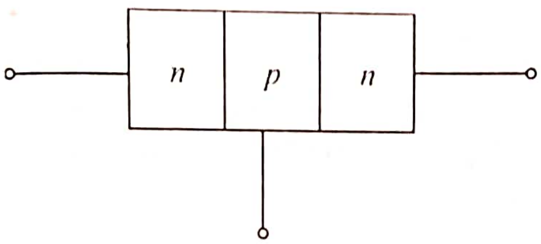
## 3.1 INTRODUCTION

A transistor consists of two *pn* junctions, formed by sandwiching either *p*-type or *n*-type semiconductor between a pair of opposite types. Accordingly, there are two types of transistors, namely

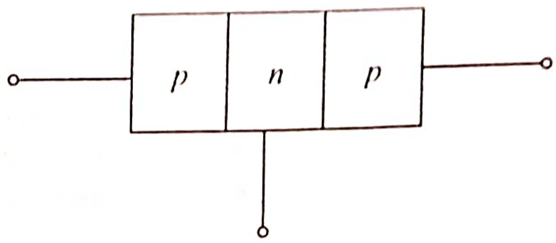
(a) *n-p-n* transistor

(b) *p-n-p* transistor

An *n-p-n* transistor is composed of two *n*-type semiconductors separated by a thin section of *p*-type as shown in Figure–3.1(a). However, a *p-n-p* transistor is formed by two *p*-sections separated by a thin section of *n*-type as shown in Figure–3.1(b).




(a)




(b)

**Figure–3.1:** (a) Schematic diagram of *npn* transistor (b) Schematic diagram of *pnp* transistor

In a transistor there are two *pn* junctions. Therefore, a transistor may be regarded as a combination of two diodes connected back to back and there are three terminals, taken from each type of semiconductor. The middle section is very thin layer.

One junction is forward biased and the other is reverse biaseded. The forward biased junction has a low resistance path whereas a reverse biaseded junction has a high resistance circuit. The weak signal is introduced in the low resistance circuit and output is taken from the high resistance circuit.

Therefore, a transistor transfers a signal from a low resistance to high resistance. The prefix 'trans' means the signal transfer property of the device while 'istor' classifies it as a solid element in the same general family with resistors.

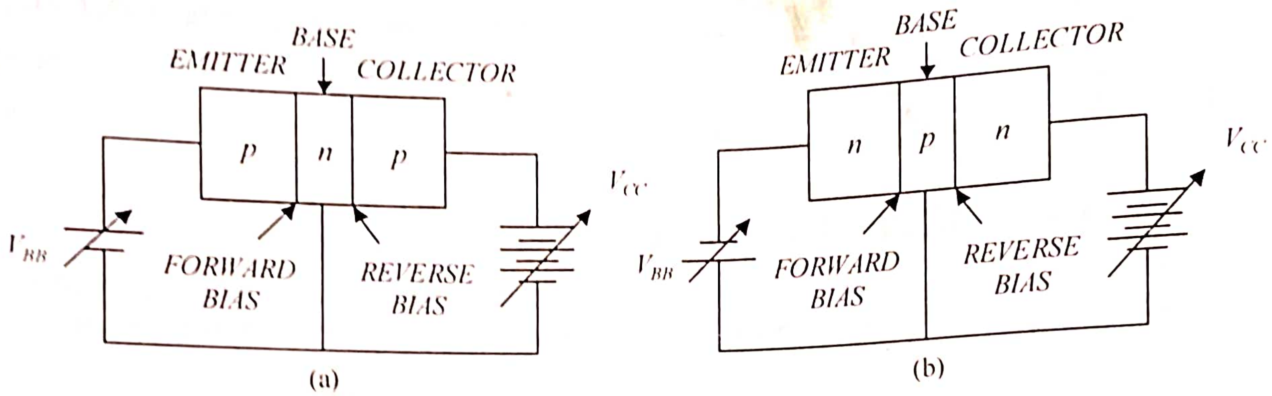
$\therefore$ Trans + istor = Transistor.

### 3.1.1 Transistor Terminals

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***

The part on one side that supplies charge carriers (electrons or holes) is called the emitter. The emitter is always forward biased with respect to base so that it can supply a large number of majority carriers.




**Figure–3.2:** (a) *pnp* transistor with external supply (b) *npn* transistor with external supply

In Figure–3.2(a), the emitter (*p*-type) of *pnp* transistor is forward biased and supplies hole charges to its junction with the base. Similarly in Figure–3.2(b). the emitter (*n*-type) of npn transistor has a forward biased and supplies free electrons to its junction with the base.

*ii.* ***Collector***

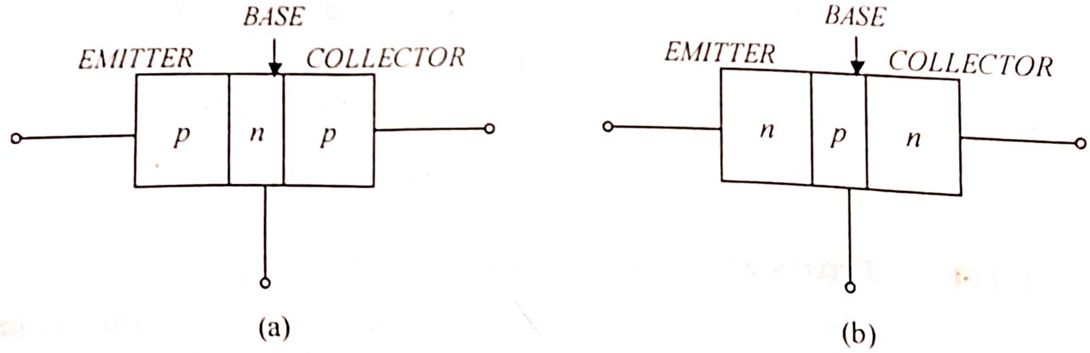
The part on the other side that collects the charges is called the collector. The collector is always reverse biaseded. Its function is to remove charges from its junction with the base. In Figure–3.2(a), the collector (*p*-type) of *pnp* transistor has a reverse biased and receives hole charges that flow in the output circuit. Similarly in Figure–3.2(b). The collector (*n*-type) of *npn* transistor has reverse biased and receives electrons.

*iii.* ***Base***

The middle part which forms two *pn* junctions with emitter and collector is called the base. The base emitter junction is forward biaseded, allowing low resistance for the emitter circuit. The base-collector junction is reverse biaseded and provides high resistance in the collector circuit.

**Note :** The following facts about the transistor must be known before discussing transistor action.

1. The transistor has three regions, namely; emitter, base and collector. The base is much thinner than the emitter while collector is wider than both as shown in Figure–3.3.
The base width is choosen deliberately small, to reduce the recombination of injected minority carriers.




**Figure–3.3:** (a) *pnp* transistor with its terminals (b) *npn* tranasistor with its terminals

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 charges carriers to the collector. The collector is moderately doped. The physical width of collector is more compared to base and emitter as it has to dissipate more power.

3. The transistor has two *pn* junctions i.e., it is like two diodes. The junction between emitter and base is called emitter base diode or simply the emitter diode or emitter junction ($J_E$). The junction between the base and collector may be called collector-base diode or simply collector diode or collector junction ($J_C$).

4. The emitter diode is always forward biased whereas collector diode is always reverse biased.

5. The resistance of emitter diode (forward biased) is very small when compared to collector diode (reverse biased). Therefore, forward biased applied to the emitter diode is generally very small whereas reverse biased on the collector diode is much larger.

6. Transistors can be used in three configurations modes

   (i) Common Base mode $C.B$

   (ii) Common Emitter mode $C.E$

   (iii) Common Collector mode $C.C.$

## 4.3 BJT Operation

### 4.3.1 Unbiased Transistor

- An unbiased transistor means a transistor with no external voltage (biasing) is applied. Obviously, there will be no current flowing from any of the transistor leads.
- Since transistor is like two pn junction diodes connected back to back, there are depletion regions at both the junctions, emitter junction and collector junction, as shown in the Fig. 4.3.1.
- During diffusion process, depletion region penetrates more deeply into the lightly doped side in order to include an equal number of impurity atoms in the each side of the junction.
- As shown in the Fig. 4.3.1, depletion region at emitter junction penetrates less in the heavily doped emitter and extends more in the base region.

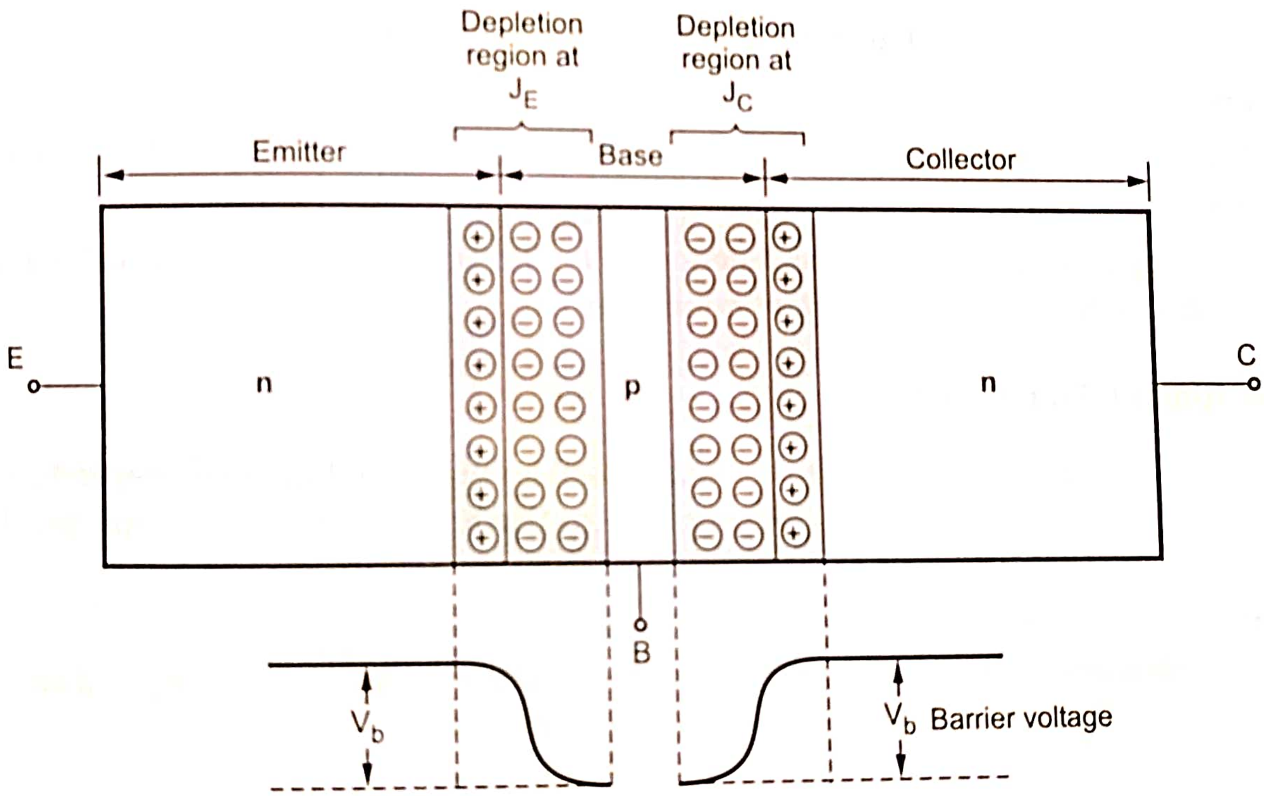



**Fig. 4.3.1 Unbiased npn transistor**

- Similarly, depletion region at collector junction penetrates less in the heavily doped collector and extends more in the base region.
- As collector is slightly less doped than the emitter, the depletion layer width at the collector junction is slightly more than the depletion layer width at the emitter junction.
- Barrier voltage is the voltage necessary to cause electrical conduction in a junction of two dissimilar materials.

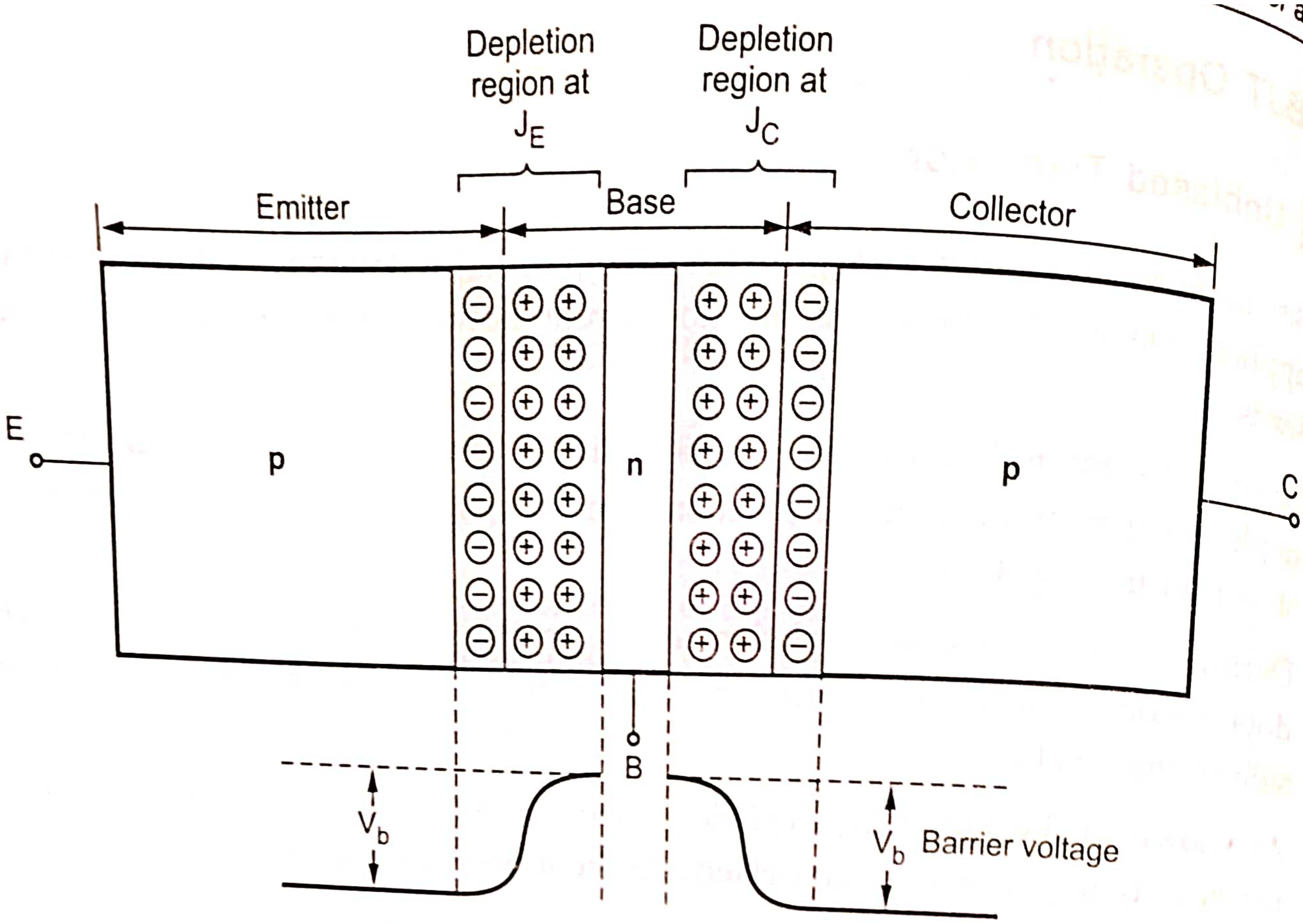



**Fig. 4.3.2 Unbiased pnp transistor**

- Like diodes, a barrier voltage exists within the transistor.
- The barrier voltage at each junction is positive on the n-side and negative on p-side.
- The barrier voltage across the junction in a silicon transistor is about 0.7 volt and approximately 0.3 volt in a germanium transistor.

## 4.3.2 Biased Transistor

The transistor can be operated in four possible bias combinations depending on whether forward or reverse bias is applied to each junction. These are listed in Table 4.3.1.

| Region of operation | Base Emitter (B-E) junction | Base Collector (B-C) junction | Application |
|---|---|---|---|
| Cut-off | Reverse biased | Reverse biased | BJT as switch |
| Forward active | Forward biased | Reverse biased | BJT as amplifier |
| Inverse active | Reverse biased | Forward biased | BJT in digital circuits |
| Saturation | Forward biased | Forward biased | BJT as switch |

**Table 4.3.1 Operating regions and bias conditions**

### 4.3.2.1 Inverse Active Mode

- The active mode of transistor is further classified as forward active and inverse active.
- In inverse active mode, B-E junction ($J_{BE}$) is reverse biased and B-C junction ($J_{BC}$) is forward bias.
- In this operating mode, the transistor is operating **upside down**; that is, the emitter is acting as the collector and the collector is operating as the emitter.
- The Fig. 4.3.3 shows the bias conditions for four modes of operations of an npn transistor.

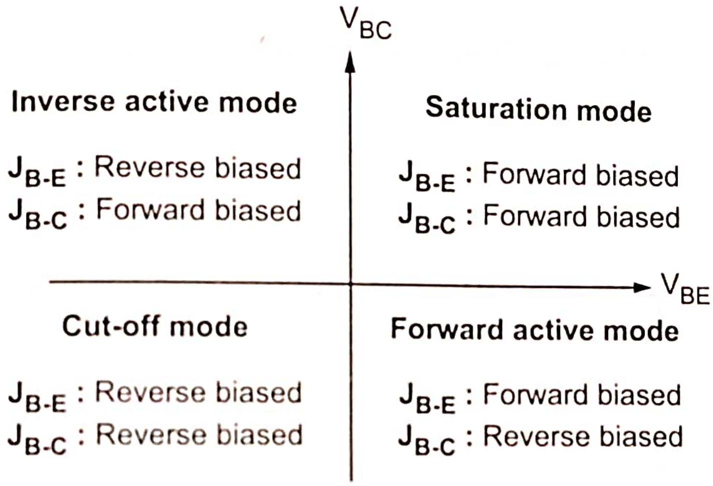
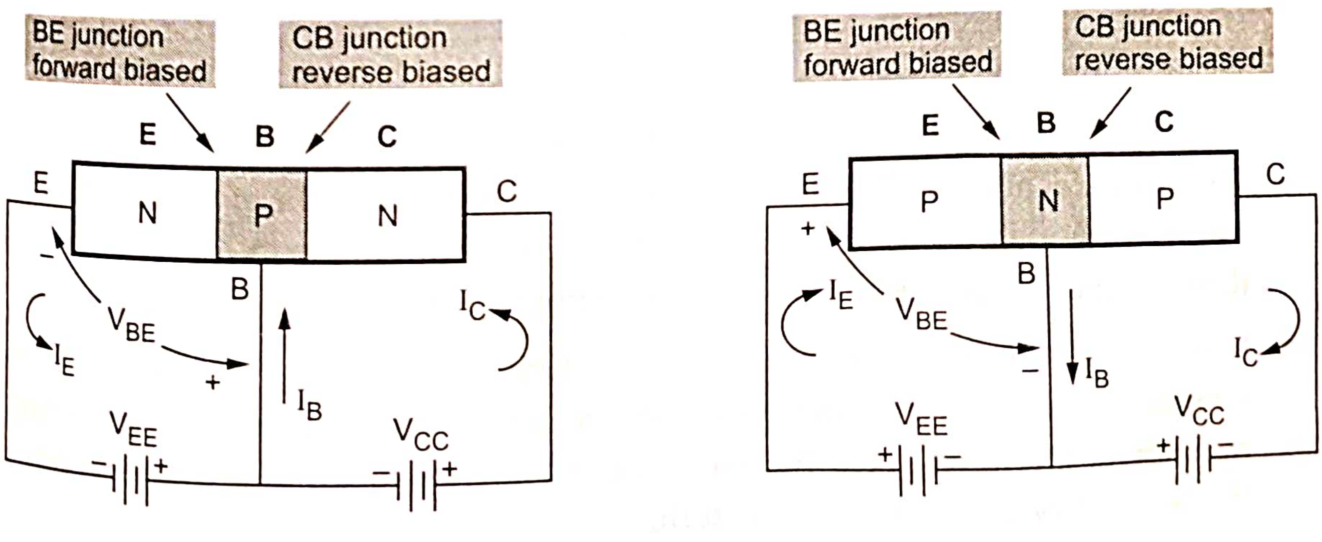



**Fig. 4.3.3 Biasing conditions for four operating modes of npn transistor**

- To bias the transistor in its active region, the emitter base junction is forward biased, while the collector-base junction in reverse-biased as shown in Fig. 4.3.4.
- The Fig. 4.3.4 shows the circuit connections for active region for both npn and pnp transistors.



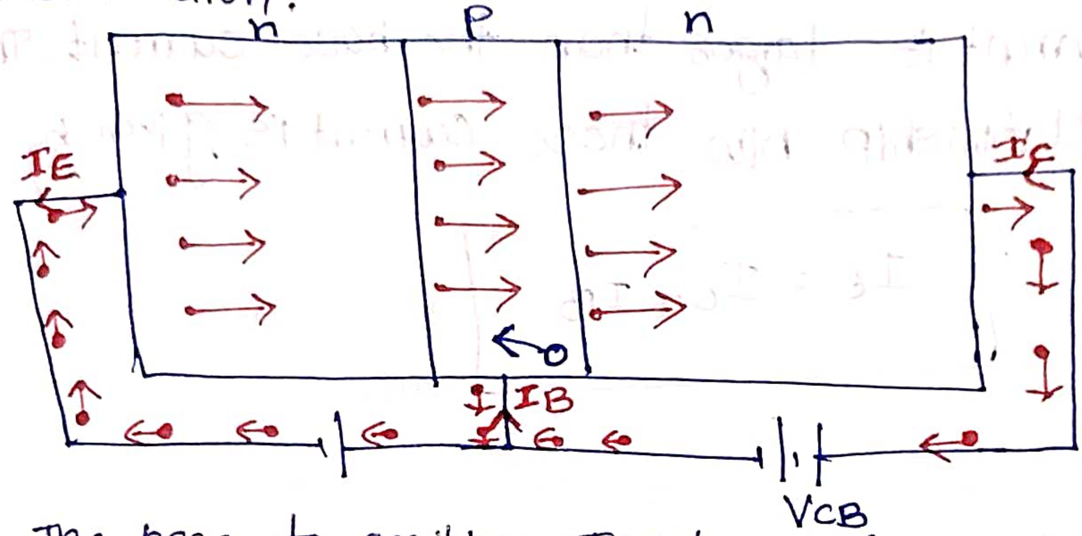

(a) npn

(b) pnp

- The externally applied bias voltages are $V_{EE}$ and $V_{CC}$, as shown in Fig. 4.3.4, which bias the transistor in its active region. The operation of the pnp is the same as for the npn except that the roles of the electrons and holes, the bias voltage polarities and the current directions are all reversed.
- Note that in both cases the base-emitter ($J_E$) junction is forward biased and the collector-base junction ($J_C$) is reversed biased.

* Operation of npn Transistor:-

→ Fig shows the npn transistor with forward biased to emitter base Junction and reverse biased to Collector base Junction.




→ The base to emitter Junction is forward biased by the D.C source VEB. Thus, The depletion Region at this Junction is reduced. This 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 in P-region.

→ Due to light doping, very few of the electrons injected into The base from the emitter recombine with holes to constitue base current $I_B$ and the remaing large number of electrons cross the base region and move through the collector region to The positive terminal of the external DC source.

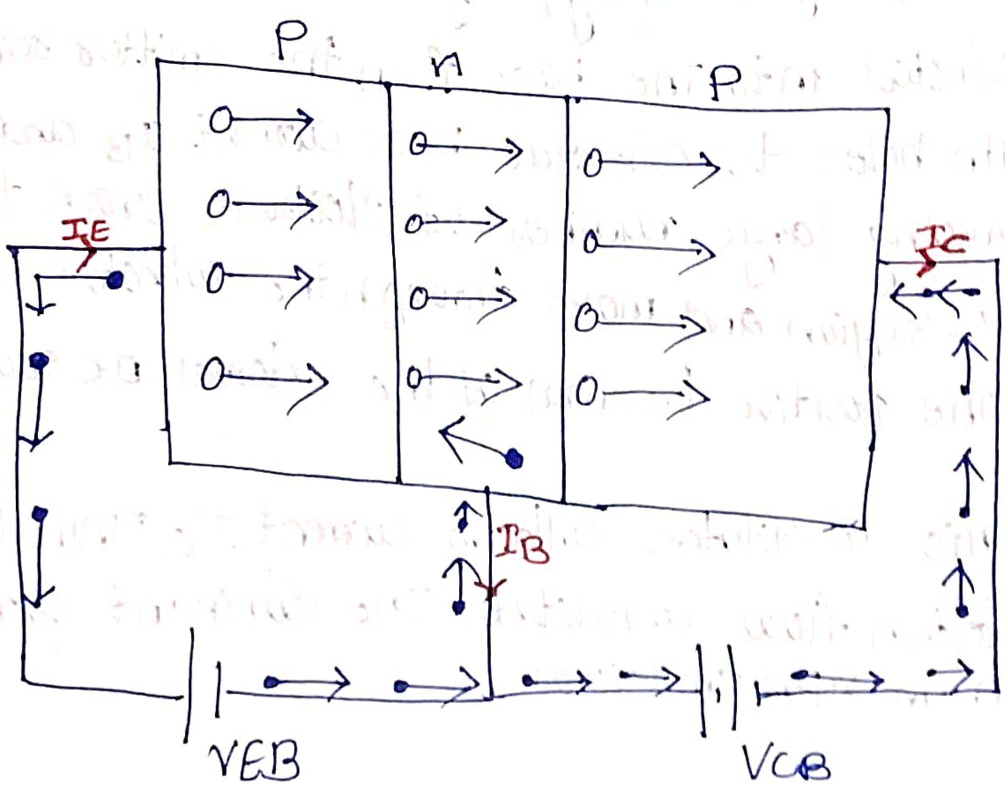
→ This constitutes collector current $I_C$. Thus the electron flow constitutes The dominant current in an npn Transistor.

→ Since, the most of the electrons from emitter flow in the collector circuit and very few combine with holes in the base. Thus, the collector current is larger than the base current. The relationship b/w these current is given by

$$\boxed{I_E = I_C + I_B}$$

* Operation of PNP Transistor:-

→ The base to emitter junction is forward biased by the d.c source $V_{EB}$. Thus the depletion region at this junction is reduced. The collector to base junction is reversed biased, increasing depletion region at collector to base junction as shown in fig.



→ The forward biased EB junction causes the holes in the p-type emitter to flow towards the base. This constitutes the emitter current $I_E$.

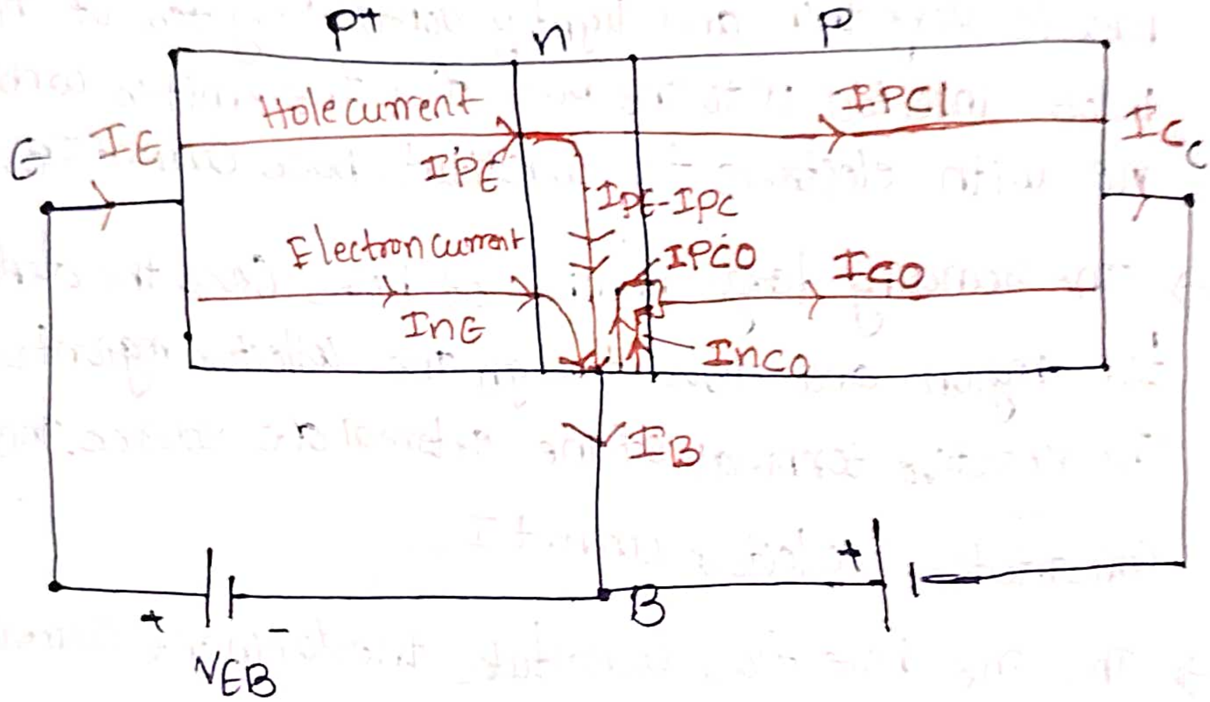
→ As these holes flow through the n-type base, they tend to combine with electrons in n-region. As the base is very thin and lightly doped, very few of the holes injected into the base from the emitter combine with electrons to constitute base current $I_B$.

→ The remaing large number of holes cross the depletion region and move through the collector region to the negative terminal of the external dc source. This constitutes collector current $I_C$.

→ Thus the hole flow constitutes the dominant current in an pnp transistor.

## * Transistor Current Component:-

→ The figure shows various current components in the PNP transistor which flow across the forward biased emitter base Junction ($J_E$) and reverse biased collector base Junction ($J_C$).




→ Since the emitter-base Junction $J_E$ is forward biased. the emitter will deliver current $I_E$. This $I_E$ has two components i.e ① The current $I_{PE}$, due to holes crossing from emitter to base. and (ii) The current $I_{nE}$, due to electrons crossing from base to emitter.

→ Since the direction of hole current $I_{PE}$ is positive, it is from left to right. The electron current $I_{nE}$ will be in the direction opposite to that of movement of electrons and therefore $I_{nE}$ will also be from left to right.

→ out of all the holes crossing $J_E$ to enter the base region, some of them recombine with electrons in the base region. Thus the numbers of holes get reduced.

→ The remaining holes cross $J_C$ and reach the Collector. Let the hole current crossing $J_C$ be $I_{PC}$

→ Hence the recombination current is equal to $I_{PE} - I_{PC}$. In a pnp transistor the actual $I_C$ will be coming out of the Collector.

→ The total current

$$I_E = I_C + I_B \quad — (1)$$

→ $$I_E = I_{PE} + I_{nE} \quad — (2)$$

$$I_C = I_{PC1} + I_{CO} \quad — (3)$$

$$I_{CO} = I_{PCO} + I_{nCO} \quad — (4)$$

$$I_{PC} = I_{PC1} + I_{CO} \quad — (5)$$

(a) Large signal current gain ($\alpha$) :- (current transfer Ratio)

→ $I_C = I_{PC1} + \cancel{I_{CO}}^{\to 0}$ → we know that $I_E = I_{PE} + \cancel{I_{nE}}^{\to 0}$

$\therefore I_{PC1} = \alpha I_{PE}$

$$\alpha = \frac{I_{PC1}}{I_{PE}} \quad — (1)$$

$$\boxed{\alpha = \frac{I_C}{I_E}}$$

(b) Emitter efficiency :- P type Emitter should inject max no. of holes into Base region.

$$\gamma = \frac{\text{Current of injected carriers at } J_E}{\text{total emitter current}}$$

$$\gamma = \frac{I_{PE}}{I_{PE}+I_{nE}} \cdot \left[\frac{I_{PE}}{I_E}\right]$$

$\boxed{I_{nE}=0}$

$$\boxed{\gamma = \frac{I_{PE}}{I_{PE}} = 1}$$

(c) Transport factor ($\beta$) :- [how many num of holes reached to the 'C']

$$\beta = \frac{\text{Current due to injected carriers reaching } J_C}{\text{Emitter Current}}$$

$$\boxed{\beta = \frac{I_{PC1}}{I_{PE}}}$$