shown. This d.c. voltage is known as bias voltage and its magnitude is such that it always keeps the input circuit forward biased regardless of the polarity of the signal.

As the input circuit has low resistance, therefore, a small change in signal voltage causes an appreciable change in emitter current. This causes almost the *same change in collector current due to transistor action. The collector current flowing through a high load resistance R_C produces a large voltage across it. Thus, a weak signal applied in the input circuit appears in the amplified form in the collector circuit. It is in this way that a transistor acts as an amplifier.

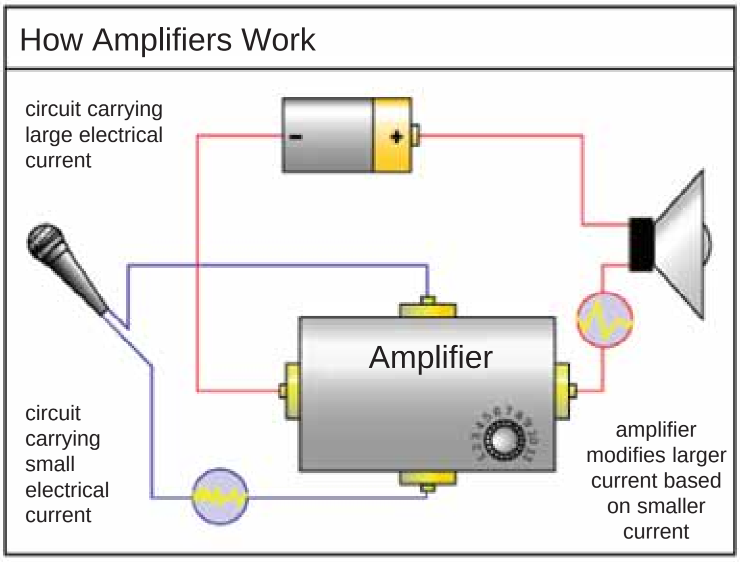

Illustration. The action of a transistor as an amplifier can be made more illustrative if we consider typical circuit values. Suppose collector load resistance R_C = 5 kΩ. Let us further assume that a change of 0.1V in signal voltage produces a change of 1 mA in emitter current. Obviously, the change in collector current would also be approximately 1 mA. This collector current flowing through collector load R_C would produce a voltage = 5 kΩ × 1 mA = 5 V. Thus, a change of 0.1 V in the signal has caused a change of 5 V in the output circuit. In other words, the transistor has been able to raise the voltage level of the signal from 0.1 V to 5 V *i.e.* voltage amplification is 50.

Example 8.1. *A common base transistor amplifier has an input resistance of 20 Ω and output resistance of 100 kΩ. The collector load is 1 kΩ. If a signal of 500 mV is applied between emitter and base, find the voltage amplification. Assume α_{ac} to be nearly one.*

Solution. **Fig. 8.8 shows the conditions of the problem. Note that output resistance is very high as compared to input resistance. This is not surprising because input junction (base to emitter) of the transistor is forward biased while the output junction (base to collector) is reverse biased.

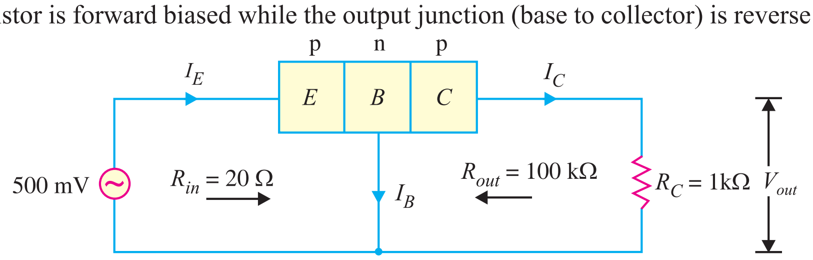

Fig. 8.8

* The reason is as follows. The collector-base junction is reverse biased and has a very high resistance of the order of mega ohms. Thus collector-base voltage has little effect on the collector current. This means that a large resistance R_C can be inserted in series with collector without disturbing the collector current relation to the emitter current *viz.* $I_C = \alpha I_E + I_{CBO}$. Therefore, collector current variations caused by a small base-emitter voltage fluctuations result in voltage changes in R_C that are quite high—often hundreds of times larger than the emitter-base voltage.

** The d.c. biasing is omitted in the figure because our interest is limited to amplification.

Input current, $I_E = \frac{\text{Signal}}{R_{in}} = \frac{500 \text{ mV}}{20 \ \Omega}$ = 25 mA. Since α_{ac} is nearly 1, output current, $I_C = I_E$ = 25 mA.

$$\text{Output voltage, } V_{out} = I_C R_C = 25 \text{ mA} \times 1 \text{ k}\Omega = 25 \text{ V}$$

$$\therefore \quad \text{Voltage amplification, } A_v = \frac{V_{out}}{\text{signal}} = \frac{25 \, V}{500 \, mV} = \mathbf{50}$$

Comments. The reader may note that basic amplifying action is produced by transferring a current from a *low-resistance* to a *high-resistance* circuit. Consequently, the name transistor is given to the device by combining the two terms given in magenta letters below :

Transfer + Res**istor** ⟶ **Transistor**

8.7 Transistor Connections

There are three leads in a transistor *viz.*, emitter, base and collector terminals. However, when a transistor is to be connected in a circuit, we 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 :

(*i*) common base connection (*ii*) common emitter connection

(*iii*) common collector connection

Each circuit connection has specific advantages and disadvantages. It may be noted here that regardless of circuit connection, the emitter is always biased in the forward direction, while the collector always has a reverse bias.

8.8 Common Base Connection

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. 8.9 (*i*), a common base *npn* transistor circuit is shown whereas Fig. 8.9 (*ii*) shows the common base *pnp* transistor circuit.

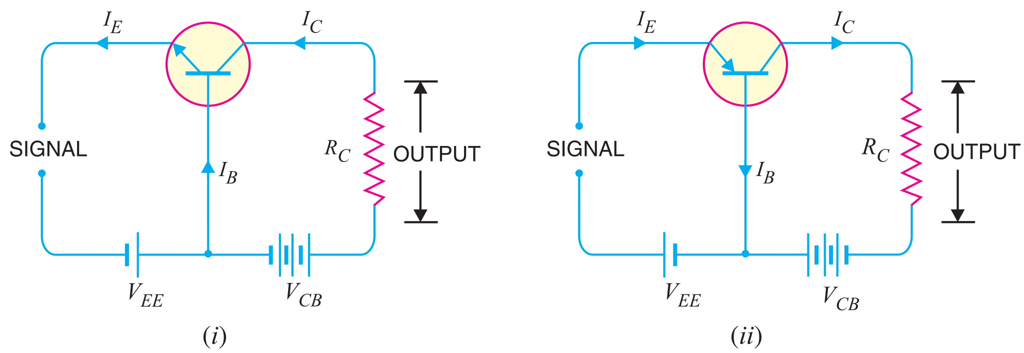

Fig. 8.9

1. Current amplification factor (α). It is the ratio of output current to input current. In a common base connection, the input current is the emitter current I_E and output current is the collector current I_C.

The ratio of change in collector current to the change in emitter current at constant collector-base voltage V_{CB} is known as **current amplification factor** *i.e.*

$$^{*}\alpha = \frac{\Delta I_C}{\Delta I_E} \text{ at constant } V_{CB}$$

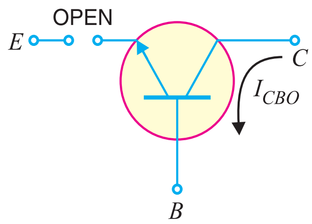

Fig. 8.10

It is clear that current amplification factor is less than **unity. This value can be increased (but not more than unity) by decreasing the base current. This is achieved by making the base thin and doping it lightly. Practical values of α in commercial transistors range from 0.9 to 0.99.

2. Expression for collector current. The whole of emitter current does not reach the collector. It is because a small percentage of it, as a result of electron-hole combinations occurring in base area, gives rise to base current. Moreover, as the collector-base junction is reverse biased, therefore, some leakage current flows due to minority carriers. It follows, therefore, that total collector current consists of :

(i) That part of emitter current which reaches the collector terminal *i.e.* ***αI_E.

(ii) The leakage current $I_{leakage}$. This current is due to the movement of minority carriers across base-collector junction on account of it being reverse biased. This is generally much smaller than αI_E.

∴ Total collector current, $I_C = \alpha I_E + I_{leakage}$

It is clear that if $I_E = 0$ (*i.e.*, emitter circuit is open), a small leakage current still flows in the collector circuit. This $I_{leakage}$ is abbreviated as I_{CBO}, meaning collector-base current with emitter open. The I_{CBO} is indicated in Fig. 8.10.

$$\therefore \quad I_C = \alpha I_E + I_{CBO} \quad \ldots(i)$$

$$\text{Now} \quad I_E = I_C + I_B$$

$$\therefore \quad I_C = \alpha (I_C + I_B) + I_{CBO}$$

$$\text{or} \quad I_C (1 - \alpha) = \alpha I_B + I_{CBO}$$

$$\text{or} \quad I_C = \frac{\alpha}{1-\alpha} I_B + \frac{I_{CBO}}{1-\alpha} \quad \ldots(ii)$$

Relation (*i*) or (*ii*) can be used to find I_C. It is further clear from these relations that the collector current of a transistor can be controlled by either the emitter or base current.

Fig. 8.11 shows the concept of I_{CBO}. In *CB* configuration, a small collector current flows even when the emitter current is zero. This is the leakage collector current (*i.e.* the collector current when emitter is open) and is denoted by I_{CBO}. When the emitter voltage V_{EE} is also applied, the various currents are as shown in Fig. 8.11 (*ii*).

Note. Owing to improved construction techniques, the magnitude of I_{CBO} for general-purpose and low-powered transistors (especially silicon transistors) is usually very small and may be neglected in calculations. However, for high power applications, it will appear in microampere range. Further, I_{CBO} is very much temperature dependent; it increases rapidly with the increase in temperature. Therefore, at higher temperatures, I_{CBO} plays an important role and must be taken care of in calculations.

---

* If only d.c. values are considered, then $\alpha = I_C/I_E$.

** At first sight, it might seem that since there is no current gain, no voltage or power amplification could be possible with this arrangement. However, it may be recalled that output circuit resistance is much higher than the input circuit resistance. Therefore, it does give rise to voltage and power gain.

*** $$\alpha = \frac{I_C}{I_E} \qquad \therefore \quad I_C = \alpha I_E$$

In other words, αI_E part of emitter current reaches the collector terminal.

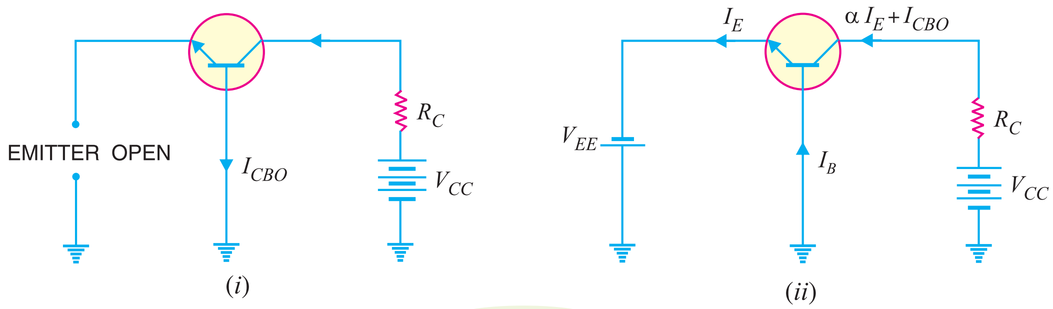

Fig. 8.11

Example 8.2. *In a common base connection, I_E = 1mA, I_C = 0.95mA. Calculate the value of I_B.*

Solution. Using the relation, $I_E = I_B + I_C$

or $1 = I_B + 0.95$

$\therefore$ $I_B = 1 - 0.95 = \mathbf{0.05\ mA}$

Example 8.3. *In a common base connection, current amplification factor is 0.9. If the emitter current is 1mA, determine the value of base current.*

Solution. Here, $\alpha = 0.9$, $I_E = 1$ mA

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

or $I_C = \alpha I_E = 0.9 \times 1 = 0.9$ mA

Also $I_E = I_B + I_C$

$\therefore$ Base current, $I_B = I_E - I_C = 1 - 0.9 = \mathbf{0.1\ mA}$

Example 8.4. *In a common base connection, I_C = 0.95 mA and I_B = 0.05 mA. Find the value of α.*

Solution. We know $I_E = I_B + I_C = 0.05 + 0.95 = 1$ mA

$\therefore$ Current amplification factor, $$\alpha = \frac{I_C}{I_E} = \frac{0.95}{1} = \mathbf{0.95}$$

Example 8.5. *In a common base connection, the emitter current is 1mA. If the emitter circuit is open, the collector current is 50 μA. Find the total collector current. Given that α = 0.92.*

Solution. Here, $I_E = 1$ mA, $\alpha = 0.92$, $I_{CBO} = 50$ μA

$\therefore$ Total collector current, $I_C = \alpha I_E + I_{CBO} = 0.92 \times 1 + 50 \times 10^{-3}$

$= 0.92 + 0.05 = \mathbf{0.97\ mA}$

Example 8.6. *In a common base connection, α = 0.95. The voltage drop across 2 kΩ resistance which is connected in the collector is 2V. Find the base current.*

Solution. Fig. 8.12 shows the required common base connection. The voltage drop across R_C (= 2 kΩ) is 2V.

$\therefore$ $I_C = 2\text{ V}/2\text{ k}\Omega = 1$ mA

Now $\alpha = I_C/I_E$

$$\therefore \quad I_E = \frac{I_C}{\alpha} = \frac{1}{0.95} = 1.05 \text{ mA}$$

Using the relation, $I_E = I_B + I_C$

$$\therefore \quad I_B = I_E - I_C = 1.05 - 1$$
$$= \mathbf{0.05\ mA}$$

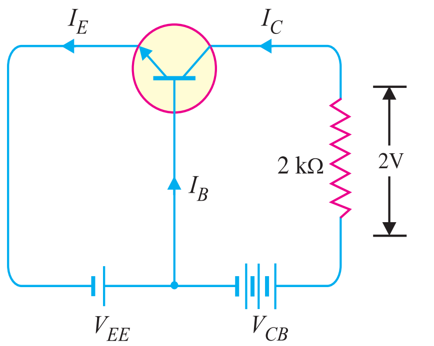

Fig. 8.12

Example 8.7. *For the common base circuit shown in Fig. 8.13, determine I_C and V_{CB}. Assume the transistor to be of silicon.*

Solution. Since the transistor is of silicon, $V_{BE} = 0.7$V. Applying Kirchhoff's voltage law to the emitter-side loop, we get,

$$V_{EE} = I_E R_E + V_{BE}$$

or $$I_E = \frac{V_{EE} - V_{BE}}{R_E}$$

$$= \frac{8V - 0.7V}{1.5 \text{ k}\Omega} = 4.87 \text{ mA}$$

$$\therefore \quad I_C \simeq I_E = \mathbf{4.87\ mA}$$

Applying Kirchhoff's voltage law to the collector-side loop, we have,

$$V_{CC} = I_C R_C + V_{CB}$$

$$\therefore \quad V_{CB} = V_{CC} - I_C R_C$$
$$= 18 \text{ V} - 4.87 \text{ mA} \times 1.2 \text{ k}\Omega = \mathbf{12.16\ V}$$

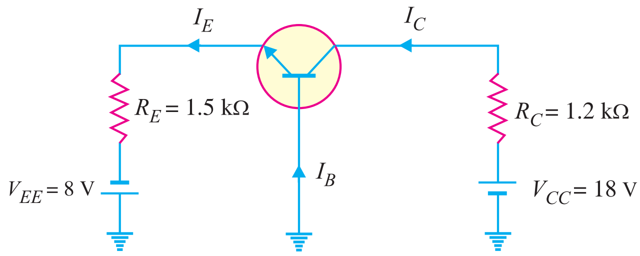

Fig. 8.13

8.9 Characteristics of Common Base Connection

The complete electrical behaviour of a transistor can be described by stating the interrelation of the various currents and voltages. These relationships can be conveniently displayed graphically and the curves thus obtained are known as the characteristics of transistor. The most important characteristics of common base connection are *input characteristics* and *output characteristics*.

1. Input characteristic. It is the curve between emitter current I_E and emitter-base voltage V_{EB} at constant collector-base voltage V_{CB}. The emitter current is generally taken along *y*-axis and emitter-base voltage along *x*-axis. Fig. 8.14 shows the input characteristics of a typical transistor in *CB* arrangement . The following points may be noted from these characteristics :

(i) The emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB}. It means that input resistance is very small.

(ii) The emitter current is almost independent of collector-base voltage V_{CB}. This leads to the conclusion that emitter current (and hence collector current) is almost independent of collector voltage.

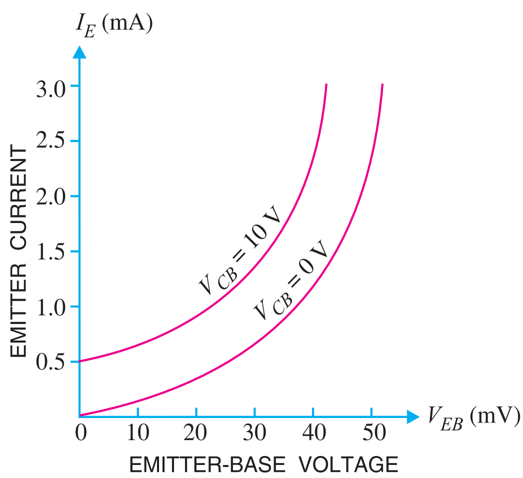

Fig. 8.14

Input resistance. It is the ratio of change in emitter-base voltage (ΔV_{EB}) to the resulting change in emitter current (ΔI_E) at constant collector-base voltage (V_{CB}) *i.e.*

$$\text{Input resistance, } r_i = \frac{\Delta V_{BE}}{\Delta I_E} \text{ at constant } V_{CB}$$

In fact, input resistance is the opposition offered to the signal current. As a very small V_{EB} is sufficient to produce a large flow of emitter current I_E, therefore, input resistance is quite small, of the order of a few ohms.

2. Output characteristic. It is the curve between collector current I_C and collector-base voltage V_{CB} at *constant emitter current I_E. Generally, collector current is taken along *y*-axis and collector-base voltage along *x*-axis. Fig. 8.15 shows the output characteristics of a typical transistor in *CB* arrangement.

The following points may be noted from the characteristics :

(i) The collector current I_C varies with V_{CB} only at very low voltages (< 1V). The transistor is *never* operated in this region.

(ii) 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. This is consistent with the theory that the emitter current flows *almost* entirely to the collector terminal. The transistor is *always* operated in this region.

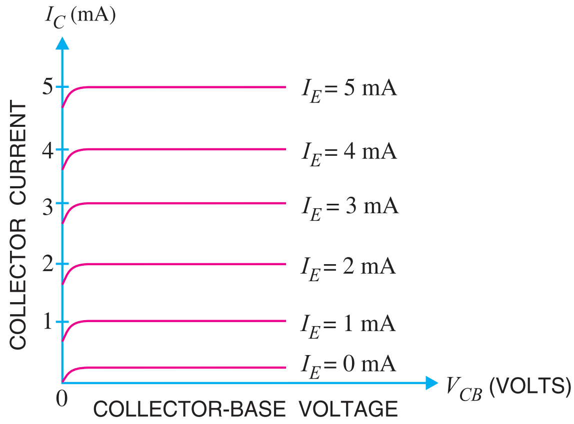

Fig. 8.15

(iii) A very large change in collector-base voltage produces only a tiny change in collector current. This means that output resistance is very high.

Output resistance. It is the ratio of change in collector-base voltage (ΔV_{CB}) to the resulting change in collector current (ΔI_C) at constant emitter current *i.e.*

$$\text{Output resistance, } r_o = \frac{\Delta V_{CB}}{\Delta I_C} \text{ at constant } I_E$$

The output resistance of *CB* circuit is very high, of the order of several tens of kilo-ohms. This is not surprising because the collector current changes very slightly with the change in V_{CB}.

8.10 Common Emitter Connection

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. 8.16 (*i*) shows common emitter *npn* transistor circuit whereas Fig. 8.16 (*ii*) shows common emitter *pnp* transistor circuit.

* I_E has to be kept constant because any change in I_E will produce corresponding change in I_C. Here, we are interested to see how V_{CB} influences I_C.

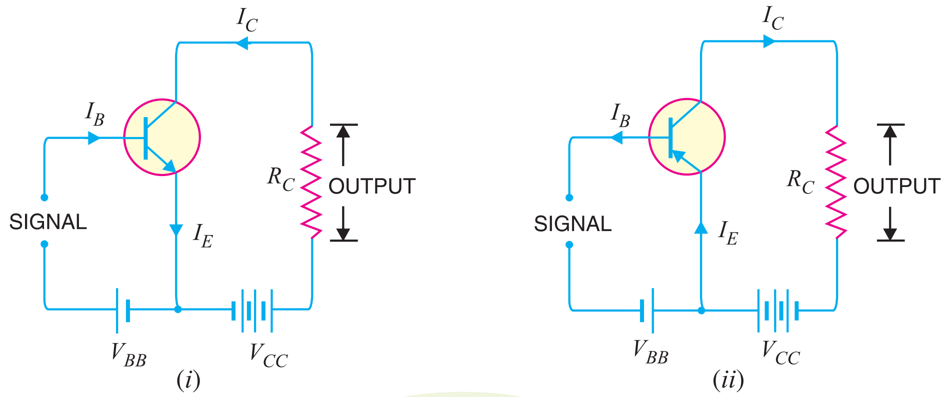

Fig. 8.16

1. Base current amplification factor (β). In common emitter connection, input current is I_B and output current is I_C.

The ratio of change in collector current (ΔI_C) *to the change in base current* (ΔI_B) *is known as* **base current amplification factor** *i.e.*

$$\beta^* = \frac{\Delta I_C}{\Delta I_B}$$

In almost any transistor, less than 5% of emitter current flows as the base current. Therefore, the value of β is generally greater than 20. Usually, its value ranges from 20 to 500. This type of connection is frequently used as it gives appreciable current gain as well as voltage gain.

Relation between β and α. A simple relation exists between β and α. This can be derived as follows :

$$\beta = \frac{\Delta I_C}{\Delta I_B} \quad \text{...(i)}$$

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{...(ii)}$$

Now $\qquad I_E = I_B + I_C$

or $\qquad \Delta I_E = \Delta I_B + \Delta I_C$

or $\qquad \Delta I_B = \Delta I_E - \Delta I_C$

Substituting the value of ΔI_B in exp. (*i*), we get,

$$\beta = \frac{\Delta I_C}{\Delta I_E - \Delta I_C} \quad \text{...(iii)}$$

Dividing the numerator and denominator of R.H.S. of exp. (*iii*) by ΔI_E, we get,

$$\beta = \frac{\Delta I_C / \Delta I_E}{\frac{\Delta I_E}{\Delta I_E} - \frac{\Delta I_C}{\Delta I_E}} = \frac{\alpha}{1-\alpha} \qquad \left[\because \alpha = \frac{\Delta I_C}{\Delta I_E}\right]$$

$$\therefore \quad \beta = \frac{\alpha}{1-\alpha}$$

It is clear that as α approaches unity, β approaches infinity. In other words, the current gain in common emitter connection is very high. It is due to this reason that this circuit arrangement is used in about 90 to 95 percent of all transistor applications.

* If d.c. values are considered, $\beta = I_C/I_B$.

2. Expression for collector current. In common emitter circuit, I_B is the input current and I_C is the output current.

$$\text{We know } I_E = I_B + I_C \qquad ...(i)$$

and
$$I_C = \alpha\, I_E + I_{CBO} \qquad ...(ii)$$

From exp. (*ii*), we get,
$$I_C = \alpha\, I_E + I_{CBO} = \alpha\,(I_B + I_C) + I_{CBO}$$

or
$$I_C\,(1-\alpha) = \alpha\, I_B + I_{CBO}$$

or
$$I_C = \frac{\alpha}{1-\alpha} I_B + \frac{1}{1-\alpha} I_{CBO} \qquad ...(iii)$$

From exp. (*iii*), it is apparent that if $I_B = 0$ (*i.e.* base circuit is open), the collector current will be the current to the emitter. This is abbreviated as I_{CEO}, meaning collector-emitter current with base open.

$$\therefore \qquad I_{CEO} = \frac{1}{1-\alpha} I_{CBO}$$

Substituting the value of $\frac{1}{1-\alpha} I_{CBO} = I_{CEO}$ in exp. (*iii*), we get,

$$I_C = \frac{\alpha}{1-\alpha} I_B + I_{CEO}$$

or
$$I_C = \beta\, I_B + I_{CEO} \qquad \left(\because \beta = \frac{\alpha}{1-\alpha}\right)$$

Concept of I_{CEO}. In *CE* configuration, a small collector current flows even when the base current is zero [See Fig. 8.17 (*i*)]. This is the collector cut off current (*i.e.* the collector current that flows when base is open) and is denoted by I_{CEO}. The value of I_{CEO} is much larger than I_{CBO}.

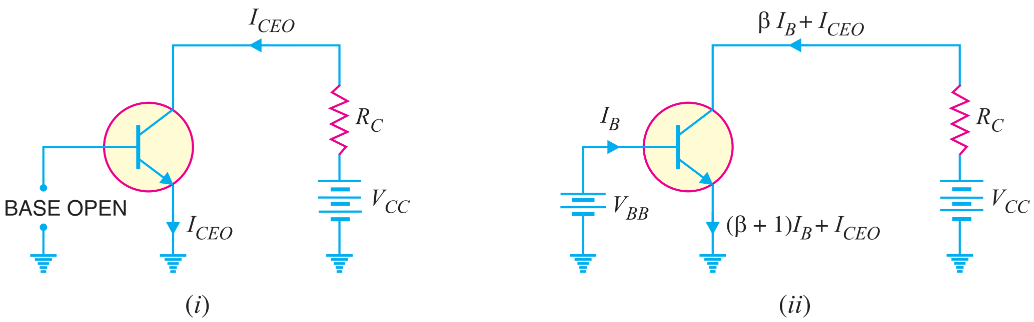

Fig. 8.17

When the base voltage is applied as shown in Fig. 8.17 (*ii*), then the various currents are :

Base current $= I_B$

Collector current $= \beta\, I_B + I_{CEO}$

Emitter current $=$ Collector current + Base current

$= (\beta\, I_B + I_{CEO}) + I_B = (\beta + 1)\, I_B + I_{CEO}$

It may be noted here that :

$$I_{CEO} = \frac{1}{1-\alpha} I_{CBO} = (\beta + 1)\, I_{CBO} \qquad \left[\because \frac{1}{1-\alpha} = \beta + 1\right]$$

8.11. Measurement of Leakage Current

A very small leakage current flows in all transistor circuits. However, in most cases, it is quite small and can be neglected.

(*i*) Circuit for I_{CEO} test. Fig. 8.18 shows the circuit for measuring I_{CEO}. Since base is open

($I_B = 0$), the transistor is in cut off. Ideally, $I_C = 0$ but actually there is a small current from collector to emitter due to minority carriers. It is called I_{CEO} (collector-to-emitter current with base open). This current is usually in the nA range for silicon. A faulty transistor will often have excessive leakage current.

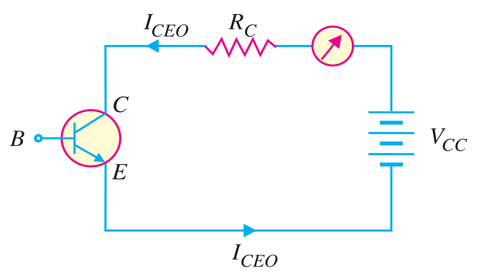

Fig. 8.18

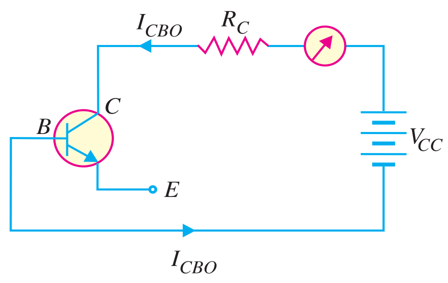

Fig. 8.19

***(ii)* Circuit for I_{CBO} test.** Fig. 8.19 shows the circuit for measuring I_{CBO}. Since the emitter is open ($I_E = 0$), there is a small current from collector to base. This is called I_{CBO} (collector-to-base current with emitter open). This current is due to the movement of minority carriers across base-collector junction. The value of I_{CBO} is also small. If in measurement, I_{CBO} is excessive, then there is a possibility that collector-base is shorted.

Example 8.8. *Find the value of β if (i) α = 0.9 (ii) α = 0.98 (iii) α = 0.99.*

Solution. (*i*)

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.9}{1-0.9} = \mathbf{9}$$

(*ii*)

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.98}{1-0.98} = \mathbf{49}$$

(*iii*)

$$\beta = \frac{\alpha}{1-\alpha} = \frac{0.99}{1-0.99} = \mathbf{99}$$

Example 8.9. *Calculate I_E in a transistor for which β = 50 and I_B = 20 μA.*

Solution. Here $\beta = 50, \quad I_B = 20\mu A = 0.02 \text{ mA}$

Now $\beta = \dfrac{I_C}{I_B}$

∴ $I_C = \beta I_B = 50 \times 0.02 = 1 \text{ mA}$

Using the relation, $I_E = I_B + I_C = 0.02 + 1 = \mathbf{1.02\ mA}$

Example 8.10. *Find the α rating of the transistor shown in Fig. 8.20. Hence determine the value of I_C using both α and β rating of the transistor.*

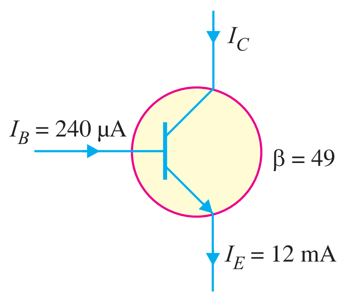

Fig. 8.20

Solution. Fig. 8.20 shows the conditions of the problem.

$$\alpha = \frac{\beta}{1+\beta} = \frac{49}{1+49} = \mathbf{0.98}$$

The value of I_C can be found by using either α or β rating as under :

$$I_C = \alpha I_E = 0.98 \text{ (12 mA)} = \mathbf{11.76\ mA}$$

Also $I_C = \beta I_B = 49 \text{ (240 μA)} = \mathbf{11.76\ mA}$

Example 8.11. *For a transistor, β = 45 and voltage drop across 1kΩ which is connected in the collector circuit is 1 volt. Find the base current for common emitter connection.*

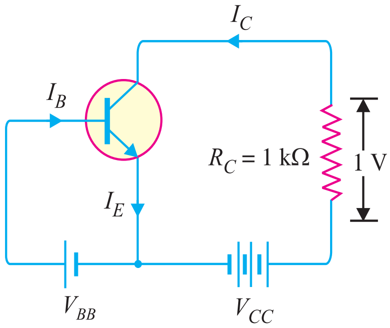

Fig. 8.21

Solution. Fig. 8.21 shows the required common emitter connection. The voltage drop across R_C (= 1 kΩ) is 1volt.

$$\therefore \quad I_C = \frac{1\,V}{1\,k\Omega} = 1 \text{ mA}$$

$$\text{Now} \quad \beta = \frac{I_C}{I_B}$$

$$\therefore \quad I_B = \frac{I_C}{\beta} = \frac{1}{45} = \mathbf{0.022 \text{ mA}}$$

Example 8.12. *A transistor is connected in common emitter (CE) configuration in which collector supply is 8V and the voltage drop across resistance R_C connected in the collector circuit is 0.5V. The value of R_C = 800 Ω. If α = 0.96, determine :*

(i) collector-emitter voltage

(ii) base current

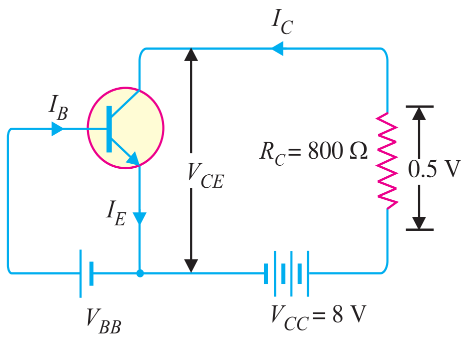

Fig. 8.22

Solution. Fig. 8.22 shows the required common emitter connection with various values.

(*i*) Collector-emitter voltage,

$$V_{CE} = V_{CC} - 0.5 = 8 - 0.5 = \mathbf{7.5 \text{ V}}$$

(*ii*) The voltage drop across R_C (= 800 Ω) is 0.5 V.

$$\therefore \quad I_C = \frac{0.5 \text{ V}}{800\ \Omega} = \frac{5}{8} \text{ mA} = 0.625 \text{ mA}$$

$$\text{Now} \quad \beta = \frac{\alpha}{1-\alpha} = \frac{0.96}{1-0.96} = 24$$

$$\therefore \text{ Base current, } I_B = \frac{I_C}{\beta} = \frac{0.625}{24} = \mathbf{0.026 \text{ mA}}$$

Example 8.13. *An n-p-n transistor at room temperature has its emitter disconnected. A voltage of 5V is applied between collector and base. With collector positive, a current of 0.2 μA flows. When the base is disconnected and the same voltage is applied between collector and emitter, the current is found to be 20 μA. Find α, I_E and I_B when collector current is 1mA.*

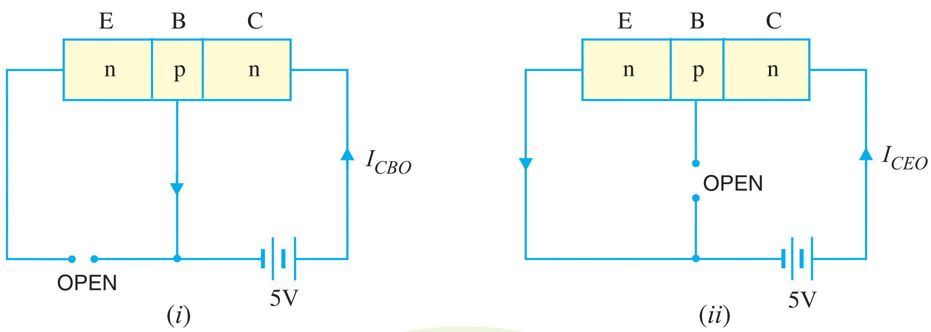

Fig. 8.23

Solution. When the emitter circuit is open [See Fig. 8.23 (*i*)], the collector-base junction is reverse biased. A small leakage current I_{CBO} flows due to minority carriers.

$\therefore \quad I_{CBO} = 0.2\ \mu A$ ...*given*

When base is open [See Fig. 8.23 (*ii*)], a small leakage current I_{CEO} flows due to minority carriers.

$\therefore \quad I_{CEO} = 20\ \mu A$ . . . *given*

We know $\quad I_{CEO} = \dfrac{I_{CBO}}{1-\alpha}$

or $\quad 20 = \dfrac{0.2}{1-\alpha}$

$\therefore \quad \alpha = \mathbf{0.99}$

Now $\quad I_C = \alpha I_E + I_{CBO}$

Here $\quad I_C = 1\text{mA} = 1000\ \mu A\ ;\ \alpha = 0.99\ ;\ I_{CBO} = 0.2\ \mu A$

$\therefore \quad 1000 = 0.99 \times I_E + 0.2$

or $\quad I_E = \dfrac{1000-0.2}{0.99} = \mathbf{1010\ \mu A}$

and $\quad I_B = I_E - I_C = 1010 - 1000 = \mathbf{10\ \mu A}$

Example 8.14. *The collector leakage current in a transistor is 300 μA in CE arrangement. If now the transistor is connected in CB arrangement, what will be the leakage current? Given that β = 120.*

Solution. $\quad I_{CEO} = 300\ \mu A$

$\beta = 120\ ;\ \alpha = \dfrac{\beta}{\beta+1} = \dfrac{120}{120+1} = 0.992$

Now, $\quad I_{CEO} = \dfrac{I_{CBO}}{1-\alpha}$

$\therefore \quad I_{CBO} = (1-\alpha)\, I_{CEO} = (1-0.992) \times 300 = \mathbf{2.4\ \mu A}$

Note that leakage current in *CE* arrangement (*i.e.* I_{CEO}) is much more than in *CB* arrangement (*i.e.* I_{CBO}).

Example 8.15. *For a certain transistor,* $I_B = 20\ \mu A$*;* $I_C = 2$ *mA and* $\beta = 80$*. Calculate* I_{CBO}.

Solution.

$I_C = \beta I_B + I_{CEO}$

or $\quad 2 = 80 \times 0.02 + I_{CEO}$

$\therefore \quad I_{CEO} = 2 - 80 \times 0.02 = 0.4$ mA

Now $\quad \alpha = \dfrac{\beta}{\beta+1} = \dfrac{80}{80+1} = 0.988$

$\therefore \quad I_{CBO} = (1-\alpha)\, I_{CEO} = (1-0.988) \times 0.4 = \mathbf{0.0048\ mA}$

Example 8.16. *Using diagrams, explain the correctness of the relation* $I_{CEO} = (\beta + 1)\, I_{CBO}$.

Solution. The leakage current I_{CBO} is the current that flows through the base-collector junction when emitter is open as shown is Fig. 8.24. When the transistor is in *CE* arrangement, the *base current (*i.e.* I_{CBO}) is multiplied by β in the collector as shown in Fig. 8.25.

$\therefore \quad I_{CEO} = I_{CBO} + \beta I_{CBO} = (\beta + 1)\, I_{CBO}$

* The current I_{CBO} is amplified because it is forced to flow across the base-emitter junction.