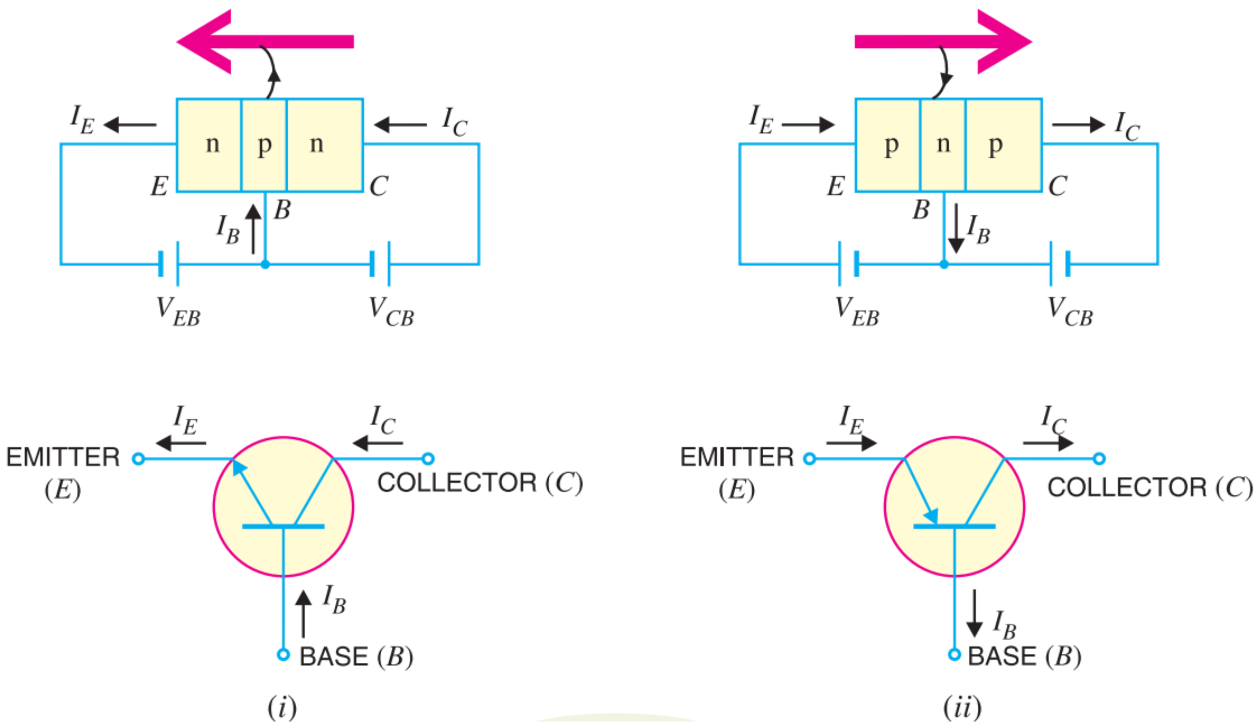


Fig. 25

Note that emitter is shown by an arrow which indicates the direction of conventional current flow with forward bias. For **npn connection**, it is clear that conventional current flows out of the emitter as indicated by the outgoing arrow in Fig. 25 (i). Similarly, for **pnp connection**, the conventional current flows into the emitter as indicated by inward arrow in Fig. 25 (ii).

CONFIGURATION OF TRANSISTOR CIRCUIT

There are three leads in a transistor viz., emitter, base and collector terminals. However, when a transistor is to be connected in a circuit, require four terminals; two for the input and two for the output. This difficulty is overcome by making one terminal of the transistor common to both input and output terminals. The input is fed between this common terminal and one of the other two terminals. The output is obtained between the common terminal and the remaining terminal. Accordingly; a transistor can be connected in a circuit in the following three ways:

TYPES OF CONFIGURATIONS

1) Common base (CB) configuration
2) Common emitter (CE) configuration
3) Common collector (CC) configuration

COMMON BASE (CB) CONFIGURATION:

In this circuit arrangement, input is applied between emitter and base and output is taken from collector and base. Here, base of the transistor is common to both input and output circuits and hence the name common base connection. In Fig. 26 (i), a common base npn transistor circuit is shown whereas Fig. 26 (ii) shows the common base pnp transistor circuit.

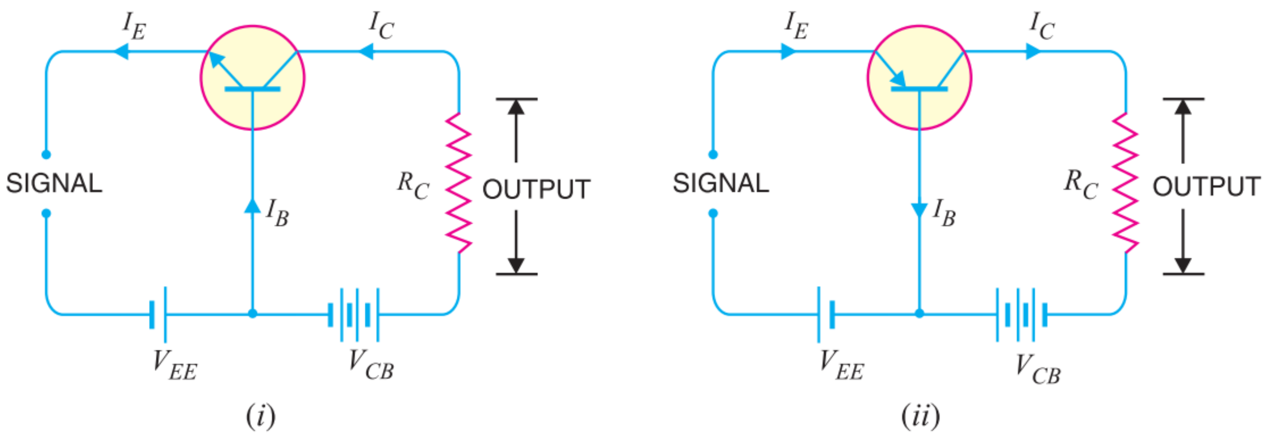
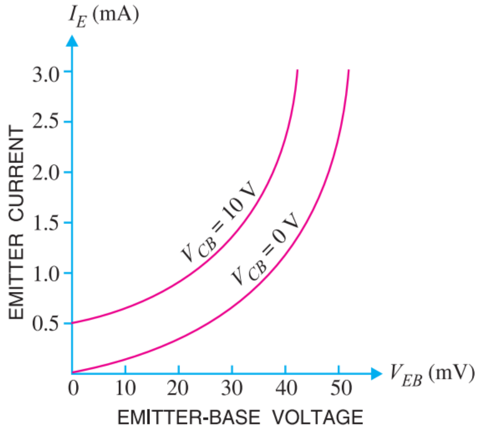


Fig. 26 CB Configuration for i) npn transistor ii) pnp transistor

Input characteristics:



It is the curve between emitter current I_E and emitter-base voltage V_{EE} or V_{EB} at constant collector-base voltage V_{CB}.

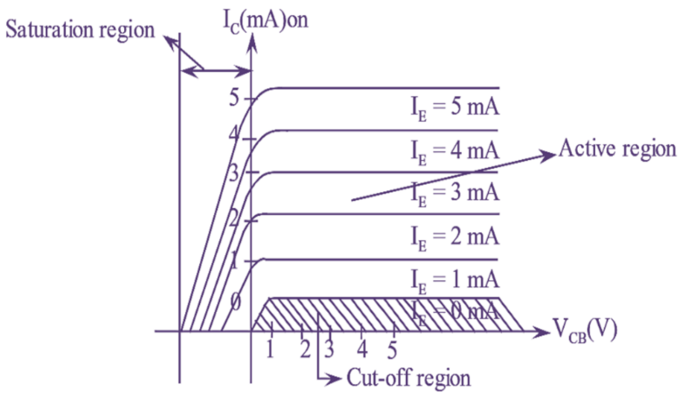
1. When $V_{CB} = 0$, the emitter-base junction is forward biased and the **junction behaves as a forward biased diode**. The emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB}. It means that input resistance is very small.

2. When V_{CB} is increased keeping V_{EB} constant, the collector – base junction gets more and more reverse biased, the width of the depletion region will increase and due to this, the base region is narrower. Then, less voltage is required to forward bias the emitter-base junction. This results in an increase in I_E.

Output characteristics:

It is the curve between collector current I_C and collector-base voltage V_{CB} at constant emitter current I_E.

1. The collector current I_C varies with V_{CB} only at very low voltages (< 1V). The transistor is never operated in this region. i.e., Cut-off and Saturation region.



When V_{CB} is negative (forward biased), electrons which have entered into the base region from the emitter will not be able to cross the collector junction and due to that, collector current starts to reducing. So, whenever, both emitter-base junction and the collector-base junction are forward biased then the BJT will operate in **Saturation Region.**

When V_{EE} is negative (Reverse biased), the emitter current I_E will be zero. At this time, even if increase the collector to base voltage (V_{CB}), the I_C almost remains zero (except current due to minority charge carriers, i.e., reverse saturation current. So, whenever, both emitter-base junction and the collector-base junction are reverse biased then the BJT will operate in **Cut-off Region.**

2. When the value of V_{CB} is raised above 1 − 2 V, the collector current becomes constant as indicated by straight horizontal curves. It means that now I_C is independent of V_{CB} and depends upon I_E only. The transistor is always operated in this region. i.e., **Active region**.

$$\mathbf{I_C = \alpha * I_E},\quad \text{where } \alpha\text{: Current gain}$$

Mode	**Emitter -base junction**	**Collector-base junction**	**Region of Operation**
I	Forward Biased	Reverse Biased	Active Region
II	Reverse Biased	Forward Biased	Inverse Active Region
III	Forward Biased	Forward Biased	Saturation Region
IV	Reverse Biased	Reverse Biased	Cut – off region

COMMON EMITTER (CE) CONFIGURATION:

In this circuit arrangement, input is applied between base and emitter and output is taken from the collector and emitter. Here, emitter of the transistor is common to both input and output circuits and hence the name common emitter connection. Fig. 27 (i) shows common emitter npn transistor circuit whereas Fig. 27. (ii) shows common emitter pnp transistor circuit.

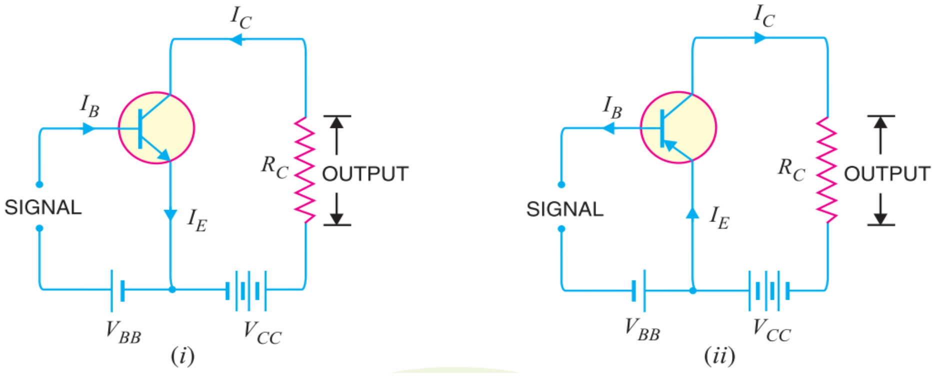
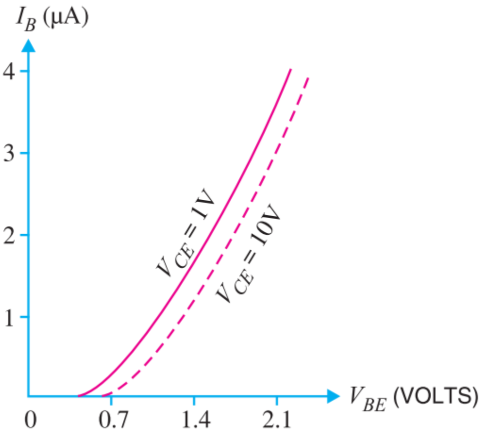


Fig. 27 CE Configuration for i) npn transistor ii) pnp transistor

Input characteristics:



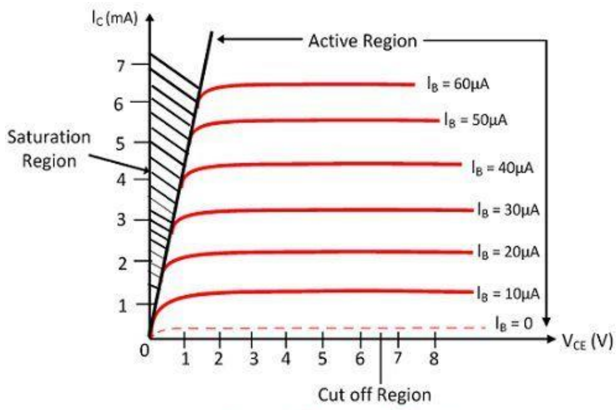
It is the curve between base current I_B and base-emitter voltage V_{BB} or V_{BE} at constant collector-emitter voltage V_{CE} or V_{CC}.

1. The characteristic resembles that of a forward biased diode curve, since the base-emitter section of transistor is a diode and it is forward biased.

2. When V_{CE} is increased ($V_{CE} = V_{CB} + V_{BE}$), the width of the depletion region at the reverse biased collector – base junction will increase. This will reduce the effective width of the base region and due to this, the probability of recombination is reduced. Then, most of the electrons will get collected at the collector terminal and leads to decrease in the base current I_B. In order to provide the same amount of I_B, V_{BE} should be increased. Hence, the curves appear to the right as V_{CE} increases.

Output characteristics:

It is the curve between collector current I_C and collector-emitter voltage V_{CE} at constant base current I_B.



Output Characteristic Curve

In the **active region**, the collector current I_C varies with V_{CE} for V_{CE} between 0 and 1V only. A small increase in I_C with increasing V_{CE} is caused by the collector depletion layer getting wider and capturing a few more majority carriers before electron-hole combinations occur in the base area. After this, collector current becomes almost constant and independent of V_{CE}. This value of V_{CE} upto which collector current I_C changes with V_{CE} is called the **knee voltage (V_{knee}).** The **transistors are always operated in the region above knee voltage.**

When the V_{CE} falls, the I_C also decreases rapidly. The collector-base junction of the transistor always in forward bias and work saturate. In the **saturation region**, the collector current becomes independent and free from the input current I_B.

In **cut-off region,** if I_B = 0, collector current I_C have finite magnitude unlike CB configuration.

COMMON COLLECTOR (CC) CONFIGURATION:

In this circuit arrangement, input is applied between base and collector while output is taken between the emitter and collector. Here, collector of the transistor is common to both input and output circuits and hence the name common collector connection. Fig. 28 (i) shows common collector npn transistor circuit whereas Fig. 28 (ii) shows common collector pnp circuit.

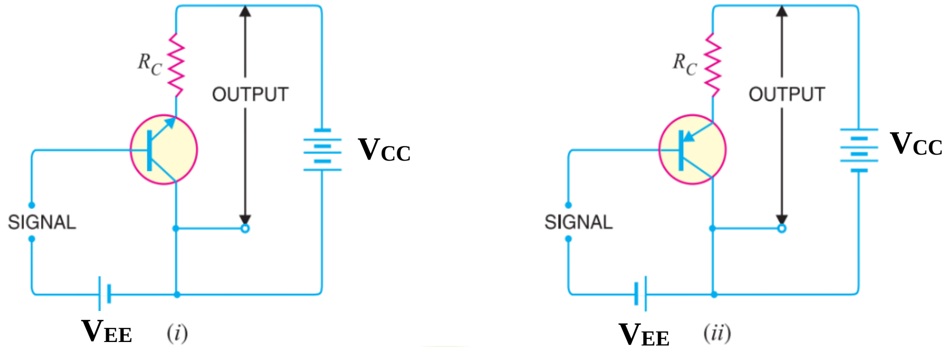
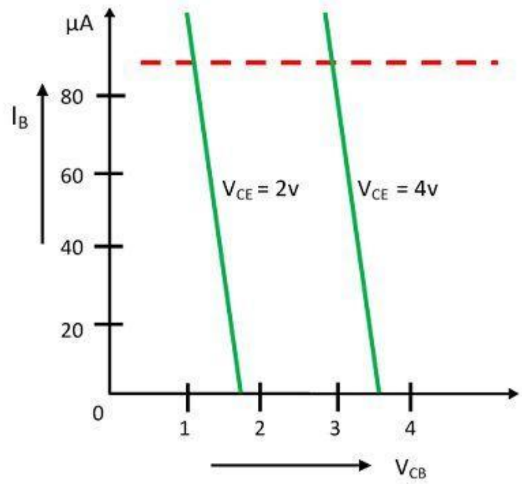


Fig. 28 CC Configuration for i) npn transistor ii) pnp transistor

Input characteristics:

It is the curve between base current I_B and base-collector voltage V_{CB} at constant collector-emitter voltage V_{CE}.

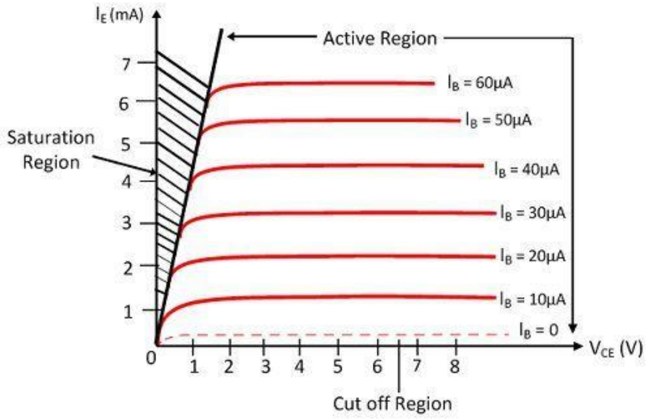


For the fixed value of V_{CE}, as increase the V_{CB}, then the base current I_B reduces. Because, $V_{CE} = V_{CB} + V_{BE}$, as V_{CB} increases, the width of the collector – base junction increases and effective base width decreases.

For the fixed value of V_{CB} , as increase the voltage V_{CE} , the voltage V_{BE} get increased and it pushes the more electrons into the base region, then I_B increases.

Output characteristics:

It is the curve between emitter current I_E and emitter-collector voltage V_{CE} at constant base current I_B. These characteristics are similar to the CE configuration as the output current, i.e., emitter current (I_E) is almost equal to the collector current (I_C).



Transistor as an Amplifier

A transistor raises the strength of a weak signal and thus acts as an amplifier. Fig. 29 shows the basic circuit of a transistor amplifier. The weak signal is applied between emitter base junction and output is taken across the load R_C connected in the collector circuit. In order to achieve faithful amplification, the input circuit should always remain forward biased. To do so, a d.c voltage V_{EE} is applied in the input circuit in addition to the signal.

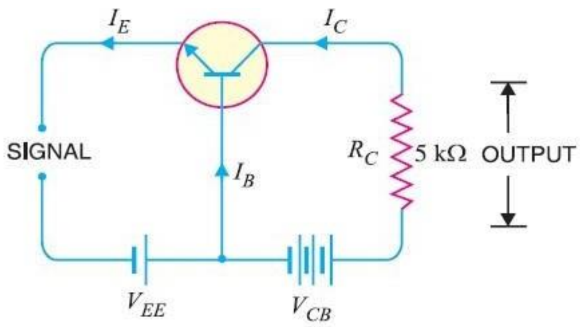


Fig. 29

SINGLE STAGE CE AMPLIFIER:

Fig. 30(i) shows the common emitter (CE) npn amplifier circuit. A battery V_{BB} is connected in the input circuit in addition to the signal voltage. This d.c. voltage is known as **bias voltage** and its magnitude is such that it always keeps the emitter-base junction forward biased regardless of the polarity of the signal source.

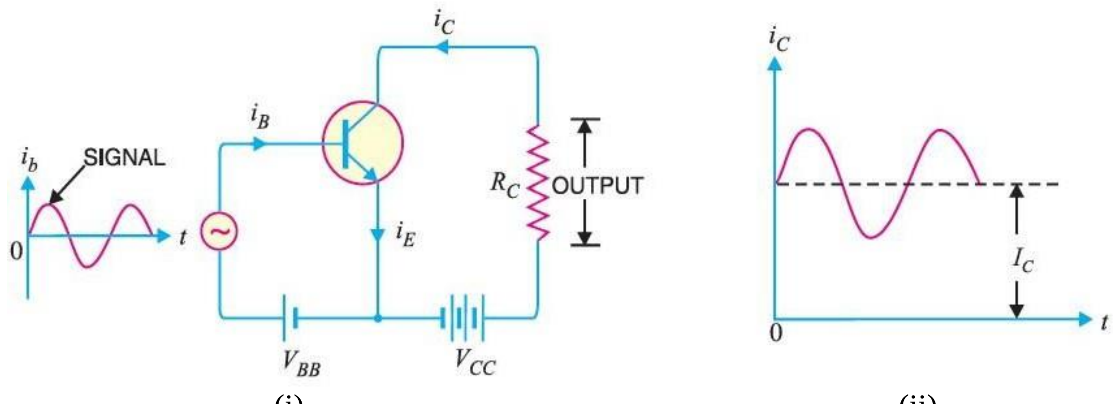


Fig. 30 Transistor as an Amplifier in CE Arrangement

Operation:

During the positive half-cycle of the signal, the forward bias across the emitter base junction is increased. Therefore, more electrons flow from the emitter to the collector via the base. This causes an increase in collector current. The increased collector current produces a greater voltage drop across the collector load resistance R_C. However, during the negative half- cycle of the signal, the forward bias across emitter-base junction is decreased. Therefore, collector current decreases. This results in the decreased output voltage (in the opposite direction). Hence, an amplified output is obtained across the load.

Analysis of collector currents:

When no signal is applied, the input circuit is forward biased by the battery V_{BB}. Therefore, a d.c. collector current I_C flows in the collector circuit. This is called **zero signal collector current.**

When the signal voltage is applied, the forward bias on the emitter base junction increases or decreases depending upon whether the signal is positive or negative. During the positive half-cycle of the signal, the forward bias on emitter-base junction is increased, causing total collector current i_C to increase. Reverse will happen for the negative half-cycle of the signal.

Fig. 30 (ii) Shows the graph of total collector current I_C versus time. From the graph it is clear that total current consists of two components namely,

(i) The dc collector current I_C (zero signal collector current) due to bias battery V_{BB}. This is the current that flows in the collector in the absence of signal.

(ii) The a.c collector current i_c due to signal

Total collector current $i_C = i_c + I_C$.