CONTENTS

CHAPTER 57

Learning Objectives

- Bipolar Junction Transistor
- Transistor Biasing
- Transistor Currents
- Transistor Circuit Configurations
- CB Configuration
- CE Configuration
- Relation between α and β
- CC Configuration
- Relation between Transistor Currents
- Leakage Currents in a Transistor
- Thermal Runaway
- Transistor Static Characteristics
- Common Base Test Circuit
- Common Base Static Characteristics
- Common Emitter Static Characteristics
- Common Collector Static Characteristic
- Different Ways of Drawing Transistor Circuits
- The Beta Rule
- Importance of V_{CE}
- Cut-off and Saturation Points
- BJT Operating Regions
- Active Region DC Model of BJT
- BJT Switches
- Normal DC Voltage Transistor Indications
- Transistor Fault Location
- Increase/Decrease Notation

CONTENTS

BIPOLAR JUNCTION TRANSISTOR

Bipolar junction transistor is used in two broad areas-as a linear amplifier to boost or amplify an electrical signal and as an electronic switch

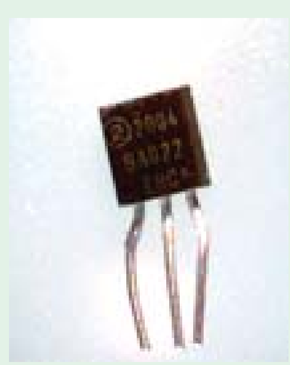
57.1. Bipolar Junction Transistor

The transistor was invented by a team of three scientists at Bell Laboratories, USA in 1947. Although the first transistor was not a bipolar junction device, yet it was the beginning of a technological revolution that is still continuing in the twenty first century. All of the complex electronic devices and systems developed or in use today, are an outgrowth of early developments in semiconductor transistors.

There are two basic types of transistors : **(1)** the bipolar junction transistor (BJT) which we will study in this chapter and the field-effect transistor (FET) which is covered in chapter 13. The bipolar junction transistor is used in two broad areas of electronics : **(1)** as a linear amplifier to boost an electrical signal and **(2)** as an electronic switch.

Basically, the bipolar junction transistor consists of two back-to-back *P-N* junctions manufactured in a single piece of a semiconductor crystal. These two junctions give rise to three regions called ***emitter, base*** and ***collector.*** As shown in Fig. 57.1 (*a*) junction transistor is simply a sandwich of one type of semiconductor material between two layers of the other type. Fig. 57.1 (*a*) shows a layer of *N*-type material sandwiched between two layers of *P*-type material. It is described as a *PNP* transistor. Fig. 57.1 (*b*) shown an *NPN* – transistor consisting of a layer of *P*-type material sandwiched between two layers of *N*-type material.

The emitter, base and collector are provided with terminals which are labelled as *E*, *B* and *C*. The two junctions are : emitter-base (*E*/*B*) junction and collector-base (*C*/*B*) junction.



Bipolar junction transistor

The symbols employed for *PNP* and *NPN* transistors are also shown in Fig. 57.1. The arrowhead is always at the emitter (not at the collector) and in each case, its direction indicates the ***conventional*** direction of current flow. For a *PNP* transistor, arrowhead points from emitter to base meaning that emitter is positive with respect to base (and also with respect to collector)* For *NPN* transistor, it points from base to emitter meaning that base (and collector as well)* is positive with respect to the emitter.

1. Emitter

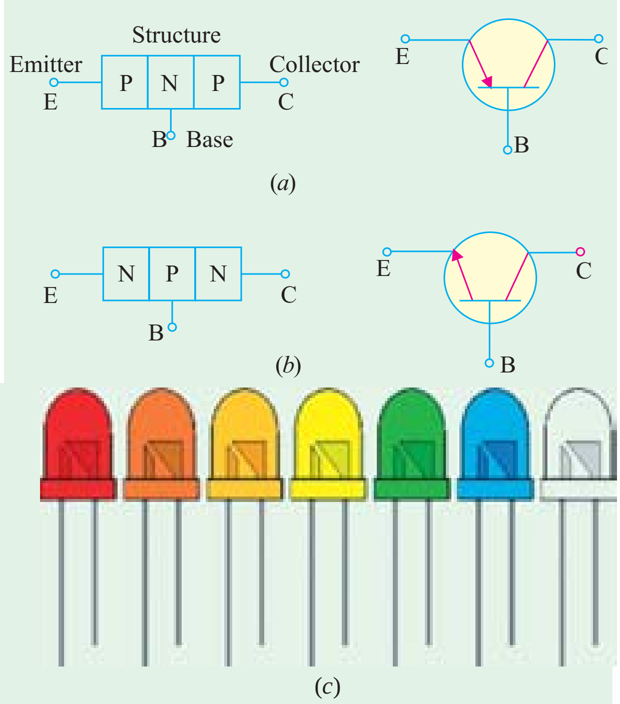
It is more heavily doped than any of the other regions because its main function is to supply majority charge carries (either electrons or holes) to the base.

2. Base

It forms the middle section of the transistor. It is very thin (10^{-6} m) as compared to either the emitter or collector and is very ***lightly-doped.***

3. Collector

Its main function (as indicated by its name) is to collect majority charge carriers coming from the emitter and passing through the base.



(*a*)

(*b*)

(*c*)

Fig. 57.1

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* In a transistor, for normal operation, collector and base have the same polarity with respect to the emitter (Art. 57.3)

In most transistors, collector region is made physically larger than the emitter region because it has to dissipate much greater power. Because of this difference, there is no possibility of inverting the transistor *i.e.* making its collector the emitter and its emitter the collector. Fig 57.1 (*c*), shows the picture of C1815 (front and the back view) transistor.

57.2. Transistor Biasing

For proper working of a transistor, it is essential to apply voltages of correct polarity across its two junctions. It is worthwhile to remember that for normal operation;

1. emitter-base junction is always forward-biased and

2. collector-base junction is always reverse-biased.

This type of biasing is known as *FR* biasing.

In Fig. 57.2, two batteries respectively provide the dc emitter supply voltage V_{EE} and collector supply voltage V_{CC} for properly biasing the two junctions of the transistor. In Fig. 57.2 (*a*), **P**ositive terminal of V_{EE} is connected to **P**-type emitter in order to repel or **P**ush holes into the base.

The negative terminal of V_{CC} is connected to the collector so that it may ***attract*** or ***pull*** holes through the base. Similar considerations apply to the *NPN* transistor of Fig. 57.2 (*b*). It must be remembered that a transistor will never conduct any current if its emitter-base junction is not forward-biased.* Also refer to the picture shown in Fig. 57.2 (*c*).

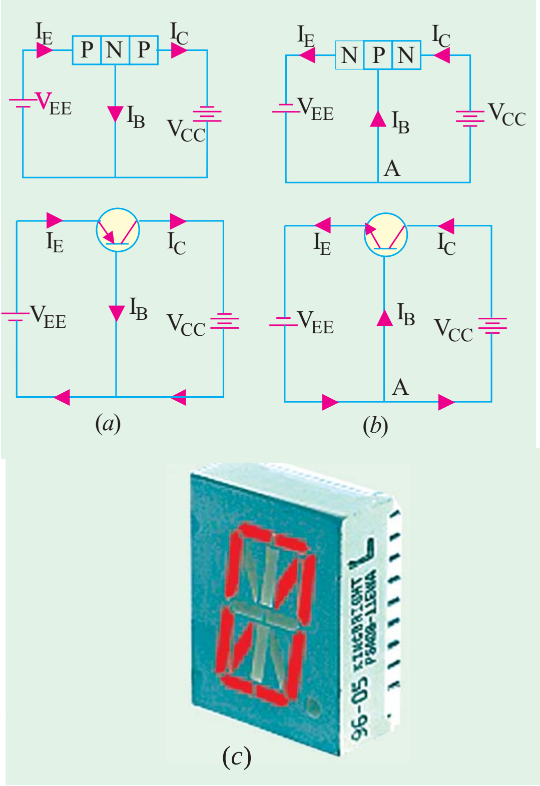

Fig. 57.2

57.3. Important Biasing Rule

For a *PNP* transistor, both collector and base are negative with respect to the emmitter (the letter *N* of Negative being the same as the middle letter of *PNP*). Of course, collector is ***more negative*** than base [Fig. 57.3 (*a*)]. Similarly, for *NPN* transistor, both collector and base are positive with respect to the emitter (the letter **P** of **P**ositive being the same as the middle letter of *N***P***N*). Again, collector is ***more positive*** than the base as shown in Fig. 57.3 (*b*).

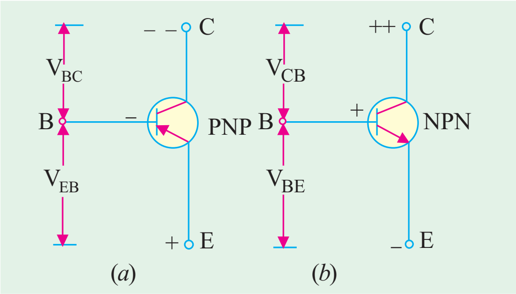

Fig. 57.3

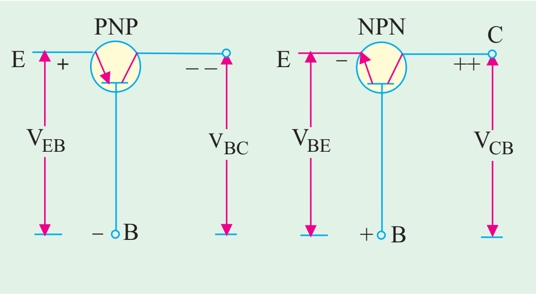

Fig. 57.4

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* There would be no current due to majority charge carriers. However, there would be an extremely small current due to minority charge carriers which is called leakage current of the transistor (Art. 57.12).

It may be noted that different potentials have been designated by double subscripts. The first subscript always represents the point or terminal which is more positive (or less negative) than the point or terminal represented by the second subscript. For example, in Fig. 57.3 (*a*), the potential difference between emitter and base is written as V_{EB} (and not V_{BE}) because ***emitter is positive with respect to base.*** Now, between the base and collector themselves, collector is more negative than base. Hence, their potential difference is written as V_{BC} and not as V_{CB}. Same is the case with voltages marked in Fig. 57.4.

57.4. Transistor Currents

The three primary currents which flow in a properly-biased transistor are I_E, I_B and I_C. In Fig. 57.5 (*a*) are shown the directions of flow as well as relative magnitudes of these currents for a *PNP* transistor connected in the common-base mode. It is seen that again,

$$I_E = I_B + I_C$$

It means that a small part (about 1—2%) of emitter current goes to supply base current and the remaining major part (98—99%) goes to supply collector current.

Moreover, I_E flows into the transistor whereas both I_B and I_C flow out of it.

Fig. 57.5 (*b*) shows the flow of currents in the same transistor when connected in the common-emitter mode. It is seen that again, $I_E = I_B + I_C$

By normal convention, currents flowing ***into*** a transistor are taken as positive whereas those flowing ***out*** of it are taken as negative. Hence, I_E is positive whereas both I_B and I_C are negative. Applying Kirchhoff's Current Law, we have

$$I_E + (-I_B) + (-I_C) = 0 \quad \text{or} \quad I_E - I_B - I_C = 0 \quad \text{or} \quad I_E = I_B + I_C$$

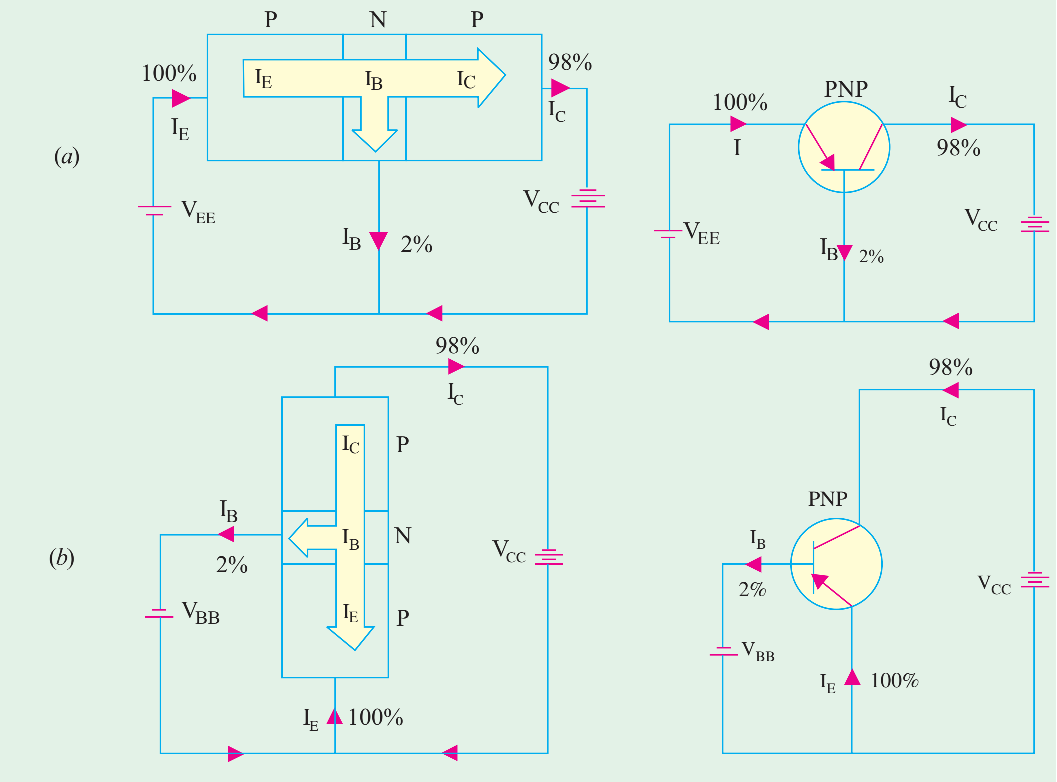


Fig. 57.5

This statement is true ***regardless of transistor type or transistor configuration.***

Note. For the time being, we have not taken into account the leakage currents which exist in a transistor (Art. 57.12).

57.5. Summing Up

The four basic guideposts about all transistor circuits are :

1. conventional current flows along the arrow whereas electrons flow against it;
2. *E/B* junction is always forward-biased;
3. *C/B* junction is always reverse-biased; **4.** $I_E = I_B + I_C$.

57.6. Transistor Circuit Configurations

Basically, there are three types of circuit connections (called configurations) for operating a transistor.

1. common-base (*CB*), **2.** common-emitter (*CE*), **3.** common-collector (*CC*).

The term 'common' is used to denote the electrode that is common to the input and output circuits. Because the common electrode is generally grounded, these modes of operation are frequently referred to as grounded-base, grounded-emitter and grounded-collector configurations as shown in Fig. 57.6 for a *PNP* – transistor.

Since a transistor is a 3-terminal (and not a 4-terminal) device, one of its terminals has to be common to the input and output circuits.

57.7. CB Configuration

In this configuration, emitter current I_E is the input current and collector current I_C is the output current. The input signal is applied between the emitter and base whereas output is taken out from the collector and base as shown in Fig. 57.6 (*a*).

The ratio of the collector current to the emitter current is called dc alpha (α_{dc}) of a transistor.

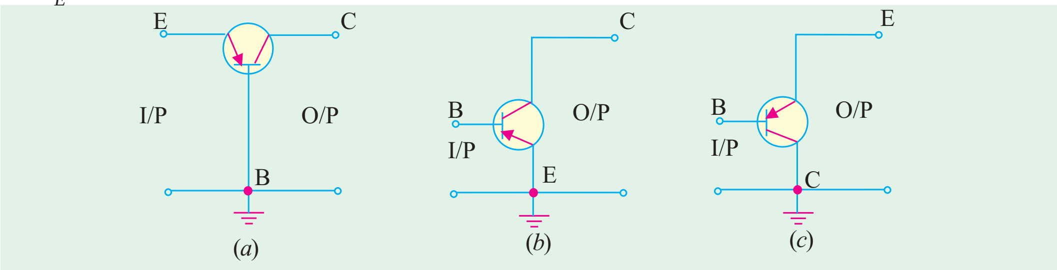
$$\therefore \qquad \alpha_{dc}{}^{*} = \frac{-I_C}{I_E}$$

The negative sign is due to the fact that current I_E flows into the transistor whereas I_C flows out of it. Hence, I_E is taken as positive and I_C as negative.

$$\therefore \qquad I_C = -\,\alpha_{dc} . I_E$$

If we write adc simply as α**, then $\alpha = I_E / I_C$

It is also called forward current transfer ratio ($-h_{FB}$). In h_{FB}, subscript *F* stands for forward and *B* for common-base. The subscript d.c. on a signifies that this ratio is defined from dc values of I_C and I_E.



(*a*) (*b*) (*c*)

Fig. 57.6

The α of a tranistor is a measure of the quality of a transistor ; higher the value of α, better the transistor in the sense that collector current more closely equals the emitter current. Its value ranges

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* More accurately, $\alpha_{dc} = \dfrac{I_C - I_{CBO}}{I_E}$ ...Art.57.12

** Negative sign has been omitted, since we are here concerned with only magnitudes of the currents involved.

from 0.95 to 0.999. Obviously, it applies only to *CB* configuration of a transistor. As seen from above and Fig. 57.7.

$$I_C = \alpha I_E. \qquad \text{Now,} \quad I_B = I_E - \alpha I_E = (1-\alpha) I_E$$

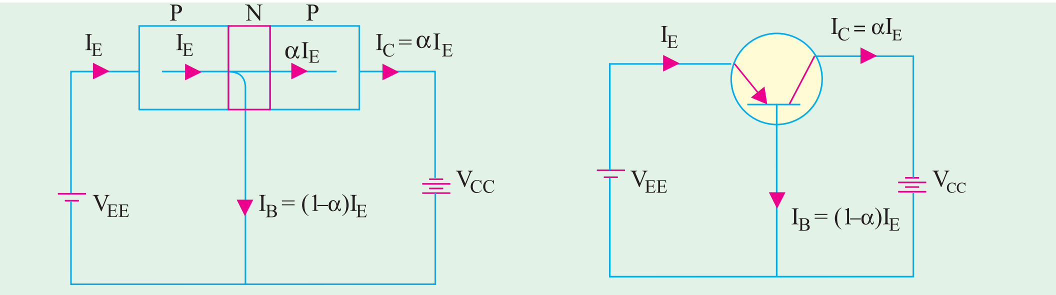


Fig. 57.7

Incidentally, there is also an a.c. α for a transistor. It refers to the ratio of ***change*** in collector current to the ***change*** in emitter current.

$$\therefore \qquad \alpha_{ac} = \frac{-\Delta I_C}{\Delta I_E}$$

It is also, known as short-circuit gain of a transistor and is written as $-h_{fb}$. It may be noted that upper case subscript '*FB*' indicates dc value whereas lower case subscript '*fb*' indicates ac value. For all practical purposes, $\alpha_{dc} = \alpha_{ac} = \alpha$.

Example 57.1. *Following current readings are obtained in a transistor connected in CB configuration :* $I_E = 2$ *mA and* $I_B = 20$ *mA. Compute the values of* α *and* I_C.

(Electronics-II, Punjab Univ. 1992)

Solution. $I_C = I_E - I_B = 2 \times 10^{-3} - 20 \times 10^{-6} =$ **1.98 mA**

$\alpha = I_C / I_E = 1.98/2 =$ **0.99**

57.8. CE Configuration

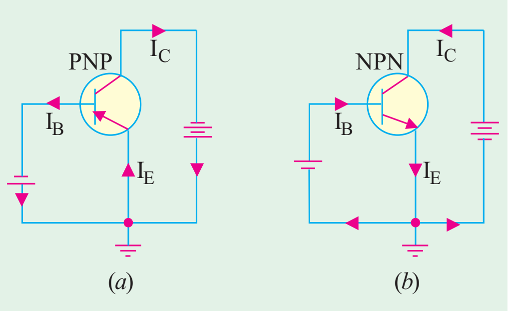
Here, input signal is applied between the base and emitter and output signal is taken out from the collector and emitter circuit. As seen from Fig. 57.6 (*b*), I_B is the input current and I_C is the output current.

The ratio of the d.c. collector current to dc base current is called dc beta (β_{dc}) or just β of the transistor.

$$\therefore \qquad \beta = -I_C/-I_B = I_C/I_B \qquad \text{or}$$

$I_C = \beta I_B$ — Fig. 57.8 (*a*)

It is also called common-emitter d.c. ***forward transfer ratio*** and is written as h_{FE}. It is possible for β to have as high a value as 500.



(*a*) (*b*)

Fig. 57.8

While analysing ac operation of a transistor, we use ac β which is given by $\beta_{ac} = \Delta I_C / \Delta I_B$.

It is also written as h_{fe}.

The flow of various currents in a *CE* configuration both for *PNP* and *NPN* transistor is shown in Fig. 57.8. As seen

$$I_E = I_B + I_C = I_B + \beta I_B = (1+\beta) I_B$$

57.9. Relation Between α and β

$$\beta = \frac{I_C}{I_B} \qquad \text{and} \qquad \alpha = \frac{I_C}{I_E} \qquad \therefore \qquad \frac{\beta}{\alpha} = \frac{I_E}{I_B} \qquad \text{— only numerical value of } \alpha$$

Now, $I_B = I_E - I_C$ $\quad\therefore\quad$ $\beta = \frac{I_C}{I_E - I_C} = \frac{I_C / I_E}{I_E / I_E - I_C / I_E}$ or $\beta = \frac{\alpha}{1 - \alpha}$

Cross-multiplying the above equation and simplifying it, we get
$\beta\,(1 - a) = \alpha$ or $\beta = \alpha\,(1 + \beta)$ or $\alpha = \beta / (1 + \beta)$
It is seen from the about 2 equations that $1 - \alpha = 1/(1 + \beta)$

57.10. CC Configuration

In this case, input signal is applied between base and collector and output signal is taken out from emitter-collector circuit [Fig. 57.6 (*c*)]. Conventionally speaking, here I_B is the input current and I_E is the output current as shown in Fig. 57.9. The current gain of the circuit is

$$\frac{I_E}{I_B} = \frac{I_E}{I_C}\cdot\frac{I_C}{I_B} = \frac{\beta}{\alpha} = \frac{\beta}{\beta/(1+\beta)} = (1 + \beta)$$

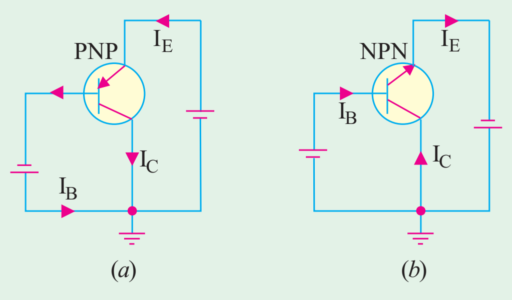


Fig. 57.9

The flow paths of various currents in a *CC* configuration are shown in Fig. 57.9. It is seen that $I_E = I_B + I_C = I_B + \beta I_B = (1 + \beta)I_B$

∴ output current = (1 + β) × input current.

57.11. Relations Between Transistor Currents

While deriving various equations, following definitions should be kept in mind.

$$\alpha = \frac{I_C}{I_E}\ , \qquad \beta = \frac{I_C}{I_B}\ , \quad \alpha = \frac{\beta}{(1+\beta)} \text{ and } \beta = \frac{\alpha}{(1-\alpha)}$$

(*i*) $I_C = \beta\, I_B = \alpha I_E = \frac{\beta}{1+\beta} I_E$ **(*ii*)** $I_B = \frac{I_C}{\beta} = \frac{I_E}{1+\beta} = (1-\alpha) I_E$

(*iii*) $I_E = \frac{I_C}{\alpha} = \frac{1+\beta}{\beta} I_C = (1+\beta)\ I_B = \frac{I_B}{(1-\alpha)}$

(*iv*) The three transistor d.c. currents always bear the following ratio*
$I_E : I_B : I_C \quad :: \quad 1 : (1 - \alpha) : \alpha$
Incidentally, it may be noted that for ac currents, small letters i_e, i_b and i_c are used.

57.12. Leakage Currents in a Transistor

(*a*) CB Circuit

Consider the *CB* transistor circuit shown in Fig. 57.11. The emitter current (due to majority carriers) initiated by the forward-biased emitter base junction is split into two parts :

(*i*) $(1 - \alpha)\ I_E$ which becomes base current I_B in the external circuit and

(*ii*) αI_E which becomes collector current I_C in the external circuit.

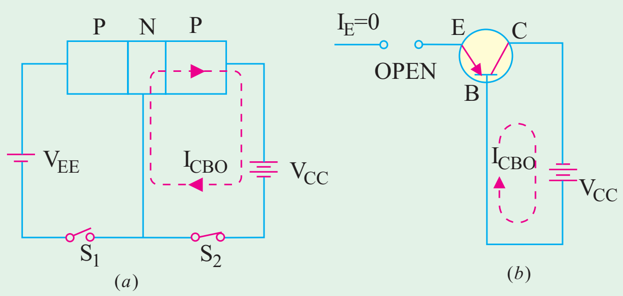


Fig. 57.10

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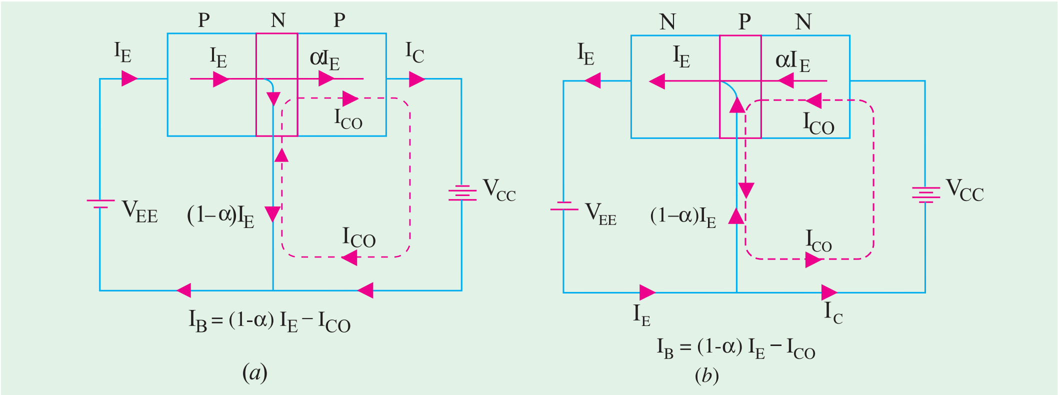
* It reminds us of the power distribution relationship in an induction motor.

As mentioned earlier (Art. 57.2), though *C/B* junction is reverse-biased for majority charge carriers (*i.e.* holes in this case), it is forward-biased so far as thermally-generated minority charge carriers (*i.e.* electrons in this case) are concerned. This current flows even when emitter is disconnected from its dc supply as shown in Fig. 57.10 (*a*) where switch, S_1 is open. It flows in the ***same*** direction* as the collector current of majority carriers. It is called leakage current I_{CBO}. The subscripts *CBO* stand for 'Collector to Base with emitter Open.' Very often, it is simply written as I_{CO}.



(*a*) (*b*)

Fig. 57.11

It should be noted that

(*i*) I_{CBO} is exactly like the reverse saturation current I_S or I_0 of a reverse-biased diode discussed in Art. 57.1.

(*ii*) I_{CBO} is extremely temperature-dependent because it is made up of thermally-generated minority carriers. As mentioned earlier, I_{CBO} doubles for every 10°C rise in temperature for *Ge* and 6°C for *Si*.

If we take into account the leakage current, the current distribution in a *CB* transistor circuit becomes as shown in Fig. 57.11 both for *PNP* and *NPN* type transistors.

It is seen that total collector current is actually the sum of two components :

(*i*) current produced by normal transistor action *i.e.* component controlled by emitter current. Its value is a I_E and is due to majority carriers.

(*ii*) temperature-dependent leakage current I_{CO} due to minority carriers.

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

Since $I_{CO} \ll I_C$, hence $\alpha \cong I_C/I_E$

(*iii*) Substituting the value of $I_E = (I_C + I_B)$ in Eq. (*i*) above, we get

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

$$\therefore \quad I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CO}}{1-\alpha}$$

(*iv*) Eliminating I_C from Eq. (i) above, we get

$$(I_E - I_B) = \alpha I_E + I_{CO} \quad \text{or} \quad I_B = (1 - \alpha)\, I_E - I_{CO}$$

(*b*) CE Circuit

In Fig. 57.12 (*a*) is shown a common-emitter circuit of an *NPN* transistor whose base lead is

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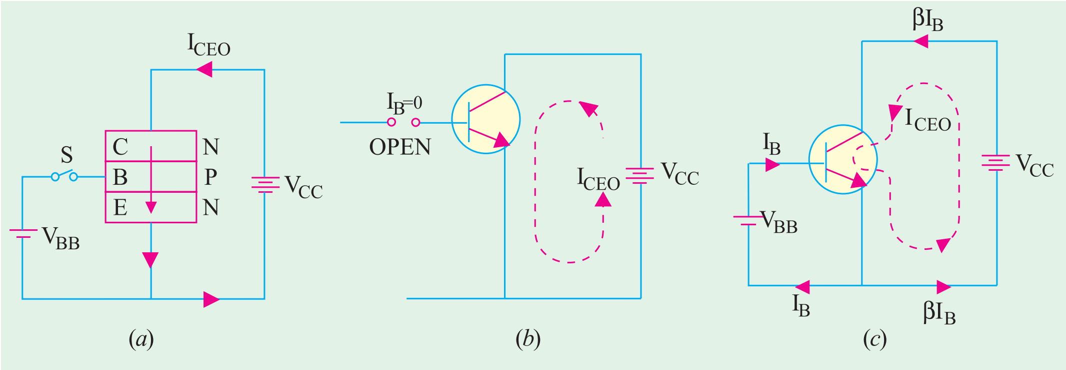
* Actually, electrons (which form minority charge carriers in collector) flow from negative terminal of collector battery, to collector, then to base through *C/B* junction and finally, to positive terminal of V_{CC}. However, conventional current flows in the opposite direction as shown by dotted lien in Fig. 57.10 (*a*)

open. It is found that despite $I_B = 0$, there is a leakage current from collector to emitter. It is called I_{CEO}, the subscripts *CEO* standing for 'Collector to Emitter with base Open'.

Taking this leakage current into account, the current distribution through a *CE* circuit becomes as shown in Fig. 57.12 (*c*).

$$I_C = \beta I_B + I_{CEO} = \beta I_B + (1+\beta)I_{CO} = \beta I_B + I_{CO}/(1-\alpha)$$

(*i*) $$\therefore \quad I_C = \frac{\alpha I_B}{1-\alpha} + \frac{I_{CO}}{1-\alpha}$$



(*a*) (*b*) (*c*)

Fig. 57.12

Now, $\beta I_B = \alpha I_E$. Substituting this value above, we get,

$I_C = \alpha I_E + I_{CEO}$. Also, $I_B = I_E - I_C$

Substituting the value of I_C from above, we have

(*ii*) $I_B = I_E - \alpha I_E - I_{CEO} = (1-\alpha)\, I_E - I_{CEO}$

57.13. Thermal Runaway

As seen from Art. 57.12, for a *CE* circuit

$$I_C = \beta I_B + (1+\beta) I_{CO}$$

The leakage current is extremely temperature-dependent. It almost doubles for every 6°C rise in temperature in *Ge* and for every 10°C rise in *Si*. Any increase in I_{CO} is magnified $(1+\beta)$ times *i.e.* 300 to 500 times. Even a slight increase in I_{CO} will affect I_C considerably. As I_C increases, collector power dissipation increases which raises the operating temperature that leads to further increase in I_C. If this succession of increases is allowed to continue, soon I_C will increase beyond safe operating value thereby damaging the transistor itself—a condition known as ***thermal runaway***. Hence, some form of stabilization is necessary to prevent this thermal runaway.

Example 57.2. *The reverse saturation current of an NPN transistor in common-base circuit is 12.5 µA. For an emitter current of 2 mA, collector current is 1.97 mA. Determine the current gain and base current.* **(Electronics-1, Gwalior Univ. 1988)**

Solution. Given : $I_{CBO} = 12.5\ \mu A$; $I_E = 2$ mA, $I_C = 1.97$ mA ; $\alpha = ?$, $I_B = ?$

$$I_C = \alpha I_E + I_{CBO} \qquad \therefore \quad \alpha = \frac{I_C - I_{CBO}}{I_E} = \frac{1.97 - 12.5\times 10^{-3}}{2} = \mathbf{0.978}$$

$I_B = I_E - I_C = 2 - 1.97 =$ **0.03 mA.**

Example. 57.3. *Derive an expression for forward current gain and leakage current of common-emitter configuration in terms of current gain and leakage current of common-base configuration. If a = 0.98, I_{CBO} = 5 mA, calculate b and ICEO.* **(Electronics-I, Mysore Univ. 1990)**

Solution. $\beta = \alpha / (1-\alpha) = 0.98/(1-0.98) =$ **49**

$I_{CEO} = (1 + \beta)\, I_{CO} = (1 + 49) \times 5 = 250\ \mu A =$ **0.25 mA**.

Example 57.4. *For a transistor, $I_B = 100\ \mu A$, $\alpha_{dc} = 0.98$ and $I_{CO} = 5\ \mu A$. Find the values of I_C and I_E.*

Solution. As seen from Art. 57.12, $I_C = \dfrac{\alpha I_B}{1-\alpha} + \dfrac{I_{CO}}{1-\alpha} = \dfrac{0.98 \times 100}{1-0.98} + \dfrac{5}{1-0.98} =$ **5.15 mA**

$I_E = I_C + I_B = 5.15 + 100 \times 10^{-3} =$ **5.25 mA**.

Example 57.5. *A transistor operating in CB configuration has $I_C = 2.98$ mA, $I_E = 3.00$ mA and $I_{CO} = 0.01$ mA. What current will flow in the collector circuit of this transistor when connected in CE configuration with a base current of 30 µA.* **(Electronics-II, M.S. Univ. Vadodra 1990)**

Solution. For *CE* configuration, $I_C = \beta I_B + (1 + \beta)\, I_{CO}$

Let us find the value of β from data given for *CB* configuration. For such a circuit $I_C = \alpha I_E + I_{CO}$ or $2.98 = \alpha \times 3 + 0.01$; $\alpha = 0.99$; $\beta = \alpha/(1 - \alpha) = 0.99/(1 - 0.09) = 99$.

∴ For *CE* circuit, $I_C = 99 \times 0.03 + (1 + 99) \times 0.01 =$ **3.97 mA**.

Example 57.6. *For a certain transistor, $I_C = 5.505$ mA, IB = 50 mA, $I_{CO} = 5$ mA. Determine* ***(i)*** *values of α, β and I_E* ***(ii)*** *the new level of I_B required to make $I_C = 10$ mA.*

Solution. (*i*) $I_C = \beta I_B + (1 + \beta)\, I_{CO}$ or $5.505 \times 10^3 = \beta \times 50 + (1 + \beta) \times 5$ ∴ $\beta = 100$

Now, $I_E = I_C + I_B = 5.505 + 50 \times 10^{-3} =$ **5.555 mA**.

Also, $I_C = \alpha I_E + I_{CO}$; $5.505 = \alpha \times 5.555 + 5 \times 10^{-3}$ ∴ $\alpha = 5.500/5.555 =$ **0.99**

(*ii*) As seen from Art. 7.12, $I_C = \beta I_B + (1 + \beta)\, I_{CO}$

∴ $10 = 100\, I_B + 101 \times 5 \times 10^{-3}$; $I_B = 0.09495$ mA $=$ **94.95 µA**.

Example. 57.7. *Discuss the operation of a PNP transistor.*

The reverse saturation current in a PNP germanium transistor type OC 71 is 8 µA. If the transistor common base current gain is 0.979, calculate the collector and emitter current for 40 µA base current. What is the collector current when base current is zero ?

(Electronics-1, Gwalior Univ. 1986)

Solution. Given : $I_{CO} = 8\ \mu A = 0.008\ \mu A$, $\alpha = 0.979$; $I_B = 40\ \mu A = 0.04$ mA

In a *CE* circuit: $I_C = \beta I_B + I_{CEO} = \beta I_B + I_C/(1 - \alpha)$.

Now, $\beta = \alpha/(1 - \alpha) = 0.979/(1 - 0.979) = 46.6$

∴ $I_C = 46.6 \times 0.04 + (1 + 46.6) \times 0.008 =$ **1.9 mA** ; $I_E = I_C + I_B = 1.9 + 0.04 =$ **1.94 mA**

57.14. Transistor Static Characteristics

There are the curves which represents relationship between different d.c. currents and voltages of a transistor. These are helpful in studying the operation of a transistor when connected in a circuit. The three important characteristics of a transistor are :

1. Input characteristic, **2.** Output characteristic, **3.** Constant-current transfer characteristic.

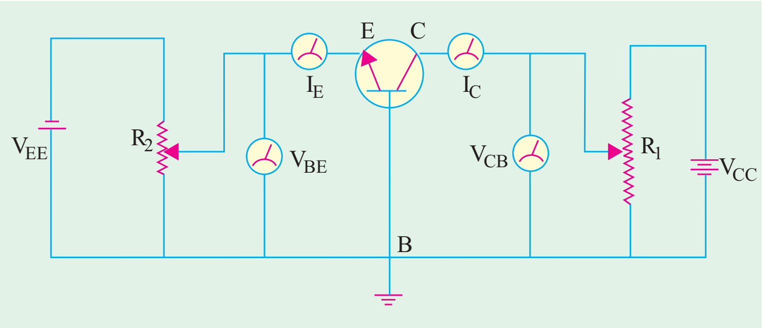


Fig. 57.13

57.15 Common Base Test Circuit

The static characteristics of an *NPN* transistor connected in common-base configuration can be determined by the use of test circuit shown in Fig. 57.13. Milliammeters are included in series with the emitter and collector circuits to measure I_E and I_C. Similarly, voltmeters are connected across *E* and *B* to measure voltage V_{BE} and across *C* and *B* to measure V_{CB}. The two potentiometer resistors R_1 and R_2 supply variable voltages from the collector and emitter dc supplies respectively.

57.16. Common Base Static Characteristics

(a) Input Characteristic

It shows how I_E varies with V_{BE} when voltage V_{CB} is held constant. The method of determining this characteristic is as follows :

First, voltage V_{CB} is adjusted to a suitable value with the help of R_1 (Fig. 57.13). Next, voltage V_{BE} is increased in a number of discrete steps and corresponding values of I_E are noted from the milliammeter connected for the purpose. When plotted, we get the input characteristic shown in Fig. 57.14, one for *Ge* and the other for *Si*. Both curves are exactly similar to the forward characteristic of a *P-N* diode which, in essence, is what the emitter-base junction is.

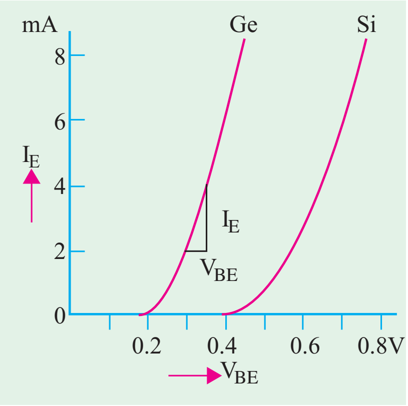


Fig. 57.14

This characteristic may be used to find the input resistance of the transistor. Its value is given by the reciprocal of its slope.

$$R_{in} = \Delta V_{BE} / \Delta I_E \qquad \text{— } V_{CB} \text{ constant.}$$

Since the characteristic is initially nonlinear, R_{in} will vary with the point of measurement. Its value over linear part of the characteristic is about 50 Ω but for low values of V_{BE}, it is considerably greater. This change in R_{in} with change in V_{BE} gives rise to distortion of signals handled by the transistor.

This characteristic is hardly affected by changes either in V_{CB} or temperature.

(b) Output Characteristic

It shows the way I_C varies with V_{CB} when I_E is held constant. The method of obtaining this characteristic is as follows:

First, movable contact, on R_2 (Fig. 57.13) is changed to get a suitable value of V_{BE} and hence that of I_E. While keeping I_E constant at this value, V_{CB} is increased from zero in a number of steps and the corresponding collector current I_C that flows is noted.

Next, V_{CB} is reduced back to zero, I_E is increased to a value a little higher than before and the whole procedure is repeated. In this way, whole family of curves is obtained, a typical family being shown in Fig. 57.15.

1. The reciprocal of the near horizontal part of the characteristic gives the output resistance R_{out} of the transistor which it would offer to an input signal. Since the characteristic is linear over most of its length (meaning that I_C is virtually independent of V_{CB}). R_{out} is very high, a typical value being 500 kΩ.

$$R_{out} = \frac{1}{\Delta I_C / \Delta V_{CB}} = \frac{\Delta V_{CB}}{\Delta I_C}$$

2. It is seen that I_C flows even when $V_{CB} = 0$. For example, it has a value = 1.8 mA corresponding to $V_{CB} = 0$ for $I_E = 2$ mA as shown in Fig. 57.15. It is due to the fact that electrons are being injected into the base under the action of forward-biased *E/B* junction and are being collected by the collector due to the action of the internal junction voltage at the *C/B* junction (Art. 57.2). For reducing I_C to zero, it is essential to neutralize this potential barrier by applying a small forward bias ac-ross *C/B* junction.

3. Another important feature of the characteristic is that a small amount of collector current flows even when emitter current $I_E = 0$. As we know (Art. 57.12), it is collector leakage current I_{CBO}.

4. This characteristic may be used to find α_{ac} of the transistor as shown in Fig. 57.15.

$$\alpha_{ac} = \frac{\Delta I_C}{\Delta I_E} = \frac{DE}{BC}$$

$$= \frac{6.2 - 4.3}{2} = 0.95$$

5. Another point worth noting is that although I_C is practically independent of V_{CB} over the working range of the transistor, yet if V_{CB} is permitted to increase beyond a certain value, I_C eventually increases rapidly due to avalanche breakdown as shown in Fig. 57.15.

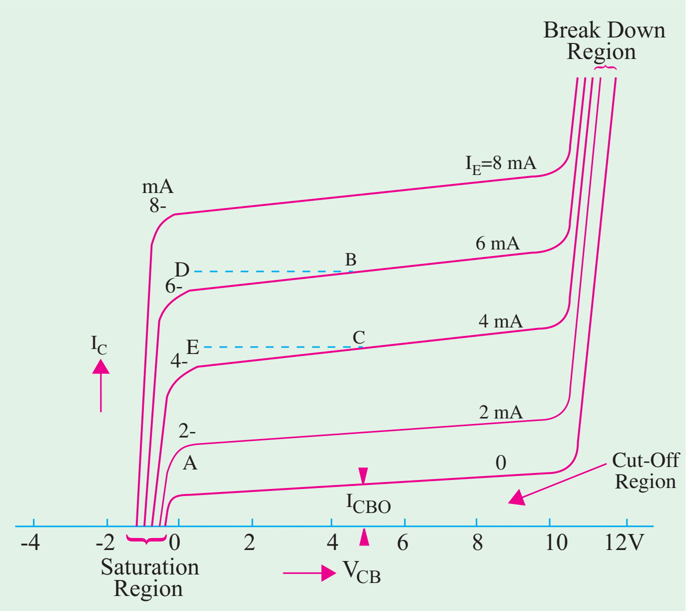
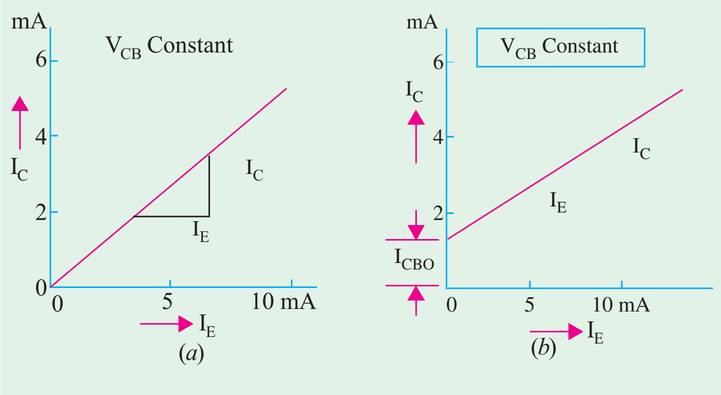


Fig. 57.15

(*c*) Current Transfer Characteristic

It shows how I_C varies with changes in I_E when V_{CB} is held constant. For drawing this characteristic, first V_{CB} is set to a convenient value and then I_E is increased in steps and corresponding values of I_C noted. A typical transfer characteristic is shown in Fig. 57.16 (*a*). Fig. 57.16 (*b*) shows a more detailed view of the portion near the origin.

As seen, α_{ac} may be found from the equation



(*a*) (*b*)

Fig. 57.16

$$\alpha_{ac} = \Delta I_C / \Delta I_E$$

Usually, α_{ac} is found from output characteristic than from this characteristic.

It may be noted in the end that *CB* connection is rarely employed for audio-frequency circuits because ***(i)*** its current gain is less than unity and ***(ii)*** its input and output resistances are so different.

57.17. Common Emitter Test Circuit

The static characteristics of an *NPN* transistor connected in *CE* configuration may be determined by the use of circuit diagram shown in Fig. 57.17. A milliammeter (or a microammeter in the case of a low-power transistor) is connected in series with the base to measure I_B. Similarly, a milliammeter is included in the collector circuit to measure I_C. A voltmeter with a typical range of 0 –1 V is connected across base and emitter terminals for measuring V_{BE}.

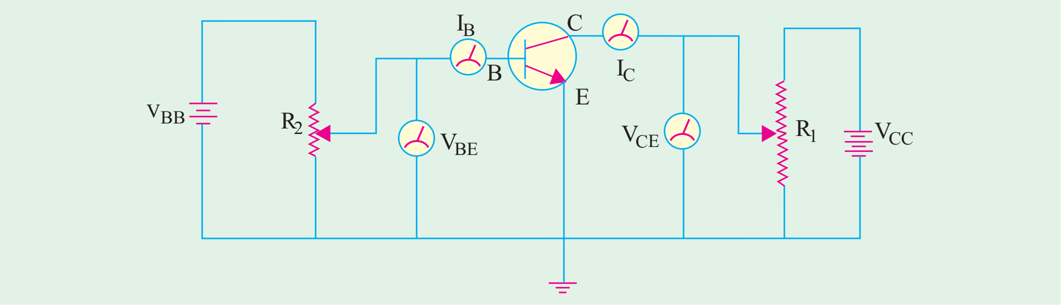


Fig. 57.17

Potentiometer R_2 connected across dc supply V_{BB} is used to vary I_B and V_{BE}. A second voltmeter with a typical range of 0–20 V is connected across collector-emitter terminals to measure the output collector-emitter voltage V_{CE}.

57.18. Common Emitter Static Characteristics

(*a*) Input Characteristic

It shows how I_B varies with changes in V_{BE} when V_{CE} is held constant at a particular value.

To begin with, voltage V_{CE} is maintained constant at a convenient value and then V_{BE} is increased in steps. Corresponding values of I_B are noted at each step. The procedure is then repeated for a different but constant value of V_{CE}. A typical input characteristic is shown in Fig. 57.18. Like *CB* connection, the overall shape resembles the forward characteristic of a *P-N* diode. The reciprocal of the slope gives the input resistance R_{in} of the transistor.

$$R_{in} = \frac{1}{\Delta I_B / \Delta V_{BE}} = \frac{\Delta V_{BE}}{\Delta I_B}$$

Due to initial non-linearity of the curve, R_{in} varies considerably from a value of 4 kΩ near the origin to a value of 600 Ω over the more linear part of the curve.

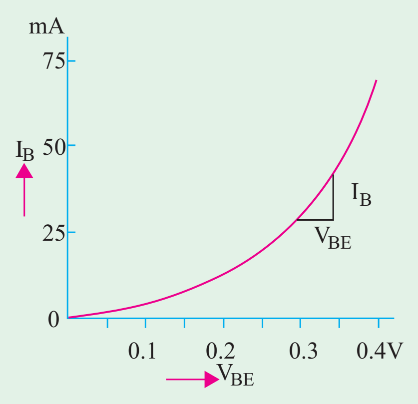


Fig. 57.18

(*b*) Output or Collector Characteristic

It indicates the way in which I_C varies with changes in V_{CE} when I_B is held constant.

For obtaining this characteristic, first I_B is set to a convenient value and maintained constant and then V_{CE} is increased from zero in steps, I_C being noted at each step. Next, V_{CE} is reduced to zero and I_B increased to another convenient value and the whole procedure repeated. In this way, a family of curves (Fig. 57.19) is obtained.

It is seen that as V_{CE} increases from zero, I_C rapidly increases to a near saturation level for a fixed value of I_B. As shown, a small amount of collector current flows even when $I_B = 0$. It is called I_{CEO} (Art. 57.12). Since main collector current is zero, the transistor is said to be **cut-off.**

It may be noted that if V_{CE} is allowed to increase too far, *C/B* junction completely breaks down and due to this avalanche breakdown, I_C increases rapidly and may cause damage to the transistor.

When V_{CE} has very low value (ideally zero), the transistor is said to be saturated and it operates in the saturation region of the characteristic. Here, change in I_B does not produce a corresponding change in I_C.

This characteristic can be used to find β_{ac} at a specific value of I_B and V_{CE}. It is given by $\beta_{ac} = \Delta I_C/\Delta I_B$.

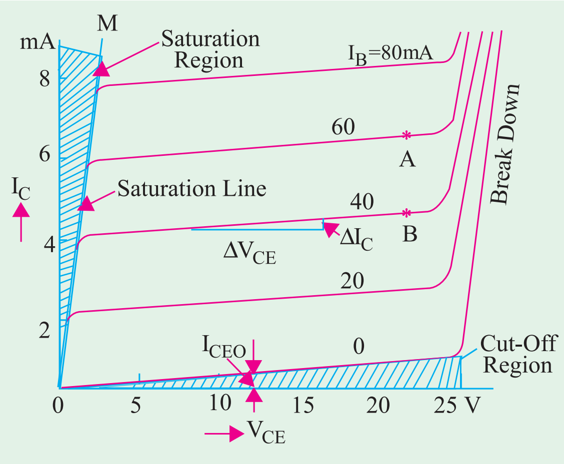


Fig. 57.19

We may select any two points A and B on the I_B = 60 µA and 40 µA lines respectively and measure corresponding values of I_C from the diagram for finding ΔI_C. Since ΔI_B = (60 – 40) = 20 µA, β_{ac} can be easily found.

The value of output resistance R_{out} (= $\Delta V_{CE} / \Delta I_C$) over the near horizontal part of the characteristic varies from 10 kΩ to 50 kΩ.

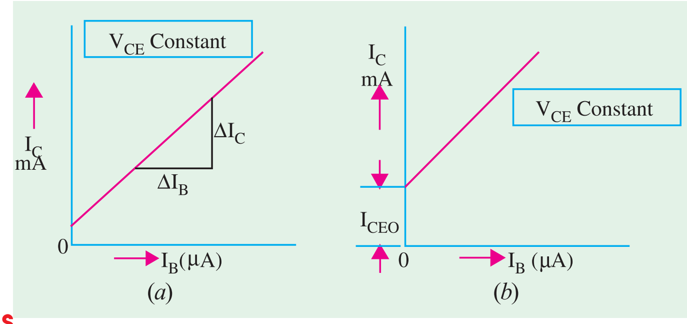
(c) Current Transfer Characteristic

It indicates how I_C varies with changes in I_B when V_{CE} is held constant at a given value.

Such a typical characteristic is shown in Fig. 57.20 (*a*). Its slope gives

$$\beta_{ac} = \Delta I_C / \Delta I_B$$

From Fig. 57.20 (*b*), it is seen that a small collector current flows even when I_B = 0. It is the common-emitter leakage current I_{CEO} = (1 + β) I_{CO}. Like I_{CO}, it is also due to the flow of minority carriers across the reverse-biased *C/B* junction.



(*a*) (*b*)

Fig. 57.20

57.19. Common Collector Static Characteristics

As shown in Fig. 57.21, in this case, collector terminal is common carrier to both the input (*CB*) and output (*CE*) carriers circuits.

The output characteristic is I_E versus V_{CE} for several fixed values of I_B. Since $I_C \cong I_E$, this characteristic is practically idential to that of the *CE* circuit and is shown in Fig. 57.22 (*a*).

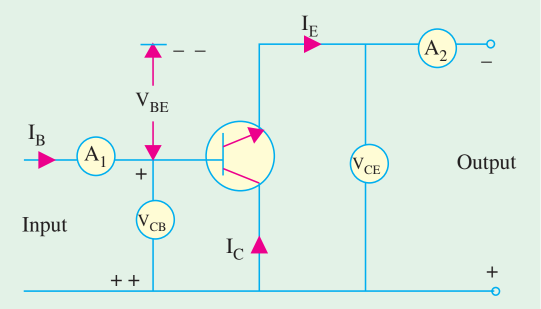


Fig. 57.21

Similarly, its current gain characteristic I_C versus I_B for different values of V_{CE} is similar to that of a *CE* circuit because $I_C \cong I_E$.

The *CC* input characteristic is a plot of V_{CB} versus I_B for different values of V_{CE} and is shown in figure 57.22 (*b*). It is quite different from those for *CB* or *CE* circuit. This difference is due to the fact that input voltage V_{CB} is largely determined by the value of *CE* voltage. Consider the input characteristic for I_B = 100 µA and V_{CE} = 2 V.

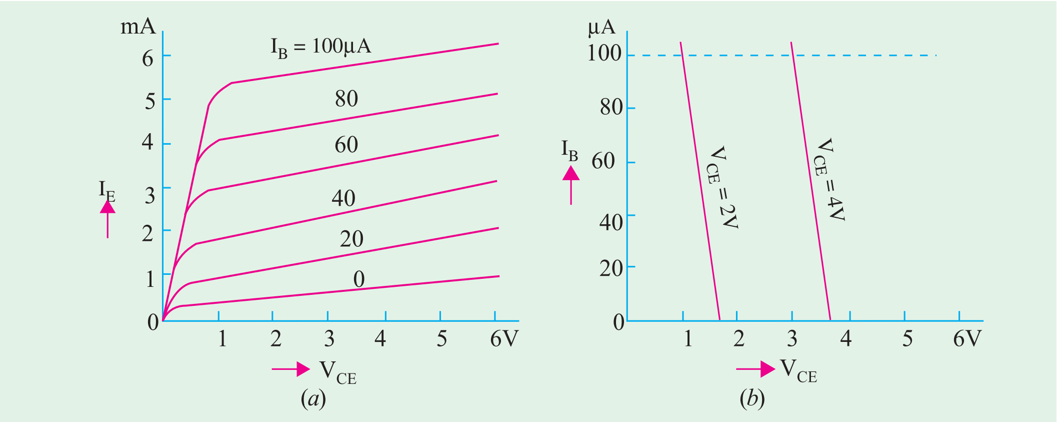
$$V_{CB} = V_{CE} - V_{BE} = 2 - 0.7 = 1.3 \text{ V} \quad \text{— for Si material}$$

Moreover, as V_{CB} is increased, V_{BE} is reduced thereby reducing I_B.

Now, consider the values V_{CE} = 4 V and I_B = 100 µA

$$V_{CB} = 4 - 0.7 = 3.3 \text{ V}$$

Again, as V_{CB} increases, I_B is decreased.

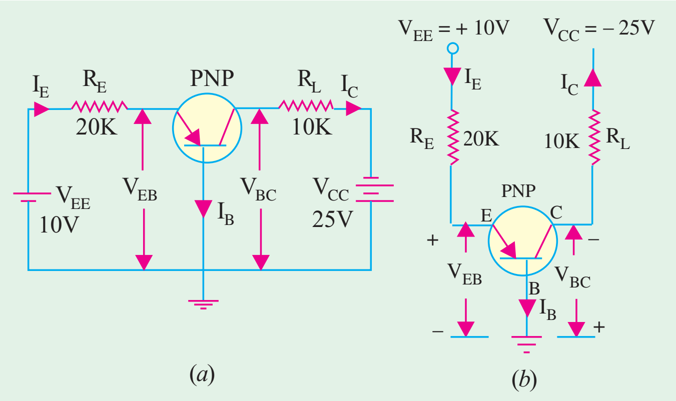


(*a*) (*b*)

Fig. 57.22

57.20. Different Ways of Drawing Transistor Circuits

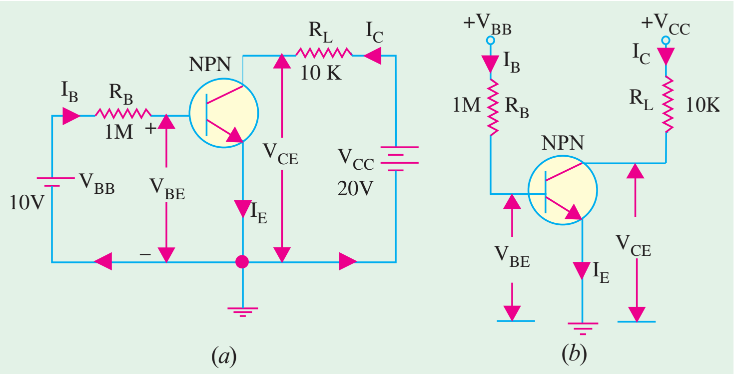
In Fig. 57.23 (*a*) is shown a *CB* transistor circuit which derives its voltage and current requirements from two independent power sources *i.e.* two different batteries. Correct battery connections can be done by remembering the transistor polarity rule (Art. 57.2) that in an *NPN* transistor, both collector and base have to be Positive with respect to the emitter. Of course, collector is a ***little bit more*** positive than base which means that between themselves, collector is at a ***slightly higher positive*** potential with the respect to the base. Conversely, base is at a little lower potential with respect to the collector.



(*a*) (*b*)

Fig. 57.23

Putting it in a slightly different way, we can say that collector is positive w.r.t. base and conversely, base is negative w.r.t. collector. That is why, potential difference between collector and base in written as V_{CB} (and not V_{BC}) because terminal at higher potential is mentioned first. Same reasoning applies to V_{BE}. Fig. 57.23 (*b*) shows another and more popular way of indicating power supply voltage. Only one terminal of the battery is shown, the other terminal is ***understood to be grounded so as to provide a complete path for the current.***



(*a*) (*b*)

Fig. 57.24

For example, negative terminal of V_{CC} and positive terminal of V_{EE} are supposed to be grounded (as is the base) even though not shown as such in the diagram.

Fig. 57.24 (*a*) shows an *NPN* transistor connected in *CE* configuration with voltages and currents drawn from two independent power sources. As seen, battery con-nections and voltage markings are as per the rule given in Art. 57.2. Fig. 57.24 (*b*) shows the more popular way of indicating power supply voltages.

As seen, both collector and base are positive with respect to the common electrode *i.e.* emitter. Hence, a single battery can be used to get proper voltages across the two as shown in Fig. 57.25.

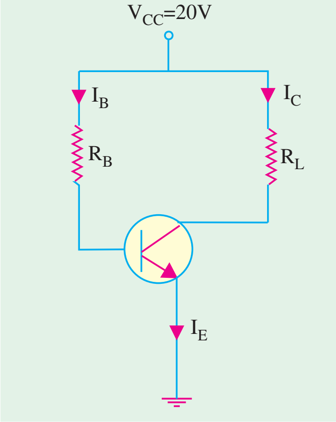


Fig. 57.25

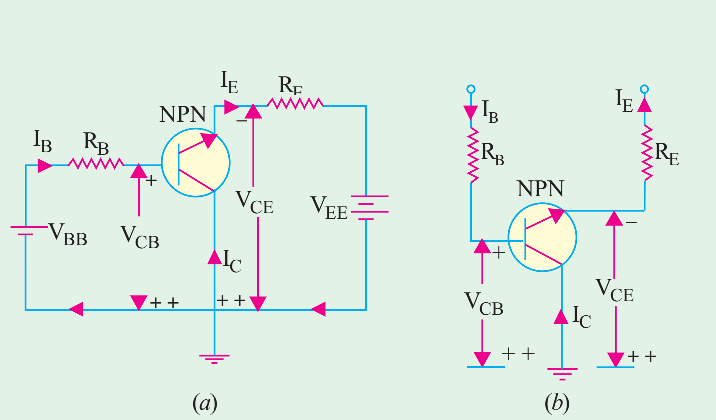


Fig. 57.26

Fig. 57.26 (*a*) shows the *CC* configuration of an *NPN* transistor and Fig. 57.26 (*b*) shows the same circuit drawn differently.

57.21. Common Base Formulas

Let us find the values of different voltages and currents for the circuit in Fig. 57.23 (*b*). Consider the circuit *MEBM*. Applying Kirchhoff's voltage law and starting from point *B* (or ground) upwards, we get

(*a*) $-V_{BE} - I_E R_E + V_{EE}{}^{*} = 0$ or $I_E = \dfrac{V_{EE} - V_{BE}}{R_E}$

where $V_{BE} = 0.3$ V (for *Ge*) and 0.7 V (for *Si*)

Since, generally, V_{EE} » V_{BE}, we can simplify the above to $I_E \cong V_{EE}/R_E = 10\text{ V}/20\text{ K} = 0.5\text{ mA}$ (Fig. 57.23).

Taking V_{BE} into account and assuming silicon transistor

$$I_E = (10 - 0.7)\text{ V}/20\text{ K} = 0.465\text{ mA}$$

(*b*) $I_C = \alpha\, I_E \cong I_E = 0.5$ mA neglecting leakage current.

(*c*) From circuit *NCBN*, we get

$$V_{CB} = V_{CC} - I_C \cong V_{CC} - I_E R_L = 25 - 0.5 \times 10 = 20\text{ V} \qquad (\therefore I_C \cong I_E)$$

Example 57.8. *In the circuit of Fig. 57.27* (*a*), what value of R_L causes $V_{CB} = 5$ V?

Solution. $I_E \cong V_{EE}/R_E = 10\text{ V}/10\text{ K} = 1\text{ mA}$

$$I_C = \alpha\, I_E \cong I_E = 1\text{ mA}$$

Now, $V_{CC} = I_{CRL} + V_{CB}$

$$\therefore\ R_L = \frac{V_{CC} - V_{CB}}{I_C} = \frac{20-5}{1\text{ mA}} = \mathbf{15K}$$

Example. 57.9. *For the circuit shown in Fig. 57.27 (b), find the value of R_E which causes $V_{BC} = 10$ V.*

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[*] It is taken positive because we are going from the negative to the positive terminal of the emitter battery.

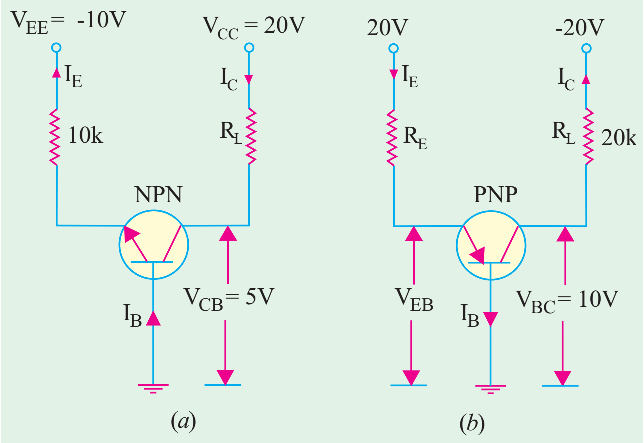

Fig. 57.27

Solution. $I_C = \frac{V_{CC} - V_{BC}}{R_L}$

$$= \frac{20-10}{20\,K} = 0.5\,\text{mA}$$

Now, $I_E = I_C/\alpha \cong I_C = 0.5$ mA

If we neglect V_{BE}, then entire V_{EE} = 20 V has to be dropped across R_E.

∴ 0.5 R_E = 20

or R_E = 20/0.5 mA = 40 K

57.22. Common Emitter Formulas

Consider the *CE* circuit of Fig. 57.28. Taking the emitter-base circuit, we have

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \cong \frac{V_{BB}}{R_B}$$

$$I_C = \beta\, I_B \qquad \text{— neglecting leakage current } I_{CEO}$$

$$V_{CE} = V_{CC} - I_C R_L$$

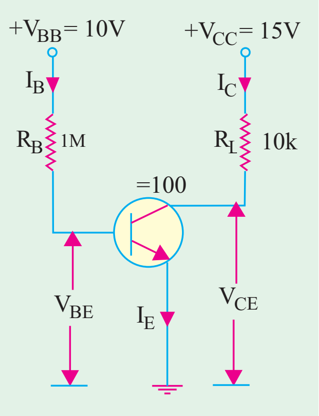

Fig. 57.28

Example 57.10. *For the circuit of Fig. 57.28, find* ***(i)*** I_B ***(ii)*** I_C ***(iii)*** I_E *and* ***(iv)*** V_{CE}. *Neglect* V_{BE}.

Sol. *(i)* $I_B \cong \frac{V_{BB}}{R_B} = \frac{10}{1M} =$ **10μA**

(ii) $I_C = \beta I_B$ = 100 × 10 μA = **1 mA**

(iii) $I_E = I_B + I_C$ = 1mA + 10 μA = **1.01 mA**

(iv) $V_{CE} = V_{CC} - I_C R_C$ = 15 – 1 × 10 = **5 V**

Example 57.11. *Find the exact value of emitter current* I_E *in the two-supply emitter bias circuit of Fig. 57.29.*

(Electronics-1, Bangalore Univ. 1989)

Solution. Let us apply Kirchhoff´s voltage law to the loop containing R_B, R_E and V_{EE}. Starting from emitter and going clock-wise, we get

$$-I_E R_E + V_{EE} - I_B R_B - V_{BE} = 0$$

or $\quad I_E R_E + I_B R_B = V_{EE} - V_{BE}$ ... ***(i)***

Now $\quad \beta = I_C/I_B \cong I_E/I_B \qquad \therefore \quad I_B \cong I_E/\beta$

Substituting this value in Eq. ***(i)*** above, we get

$$I_E R_E + \frac{I_E R_B}{\beta} = V_{EE} - V_{BE} \qquad \text{or}$$

$$I_E = \frac{V_{EE} - V_{BE}}{R_E + R_B/\beta}$$

Since, in most cases, $(R_B/\beta) \ll R_E$

∴ $\quad I_E = (V_{EE} - V_{BE})/R_E \cong V_{EE}/R_E$

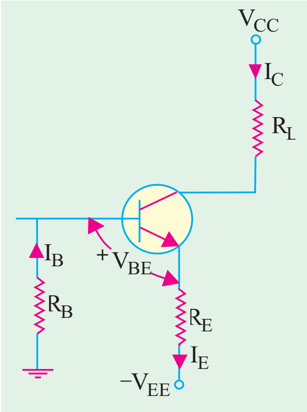

Fig. 57.29

Also, $I_B = I_E/(1+\beta) \cong I_E/\beta$

Example. 57.12. *In the circuit of Fig. 57.30, find* **(i)** I_E, **(ii)** I_B, **(iii)** I_C *and* **(iv)** V_{CE}. *Neglect* V_{BE} *and take* $\beta = 100$.

Sol. (i) $I_E = \dfrac{V_{EE}}{R_E + R_B/\beta} = \dfrac{30}{30+20/100} \cong$ **1 mA**

(ii) $I_B \cong I_E/\beta = 1/100 =$ **0.01 mA**

(iii) $I_C = I_E - I_B = 1 - 0.01 =$ **0.99 mA**

(iv) $V_{CE} = V_{CC} - I_C R_L = 30 - 10 \times 0.99 =$ **20.1 V**.

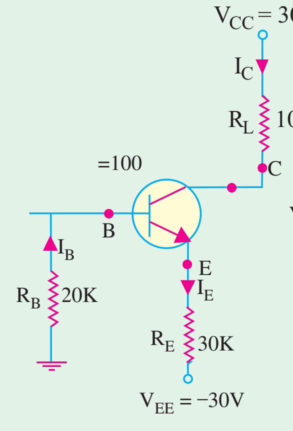

Fig. 57.30

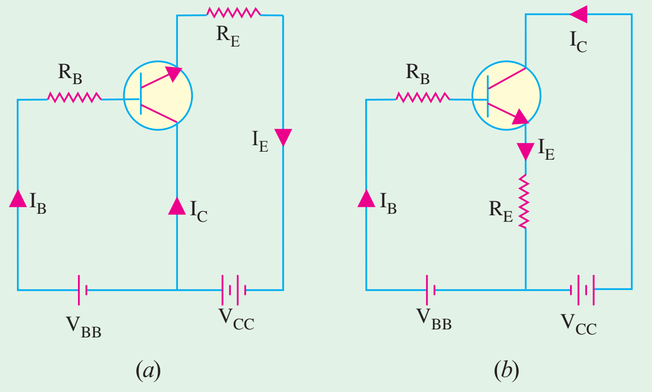

Fig. 57.31

57.23. Common Collector Formulas

The *CC* circuit with its proper d.c. biasing voltage sources is shown in Fig. 57.31 (*a*). The two circuits given in Fig. 57.31 represent the same thing.

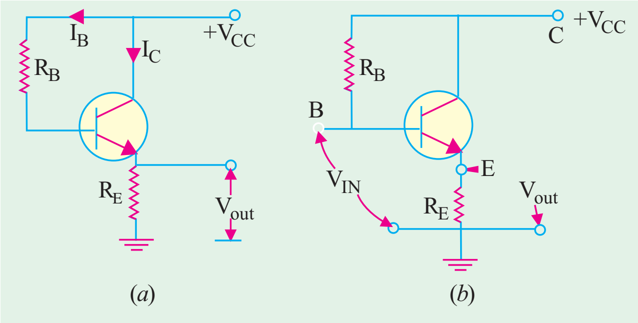

Fig. 57.32

Another way of drawing the same circuit is shown in Fig. 57.32 (*a*) where only one battery has been used. It should be noted that load resistor is not in the collector lead but in the emitter lead as shown.

Fig. 57.32 (*b*) makes the circuit connection quite clear. Input is between base and collector terminals whereas output is between emitter and collector terminals.

It is seen that

$$I_E = \frac{V_{CC} - V_{BE}}{R_E + R_B/\beta}\ ; \quad V_{CC} = V_{CE} + I_E R_E\ ; \quad I_E = \frac{V_{CC} - V_{BE}}{R_E + \beta R_E}\ ; \ I_C = \beta I_B$$

Example 57.13. *In the CC circuit of Fig. 57.33, find* **(a)** I_B, **(b)** I_E, **(c)** V_{CE}, **(d)** V_E and **(e)** V_B.

Take $\beta = 49$ and $V_{BE} = 0.7$ V.

Solution. (*a*) $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (1+\beta) R_E}$

$$= \frac{9.0 - 0.7}{100 + 50 \times 2} = \mathbf{41.5\ \mu A}$$

(*b*) $I_E = (1 + \beta)\, I_B = 50 \times 41.5 = \mathbf{2.075\ mA}$

(*c*) $V_{CE} = V_{CC} - I_E R_E = 9 - 2.075 \times 2 = \mathbf{5.85\ V}$

(*d*) $V_E = I_E R_E = 2.075 \times 2 = \mathbf{4.15\ V}$

(*e*) $V_B = V_{BE} + I_E R_E = 0.7 + 4.15 = \mathbf{4.85\ V}$

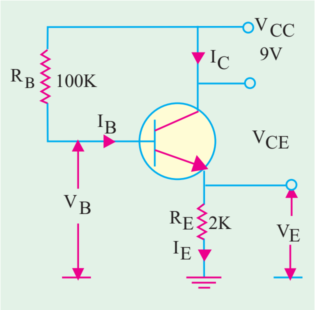

Fig. 57.33

57.24. The Beta Rule

According to this rule, resistance from one part of a transistor circuit can be referred to another of its parts (as we do with the primary and secondary winding impedances of a transformer). For example, resistance R_L in the collector circuit can be referred to the base circuit and ***vice versa.*** Similarly, R_E can be referred to the base circuit and, reciprocally, R_B can be referred to the emitter circuit. Since current through R_L is I_C ($= \beta\, I_B$), hence β-factor comes into the picture. Similarly, current through R_E is I_E which is (1 + β) times I_B, hence (1 + β) or approximately β-factor comes into the picture again, Use of this 'β-rule' makes transistor circuit calculations quite quick and easy. It makes the calculation of I_B quite simple.

The 'β-rule' may be stated as under :

1. When referring R_L or R_C to the base circuit, **multiply** it by β. When referring R_B to the collector circuit, **divide** it by β.
2. When referring R_E to base circuit, **multiply** it by (1 + β) or just β (as a close approximation).
3. Similarly, when referring R_B to emitter circuit, **divide** it by (1 + β) or β.

Before you apply this rule to any circuit, you must remember one very important point otherwise you are likely to get wrong answers. The point is that ***only those resistances are transferred which lie in the path of the current being calculated.*** Not otherwise. The utility of this rule will be demonstrated by solving the following problems.

Example 57.14. *Calculate the value of V_{CE} in the collector stabilisation circuit of Fig. 57.34.*

Solution. We will use β-rule to find I_C in the following two ways.

(*i*) First Method

Here, we will transfer R_L to the base circuit.

$$I_B = \frac{V_{CC}}{R_B + \beta R_L} = \frac{20}{1000 + 100\,(10)} = 10\,\text{mA}$$

$$I_C = \beta I_B = 100 \times 10 = 1000\ \text{mA} = 1\ \text{A}$$

$$V_{CE} \cong V_{CC} - I_C R_L = 20 - 1 \times 10 = \mathbf{10\ V}$$

(*ii*) Second Method

Now, we will refer R_B to collector circuit.

$$I_C \cong \frac{V_{CC}}{R_L + R_B/\beta} = \frac{20}{10 + 1000/100} = 1\,\text{mA}$$

$$V_{CE} = V_{CC} - I_C R_L = 10\ \text{V} \qquad \text{— as above}$$

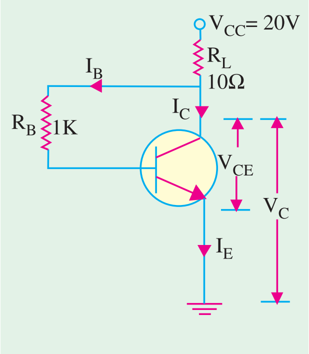

Fig. 57.34

It was a simple circuit because $R_E = 0$ and R_B was connected to V_{CC} through R_L and not directly (in which case, R_L would not lie in the path of I_B). Now, we will consider the case when R_E is present and R_L does not lie in the path of I_B.

Example 57.15. *Calculate the three transistor currents in the circuit of Fig. 57.35.*

Solution. (*i*) First Method

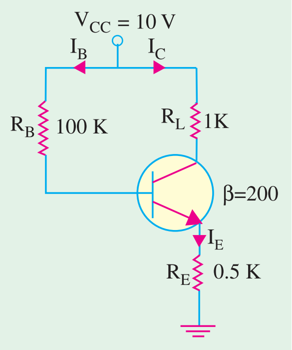

Fig. 57.35

Since R_E lies in the path of I_B

$$\therefore \quad I_B = \frac{V_{CC}}{R_L + \beta R_E} \qquad \text{— neglecting } V_{BE}$$

$$= \frac{10}{100 + 200\,(0.5)} = \mathbf{0.05\ mA}$$

$I_C = \beta I_B = 200 \times 0.05 = \mathbf{10\ mA}$, $I_E = I_B + I_C = \mathbf{10.05\ mA}$

(*ii*) Second Method

Now, we will transfer R_B to emitter circuit and find I_E directly.

$$I_E = \frac{V_{CC}}{R_E + R_B/\beta} = \frac{10}{0.5 + 100/200} = 10\,\text{mA} \qquad \text{— as before}$$

$I_B = I_C/\beta \cong 10/200 = \mathbf{0.05\ mA}$

Example 57.16. *Calculate I_E in the circuit of Fig. 57.36.*

(Electronic & Commu., Ranchi Univ. 1990)

Solution. If we neglect V_{BE}, then as seen from the circuit of Fig. 57.36.

$$I_E = \frac{V_{EE}}{R_E + R_B/\beta} = \frac{10}{10 + 10/100} = \mathbf{0.99\ mA}$$

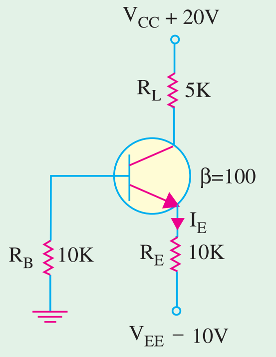

Fig. 57.36

57.25. Importance of V_{CE}

The voltage V_{CE} is very important in checking whether the transistor is

(*a*) defective, (*b*) working in cut-off,

(*c*) in saturation or well into saturation (Example 57.17 and 57.18)

When $V_{CE} = V_{CC}$, the transistor is in cut-off *i.e.* it is turned OFF. When $V_{CE} = 0$, the transistor is in saturation *i.e.* it is turned fully ON. When V_{CE} is less than zero *i.e.* negative, the transistor is said to be well into saturation. In practice, both these conditions are avoided. For amplifier operation, $V_{CE} = \frac{1}{2} V_{CC}$ *i.e.* transistor is operated at approximately $\frac{1}{2}$ ON. In this way, variations in I_B in either direction will control I_C in both directions. In other words, when I_B increases or decreases, I_C also increases or decreases. However, if I_B is OFF, I_C is also OFF. On the other hand, if collector has been turned fully ON, maximum I_C flows. Hence, no further increase in I_B can be reflected in I_C.

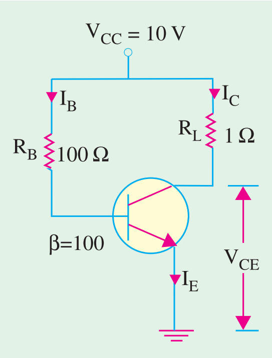

Fig. 57.37

Example 57.17. *For the CE circuit of Fig. 57.37, find the value of V_{CE}. Take β = 100 and neglect V_{BE}. Is the transistor working in cut-off or saturation ?*

Solution. $I_B = 10/100 \qquad = 0.1\ \text{A}$

$I_C = \beta\, I_B \qquad = 100 \times 0.1 = 10\ \text{A}$

$V_{CE} = V_{CC} - I_C R_L = 10 - 10 \times 1 = 0$

Obviously, the transistor is operating just at saturation and not well into saturation.

Example 57.18. *Find out whether the transistor of Fig. 57.38 is working in saturation or well into saturation. Neglect V_{BE}.* **(Basic Electronics, Bombay Univ.)**

Solution. $I_B = 10/10 = 1\ \text{A}$

$I_C = 100 \times 1 = 100\ \text{A}$

Obviously, I_C cannot be that large because its maximum value is given by V_{CC}/R_L = 10/1 = 10 A. However, let us assume that I_C takes this value temporarily. Then,

$$V_{CE} = V_{CC} - I_C R_L$$
$$= 10 - 100 \times 1 = -90 \text{ V}$$

It means that the transistor **is working well into saturation**.

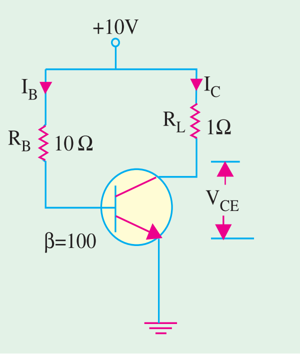

Fig. 57.38

57.26. Cut-Off And Saturation Points

Consider the circuit of Fig. 57.39 (*a*). As seen from Art 57.22,

$V_{CE} = V_{CC} - I_C R_L$.

Since, $I_B = 0$, $\therefore$ $I_C = 0$.

Hence, $V_{CE} = V_{CC}$

Under these conditions, the transistor is said to be cut-off for the simple reason that it does not ***conduct any current***. This value of V_{CE} is written as $V_{CE\text{ (cut-off)}}$. Incidentally, a transistor when cut-off acts like an open switch.

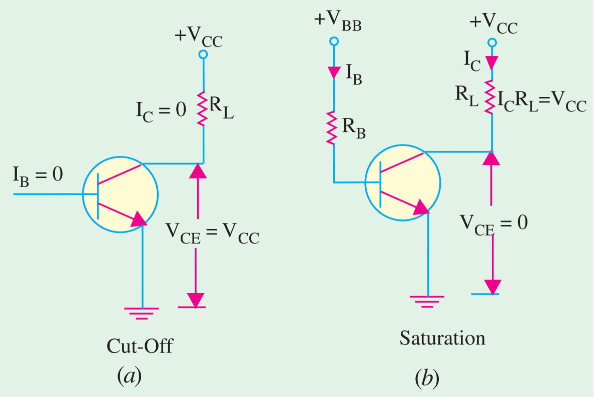

Fig. 57.39

If, in Fig. 57.39 (*b*), values of R_B and R_L are such that V_{CE} comes out to be zero, then transistor is said to be saturated. Putting $V_{CE} = 0$ in the above equation, we get

$$0 = V_{CC} - I_C R_L$$

or $\quad I_C = V_{CC} / R_L$

It should be noted that a transistor, when saturated, acts as a closed switch of negligible resistance.

It is obvious that under saturation condition,

(*i*) whole of V_{CC} drops across R_L.

(*ii*) collector current has maximum possible value called I_C (*sat*).

Normal operation of a transistor lies between the above two extreme conditions of cut-off and saturation.

Example. 57.19. *In a simple amplifier circuit (Fig. 57.40) with base resistance, R_B = 50 K, R_E = 2 K, R_C = 3K, V_{CC} = 10 V, h_{FE} = 100, determine whether or not the silicon transistor is in the saturation and find I_B and I_C. Explain the saturation region in common-emitter characteristics.*

(Electronics, MS. Univ. Baroda,)

Solution. Whether the transistor is in saturation or not will depend on the value of V_{CE}.

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + R_B/\beta} \cong \frac{V_{BB}}{R_E + R_B/\beta}$$

$$= \frac{5}{2 + 50/100} = 2 \text{ mA}$$

$I_C \cong I_E = 2$ mA ; $I_B = I_C/\beta = 2/100$
$= 0.02$ mA

Now, $\quad V_{CC} = I_C R_C + V_{CE} + I_E R_E$

or $\quad V_{CE} = 10 - (2 \times 3)\ (2 \times 2) = 0$

Obviously, the transistor has entered saturation.

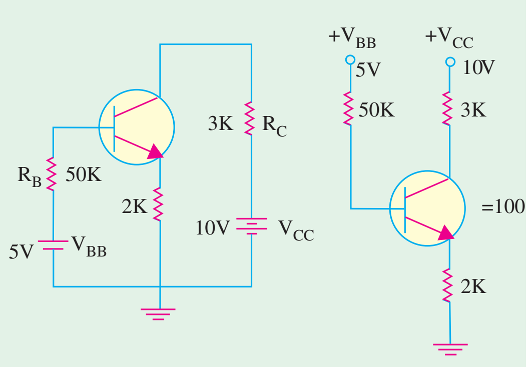

Fig. 57.40

57.27. BJT Operating Regions

A BJT has two junctions *i.e.* base-emitter and base-collector junctions either of which could be forward-biased or reverse-biased. With two junctions, there are four possible combinations of bias condition.

(i) both junctions reverse-biased,
(ii) both junctions forward-biased,
(iii) *BE* junction forward-biased, *BC* junction reverse-biased.
(iv) *BE* junction reverse-biased, *BC* junction forward-biased.

Since condition ***(iv)*** is generally not used, we will tabulate the remaining three conditions below.

Table No. 57.1: Transistor Operation Regions

BE Jn	BC Jn	Region
RB*	RB	cut-off
FB**	FB	saturation
FB	RB	active

* Reverse-biased, ** Forward-biased

(*a*) Cut-off

This condition corresponds to reverse-bias for both base-emitter and base-collector junctions. In fact, both diodes act like open circuits under these conditions as shown in Fig. 57.41, which is true for an ideal transistor. The revese leakage current (Art 57.12) has been neglected. As seen, the three transistor terminals are uncoupled from each other. In cut-off, $V_{CE} = V_{CC}$.

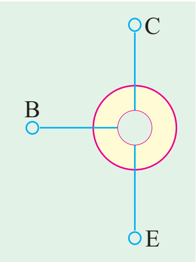

Fig. 57.41

(*b*) Saturation

This condition corresponds to forward-bias for both base-emitter and base-collector junctions. The transistor becomes saturated *i.e.* there is perfect short-circuit for both base-emitter and base-collector diodes. The ideal case is shown in Fig. 57.42, where the three transistor terminals have been connected together thereby acquiring equal potentials. In this case, $V_{CE} = 0$.

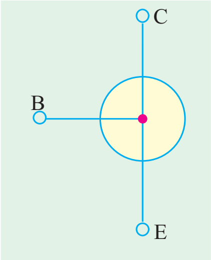

Fig. 57.42

(*c*) Active Region

This condition corresponds to forward-bias for base-emitter junction and reverse bias for base-collector junction. In this, $V_{CE} > 0$.

57.28. Active Region DC Model of a BJT

Such a model is used for predicting transistor operation in the active region. This condition is shown in Fig. 57.43 both for a *PNP* and an *NPN* transistor. A base-emitter junction voltage of 0.7 V has been assumed for silicon transistor. The *BE* junction is represented by a constant voltage source since it is forward-biased. As seen, in an *NPN* transistor, base is 0.7 V higher than the emitter terminal. However, in a *PNP* transistor, base is 0.7 V lower than the emitter terminal.

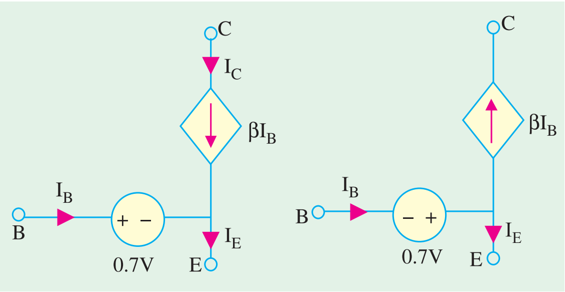

Fig. 57.43

To account for the effect of base control, a current source of βI_B is placed between collector and base terminals. It is called a dependent or controlled source because it is a function of a variable in another circuit. It may be noted that $I_E = (I_B + I_C)$ in both cases.

57.29. BJT Switches

Very often, bipolar junction transistors are used as electronic switches. With the help of such a switch, a given load can be turned ON or OFF by a small control signal. This control signal might be the one appearing at the output of a digital logic or a microprocessor. The power level of the control signal is usually very small and, hence, it is incapable of switching the load directly. However, such a control signal is certainly capable of providing enough base drive to switch a transistor ON or OFF and, hence, the transistor is made to switch the load.

When using BJT as a switch, usually two levels of control signal are employed. With one level, the transistor operates in the cut-off region (open) whereas with the other level, it operates in the saturation region and acts as a short-circuit. Fig. 57.44 (*b*) shows the condition when control signal $v_i = 0$. In this case, the *BE* junction is reverse-biased and the transistor is open and, hence acts as an open switch. However, as shown in Fig. 57.44 (*c*) if v_i equals a positive voltage of sufficient magnitude to produce saturation *i.e.* if $v_i = v_i$ the transistor acts as a closed switch.

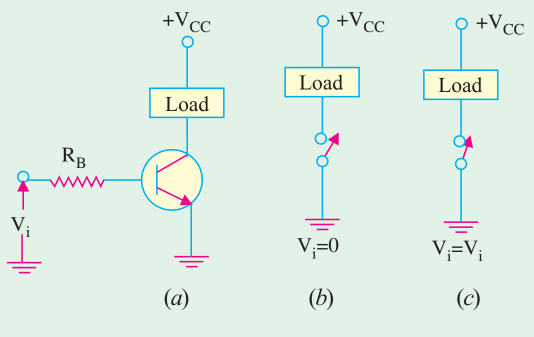

Fig. 57.44

Fig. 57.45 shows a form of series switching circuit utilizing an *NPN* transistor with a negative dc supply and a control signal voltage having levels of zero and $-v_i$.

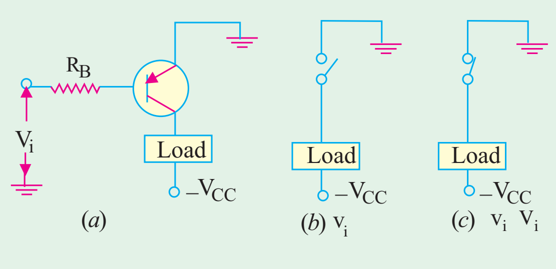

Fig. 57.45

Example 57.20. *The circuit of Fig. 57.46 is designed to produce nearly constant current through the variable collector load resistance. An ideal 6V source is used to establish the current. Determine* **(a)** *value of* I_C *and* V_E, **(b)** *range of* R_C *over which the circuit will function properly. Assume silicon transistor and a b large enough to justify the assumptions used.*

(Applied Electronics-II, Punjab Univ. 1993)

Solution. (*a*) $I_C \cong I_E = (6 - 0.7)/530 = \mathbf{10\ mA}$

$V_E = 6 - 530 \times (10 \times 10) = \mathbf{5.3\ V}$.

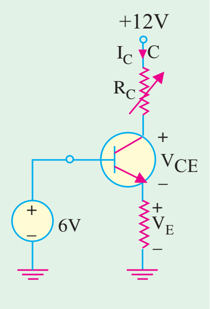

Fig. 57.46

This voltage will remain constant so long as transistor operation is confined to active region.

(*b*) When $R_C = 0$

$$V_{CE} = 12 - 5.3 = 6.7\ \text{V}$$

It is certainly well within the active region. As R_C increases, its drop increases and hence, V_{CE} decreases. There will be some value of R_C at which active region operation ceases.

Now, $V_{CE} = 12 - 5.3 - I_C R_C = 6.7 - I_C R_C$

Value of $R_{C(max)}$ can be found by puting $V_{CE} = 0$

$\therefore \quad 0 = 6.7 - I_C R_{C(max)}$

or $R_{C(max)} = 6.7/I_C = 6.7/0.01 = \mathbf{670\ \Omega}$

Hence, circuit will function as a constant current source so long as R_C is in the range $0 < R_C <$ 670 Ω. When R_C exceeds 670 Ω, the *BJT* becomes saturated.

57.30. Normal DC Voltage Transistor Indications

For a transistor to operate as an amplifier, it is desirable that $V_{CE} = \frac{1}{2}V_{CC}$. However, in actual practice, wide tolerances are allowed. Generally, V_{CE} varies between 25% to 75% of V_{CC}. Any transistor amplifier with $V_{CE} = V_{CC}$ is either open or is operating in cut-off. When operating with V_{CE} near cut-off, the amplifier causes lot of distortion. Same is the case when V_{CE} is nearly zero. Hence, any transistor amplifier with V_{CE} more than 75% V_{CC} or less than 25% V_{CC} should be suspected of having a problem and further investigated.

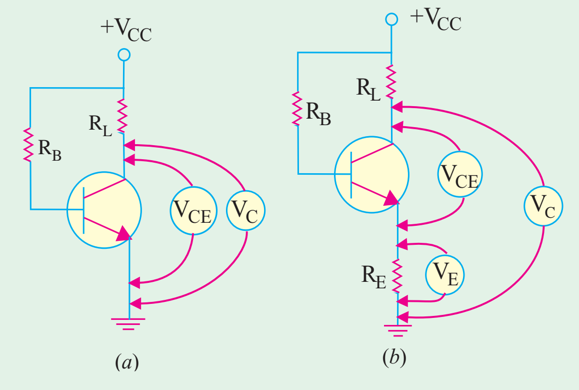

Fig. 57.47

In the circuit shown in Fig. 57.47 (*a*), V_{CE} should be in the range 25 –75% of V_{CC}. In the circuit of Fig. 57.47 (*b*), V_{CE} may be normal but either R_L or R_E could be shorted. Hence, V_C and V_E should be measured seperately. Moreover, V_{CE} could be found by subtracting V_E from V_C.

For the circuit of Fig. 57.47 (*b*), the normal voltmeter readings are

$$V_{CE} = \frac{1}{2}V_{CC} \quad ; \qquad V_E = \frac{1}{4}V_{CC} \quad ; \qquad V_E = \frac{3}{4}V_{CC}$$

If instead of R_L, there is a low-resistance coil in the circuit, then

$$V_{CE} = \frac{1}{2}V_{CC} \quad ; \qquad V_E = \frac{1}{2}V_{CC} \quad ; \qquad V_C = V_{CC}$$

57.31. Transistor Fault Location

Voltage measurements are employed in the vast majority of trouble situations because current measurements are comparatively difficult to make. Magnitude of V_{CE} is of great diagnostic value in finding and locating faults in a transistor circuit. Following possibilities are considered :

***(a)* $V_{CE} = 0$**

Possibilities are that the transistor is

1. shorted out, **2.** operating in saturation, **3.** disconnected from V_{CC}

***(b)* $V_{CE} = \frac{1}{2}V_{CC}$**

It shows that the circuit is operating normally and is well-designed.

***(c)* $V_{CE} = V_{CC}$**

Possibilities are that the transistor is

1. open-circuited,

2. operating in out-off

3. having all resistors in series with V_{CE} shorted.

Example 57.21. *Compute the value of V_{CE} for the CE circuit shown in Fig. 57.48.*

Solution. Since the collector is disconnected from the supply due to 'open' in the

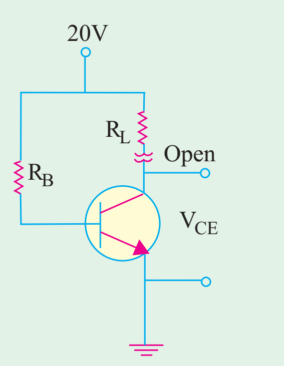

Fig. 57.48

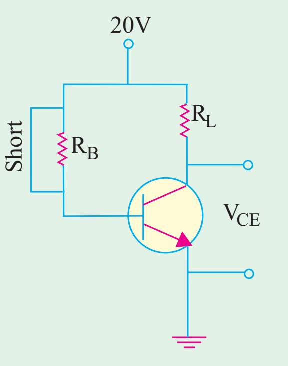

Fig. 57.49

circuit, $V_{CE} = 0$. It represents fault condition No. (*a*) 3 in Art. 57.31.

Example. 57.22. *What is the value of V_{CE} in the CE circuit of Fig. 57.49.*

Solution. Since R_B is shorted out, I_B, would increase and probably burn out the *E/B* junction. But this burn out is not indicated in the question. Hence, with high base current, the transistor is operating in saturation so that $V_{CE} = 0$.

Example 57.23. *What is the value of V_{CE} in the circuit of Fig. 57.50.*

Solution. Since R_L is the only resistor in series with the transistor and is shorted out, it means that there is no voltage drop anywhere. Hence, $V_{CE} = V_{CC}$. It represents fault No. (*c*) 3 stated in Art. 7.31 above.

Example 57.24. *Find the possible value of V_{CE}, V_C and V_E for the circuit shown in Fig. 57.51.*

Solution. In the circuit of Fig. 57.51, there is neither a short nor an open and the voltage polarities are correct for an *NPN* transistor. It looks like a well-designed circuit operating normally. Hence, according to Art. 57.30.

$$V_{CE} = \frac{1}{2}V_{CC} = \mathbf{10\ V};\ V_E = \frac{1}{4}V_{CC} = \mathbf{5\ V}$$

$$V_C = \frac{3}{4}V_{CC} = \mathbf{15\ V}$$

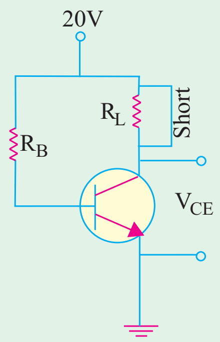

Fig. 57.50

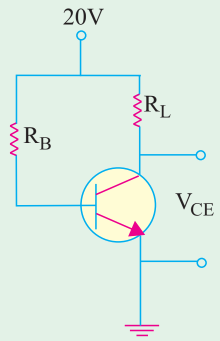

Fig. 57.51

Example 57.25. *Find the values of V_C, V_E and V_{CE} in the circuit of Fig. 57.52.*

Solution. Since $I_B = 0$, transistor is cut off.

Hence, $V_E = \mathbf{0}$

Also $V_C = \mathbf{-20\ V}$

and $V_{CE} = \mathbf{-20\ V}$

Example 57.26. *What would be the values of V_C, V_E and V_{CE} for the circuit shown in Fig. 57.53.*

Solution. Since emitter is open, no current flows in any part of the circuit. The transistor is essentially cut off. Without IR drops, all points above the emitter are at 30 V.

$\therefore$ $V_E = \mathbf{30\ V}$;

$V_C = \mathbf{30\ V}$ and

$V_{CE} = \mathbf{0\ V}$

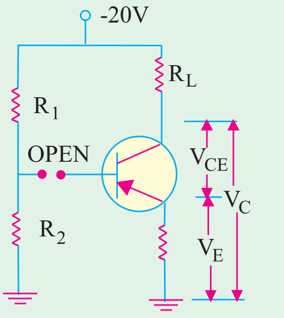

Fig. 57.52

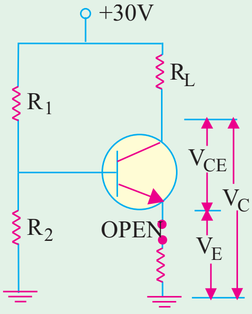

Fig. 57.53

57.32. Solving Universal

Stabilization Circuit

Such a circuit is shown in Fig. 57.54 in which ***R_E appears*** to be in parallel with R_2. But according to the β-rule (Art 57.24), R_2 is actually in parallel with $\beta\ R_E$. In a well-designed circuit, the resistance $\beta\ R_E$ is much larger than R_2. Hence, their combined resistance = $R_2 \| \beta\ R_E \cong R_2$. On this assumption as well as another that I_B is practically zero, we can find voltage drop across R_2 by the Proportional Voltage Formula. Since V_{CC} is applied across $R_1 - R_2$ potential divider circuit, drop across R_2.

$$= V_{CC} \cdot R_2/(R_1 + R_2)$$

If we neglect V_{BE}, then this drop equals V_E.

$$\therefore \qquad V_E \cong V_{CC}\,\frac{R_2}{R_1+R_2}$$

and $$I_E \cong \frac{V_E}{R_E}$$

Having found I_E, other currents and voltage drops can be easily found.

$V_{EE} = V_{CC} - I_C R_L - I_E R_E$

Since, $I_E \cong I_C$

$\therefore\ V_{CE} = V_{CC} - I_E R_L - I_E R_E = V_{CC} - I_E (R_L + R_E)$

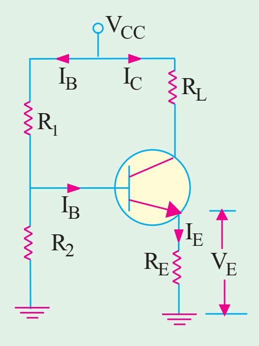

Fig. 57.54

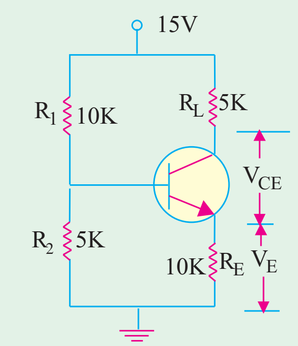

Fig. 57.55

Example 57.27. *Find V_{CE} and V_E for the circuit shown in Fig. 57.55. Neglect V_{BE}.*

Solution. As explained above

$$V_E = V_2 = V_{CC}\,\frac{R_E}{R_1+R_2} = 15 \times \frac{5}{15} = \mathbf{5\ V}$$

$$I_E = V_E/R_E = 5\text{ V}/10\text{ K} \quad = 0.5\text{ mA}$$

$$I_C \cong I_E = 0.5\text{ mA},\ V_{CE} = V_{CC} - I_E(R_L + R_E) = 15 - 0.5 \times 15 = \mathbf{7.5\ V}$$

57.33. Notation for Voltages and Currents

In order to avoid confusion while dealing with dc and ac voltages and currents, following notation will be employed :

1. For d.c. or non-time-varying quantities

We will use capital letters with capital subscripts such as

I_E, I_B, I_C	—	for *dc* currents
V_E, V_B, V_C	—	for *dc* voltages to ground
V_{BE}, V_{CB}, V_{CE}	—	for *dc* potential differences
V_{EE}, V_{CC}, V_{BB}	—	for *dc* source or supply voltages

2. For ac quantities

We will use the following symbols :

i_e, i_b, i_c	—	for instantaneous values of ac currents
I_e, I_b, I_c	—	for r.m.s values of a.c. currents
v_e, v_b, v_c	—	for instantaneous values of a.c. voltages to ground
v_{be}, v_{eb}, v_{ce}	—	for a.c. voltage differences

3. Total ac and dc voltages and currents

In this case, we will use a hybrid notation. For example, i_E will be used to represent the total emitter current, *i.e.* sum of dc and ac currents in the emitter.

Fig. 57.56 illustrates the notation discussed above.

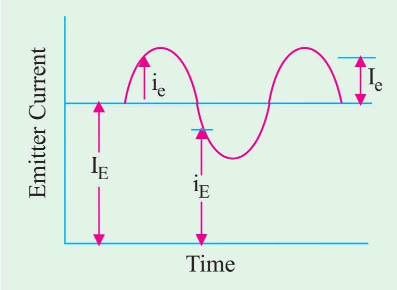

Fig. 57.56

57.34. Increase/Decrease Notation

This notation is very helpful in analysing transistor operation when ac signal is applied to it. It is simply this:

↑ means increases and ↓ means decrease.

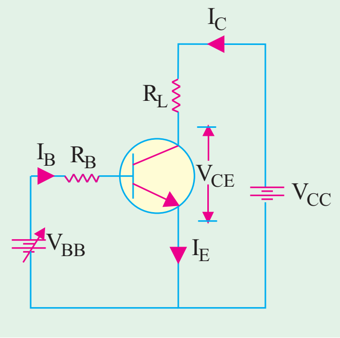

Fig. 57.57

As an illustration, consider the transistor circuit of Fig. 57.57. If V_{BB} were increased (↑), I_B would increase (↑). This would increase I_C (↑) because it equals β I_B. The drop $I_C R_L$ would increase (↓) and, hence, V_{CE} will decrease (↓) because $V_{CE} = V_C - I_C R_L$.

Using increase/decrease notation, the above sequence of changes can be written as

$$V_{BB}\uparrow,\ I_B\uparrow,\ I_C\uparrow,\ I_C R_L\uparrow\ V_{CE}\downarrow$$

At one look, we can straight away say that as input voltage is increased, output voltage is decreased.

57.35. Applying AC to a DC Biased Transistor

Suppose we want to apply an ac signal to the input emitter-base circuit of a properly-biased transistor shown in Fig. 57.58. If we apply the a.c. source directly across the *EBJ* as shown in Fig. 57.58 (*a*), it will upset the d.c. bias. It should be kept in mind that most ***ac signal sources are nearly a short to dc.*** Hence, nearly whole of I_B would pass through a.c. source rather than the base thereby spoiling the transistor bias.

In order to connect the ac source and at the same time not upset the d.c. bias, the ac source is connected via a coupling capacitor *C* as shown in Fig. 57.58 (*b*). This capacitor acts as an 'open' for dc but almost a short for ac source provided it is of sufficiently large capacitance.

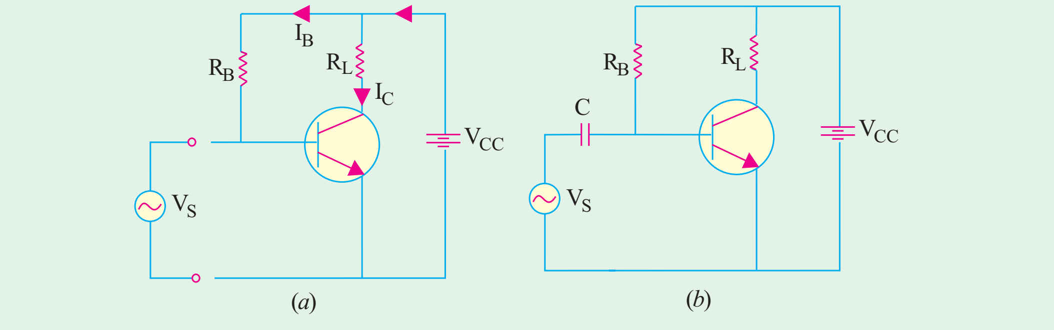

Fig. 57.58

57.36. Transistor AC/DC Analysis

In Fig. 57.59 is shown a *CE* amplifier circuit having an ac signal voltage v_{be}* applied across its *E/B* junction. This voltage will be added to the dc voltage V_{BE} as if the two were connected in series. The resultant voltage is shown in Fig. 57.59 (*b*) which shows ac voltage riding the d.c. level. The variations in the resultant output voltage V_{CE} [Fig. 57.59 (*b*)] can be expressed in terms of the increase/decrease notation. It will be assumed that V_{BE} is such as to bias V_{CE} at V_{CC} when no a.c. signal is applied.

(*i*) First Quarter Cycle

In the first quarter-cycle of the input signal, both V_{BE} and V_{BE} increase thereby giving rise to the following sequence of changes :

$$V_{BE}\ \uparrow,\ i_B\ \uparrow,\quad i_C\quad \uparrow,\quad i_C R_L\uparrow\ V_{CE}\downarrow$$

Hence, output voltage decreases as shown in Fig. 57.59 (*c*)

(*ii*) Second Quarter Cycle

Here, V_{bc} as well as V_{BE} decrease. Hence,

$$V_{BE}\downarrow,\quad i_B\downarrow,\quad i_C\downarrow,\quad i_C R_L\downarrow,\quad V_{CE}\downarrow$$

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* Normally, we will use the notation υ_i or cin or c_i while discussing amplifiers.

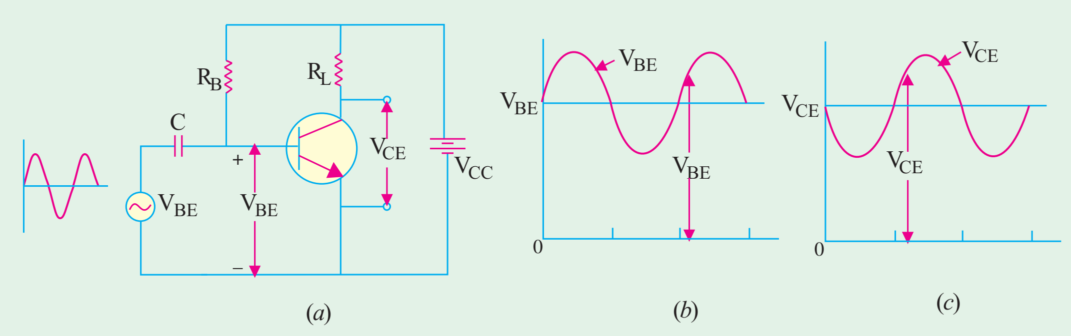

Fig. 57.59

Again, V_{CE} does the opposite of V_{BE}.

Same changes will happen in third quarter cycle as happened in the first quarter-cycle and so on. It is seen from Fig. 57.60 (*c*) that output *ac* voltage is 180° out of phase with the input voltage.

Example 57.28. *Calculate the value of* V_{CE} *in the circuit of Fig. 57.60 (a) if a.c. signal voltage is sinusoidal with a peak value of 0.01 V. Take voltage gain* A_v *of the circuit as 100 and* $\beta = 100$. *Depict the waveform of the output voltage separately*.

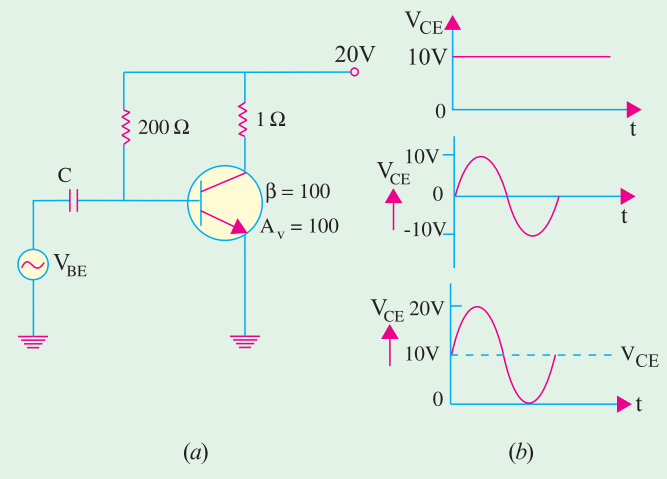

Fig. 57.60

Solution.
$$I_B = \frac{V_{CC}}{R_B} = \frac{20}{200} = 0.1\text{A}$$
$$I_C = \beta I_B = 100 \times 0.1 = 10 \text{ A}$$

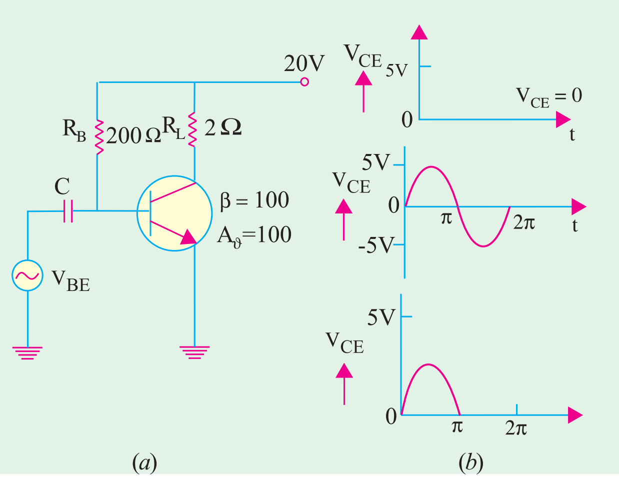

Fig. 57.61

$V_{CE} = V_{CC} - I_C R_L = 20 - 10 \times 1 = 10$ V;

$v_{CE} = A_V v_{BE} = 100 \times\ 0.01 = 10$ V

The combined output voltage v_{CE} is the sum of v_{CE} and v_{CE} and is shown graphically in Fig. 57.60 (*b*). It is seen that 100 times amplified ac signal rides the dc voltage.

Example 57.29. *Find* v_{CE} *in the circuit of Fig. 57.61 (a) and sketch its waveform. Take* $A_u = 100$ *and* $\beta = 100$ *and peak input signal voltage as 0.05 V.*

Solution. $I_B = 20/200 = 0.1$ A ; $I_C = 100 \times 0.1 = 10$ A ; $V_{CE} = 20 - (10 \times 2) = 0$.

Obviously, the transistor has been biased at saturation as shown in Fig. 57.61 (*b*).

The addition of v_{CE} and v_{CE}, is shown graphically in Fig. 57.61 (*b*). During the positive half-cycle of the signal, the transistor comes out of saturation and lets pass the half-cycle. However, during the negative half-cycle of input signal, transistor is further driven into saturation. Since it is already biased at V_{CC}´*s* most negative limit (0 volt), it cannot further go negative. Hence, the negative half-cycle of the signal is lost in saturation.

Tutorial Problems No. 57.1

1. A *CB*-connected transistor has $\alpha = 0.96$ and $I_E = 2$ mA. Find its I_C and I_B. **[1.92 mA, 80 μA]**

2. A *CB*-connected transistor has $I_B = 20$ μA and $I_E = 2$ mA. Compute the value of α and I_C. **[0.99, 1.98 mA]**

3. A *CE*-connected transistor has $\alpha = 100$ and $I_B = 50$ μA. Compute the values of α, I_C and I_E. **[0.99 ; 5 mA ; 5.05 mA]**

4. The following quantities are measured in a *CE* transistor : $I_C = 5$ mA ; $I_B = 100$ μA. Determine β and I_E. **[0.98 ; 50 ; 51 mA]**

5. A transistor has $\alpha = 0.98$, $I_{CBO} = 5$ μA and $I_B = 100$ μA. Find the values of I_C and I_E. **[5.15 mA ; 5.25 mA]**

6. Following measurements are made in a transistor ; $I_C = 5.202$ mA, $I_B = 50$ mA, $I_{CBO} = 2$ mA. Compute the values of α, β and I_E. **[0.99 ; 100 ; 5.252 mA]**

7. Following measurements were made in a certain transistor :

$I_C = 5.202$ mA; $I_B = 50$ mA ; $I_{CBO} = 2$ mA.

Determine (*i*) α, β and I_E (*ii*) new value of I_B required to make $I_C = 10$ mA. **[(*i*) 0.99 ; 100 ; 5.252 mA (*ii*) 97.98 A]**

8. For the *CB* circuit of Fig. 57.62, find the value of V_{CB}. Neglect junction voltage V_{BE}. **[5 V]**

9. In the *CB* circuit of Fig. 57.63, what value of R_E causes $V_{BC} = 10$ V? Neglect V_{EB}. **[5 K]**

10. For the *CE* circuit of Fig. 57.64, calculate the values of I_B, I_C, I_E and V_{CE}. Take $\beta = 50$ and neglect V_{BE}. **[100 μA, 5 mA, 5.1 mA, 7.5 V]**

11. In the circuit of Fig. 57.65, calculate I_B, I_C, I_E and V_{CE}. Take transistor $\beta = 50$ and neglect V_{BE}. **[100 μA, 5 mA, 5.1 mA, 5V]**

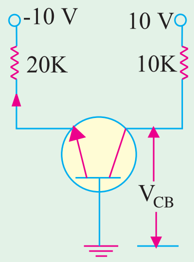

Fig. 57.62

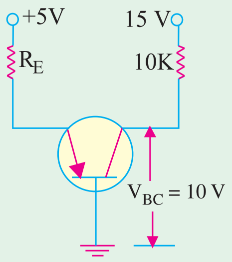

Fig. 57.63

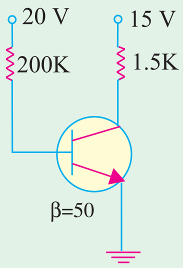

Fig. 57.64

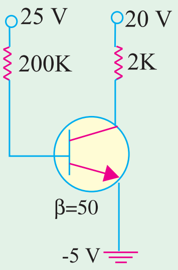

Fig. 57.65

12. In the *CC* circuit of Fig. 57.66, compute the values of I_E, I_B, I_C and V_{CE}. Neglect V_{BE}. **[0.25 mA, 2.48 μA, 0.248 mA, 5 V]**

13. In the *CC* circuit of Fig. 57.67, find IE, I_B, I_C and V_{CE}. Neglect V_{BE}. **[0.25 mA, 2.48 μA, 0.248 mA, 5 V]**

14. In the circuit of Fig. 57.68, find the drop across R_L. The transistor $\beta = 100$. **[5 V]**

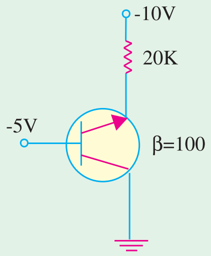

Fig. 57.66

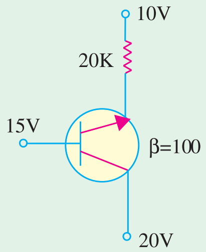

Fig. 57.67

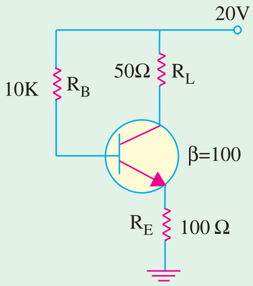

Fig. 57.68

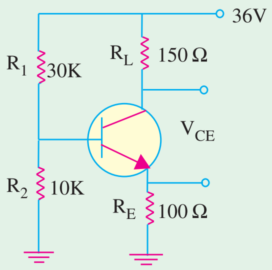

Fig. 57.69

15. Find the value of V_{CE} for the universal stabilization circuit of Fig. 57.69.

[13.5 V]

16. *(i)* The reverse saturation current for the Ge transistor in Fig. 57.70 is 2μ A at room temperature (25°C) and increases by a factor of 2 for each temperature increase of 10°C. Bias voltage V_{BB} = 5V. Find the maximum allowable value for R_B if the transistor is to remain cutoff at a temperature of 75°C.

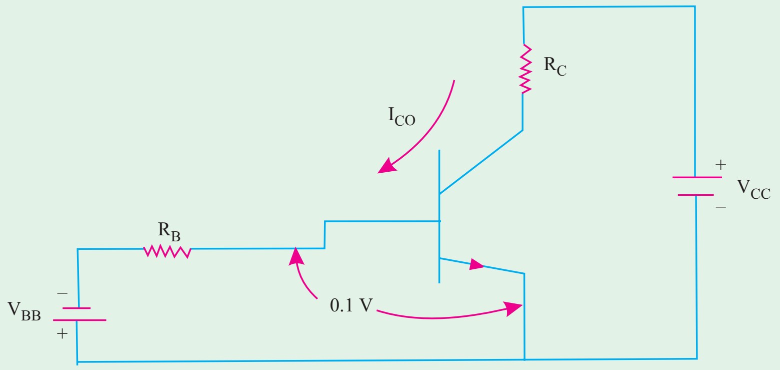

Fig. 57.70

(ii) If V_{BB} = 1.0V and R_B = 50 k-ohm, how high may the temperature increase before the transistor comes out of cut-off *(Electronic Devices and Circuits Nagpur University Summer, 2004)*

17. Calculate the exact value of emitter current and V_{CE} in the circuit shown in Fig. 57.71 Assume transistor to be silicon and β= 100.

(Electronic Devices of Circuits, Nagpur University Summer, 2004)

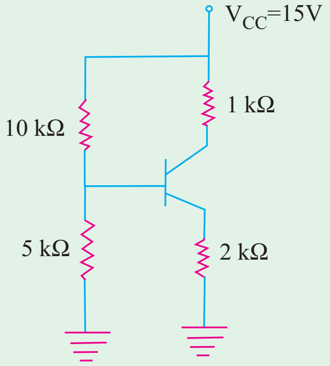

Fig. 57.71

OBJECTIVE TESTS – 57

1. The emitter of a transistor is generally doped the heaviest because it
(*a*) has to dissipate maximum power
(*b*) has to supply the charge carriers
(*c*) is the first region of the transistor
(*d*) must possess low resistance.

2. For current working of an *NPN* bipolar junction transistor, the different electrodes should have the following polarities with respect to emitter.
(*a*) collector +ve, base –ve
(*b*) collector –ve, base + ve
(*c*) collector – ve, base –ve
(*d*) collector + ve, base +ve

3. Select the CORRECT alternative.
In a bipolar transistor
(*a*) emitter region is of low/high resistivity matterial which is lightly/ heavily-doped.
(*b*) collector region is of lower/higher conductivity than emitter region
(*c*) base region is of high/low resistivity material which is only lightly/ heavily doped.

4. In a properly-biased *NPN* transistor, most of the electrons from the emitter
(*a*) recombine with holes in the base
(*b*) recombine in the emitter itself
(*c*) pass through the base to the collector
(*d*) are stopped by the junction barrier.

5. The following relationships between α and β are correct EXCEPT
(*a*) $\beta = \dfrac{\alpha}{1-\alpha}$ (*b*) $\alpha = \dfrac{\beta}{1-\beta}$
(*c*) $\alpha = \dfrac{\beta}{1+\beta}$ (*d*) $1-\alpha = \dfrac{1}{1+\beta}$

6. The value of total collector current in a *CB* circuit is
(*a*) $I_C = \alpha I_E$ (*b*) $I_C = \alpha I_E + I_{CO}$
(*c*) $I_C = \alpha I_E - I_{CO}$ (*d*) $I_C = \alpha I_E$.

7. In a junction transistor, the collector cut off current I_{CBO} reduces considerably by doping the
(*a*) emitter with high level of impurity
(*b*) emitter with low level of impurity
(*c*) collector with high level of impurity
(*d*) collector with low level of impurity

8. In a transistor amplifier, the reverse saturation current I_{CO}
(*a*) doubles for every 10°C rise in temperature
(*b*) doubles for every 1°C rise in temperature
(*c*) increases linearly with the temperature
(*d*) doubles for every 5°C rise in temperature

9. In the case of a bipolar transistor, α is
(*a*) positive and > 1
(*b*) positive and < 1
(*c*) negative and > 1
(*d*) negative and < 1.

10. The *EBJ* of a given transistor is forward- biased and its *CBJ* reverse-biased. If the base current is increased, then its
(*a*) I_C will decrease
(*b*) V_{CE} will increase
(*c*) I_C will increase
(*d*) V_{CC} will increase.

11. The collector characteristics of a *CE* - connected transistor may be used to find its
(*a*) input resistance
(*b*) base current
(*c*) output resistance
(*d*) voltage gain.

12. Which of the following approximations is often used in electronic circuits ?
(*a*) $I_C \cong I_E$ (*b*) $I_B \cong I_C$
(*c*) $I_B \cong I_E$ (*d*) $I_E \cong I_B + I_C$

13. When a transistor is fully switched ON, it is said to be
(*a*) shorted (*b*) saturated
(*c*) open (*d*) cut-off

14. If a change in base current does not change the collector current, the transistor amplifier is said to be
(*a*) saturated (*b*) cut-off
(*c*) critical (*d*) complemented.

15. When an *NPN* transistor is saturated, its V_{CE}
(*a*) is zero and I_C is zero
(*b*) is low and I_C is high
(*c*) equals V_{CC} and I_C is zero
(*d*) equals V_{CC} and I_C is high.

16. When an *NPN* transistor is cut-off, its V_{CC}
(*a*) equals V_{CC} and I_C is high
(*b*) equals V_{CC} and I_C is zero
(*c*) is low and I_C is high
(*d*) is high and I_C is low.

17. If, in a bipolar junction transistor, $I_B = 100\ \mu A$ and $I_C = 10$ mA, in what range does the value of its beta lie ?
(*a*) 0.1 to 1.0 (*b*) 1.01 to 10
(*c*) 10.1 to 100 (*d*) 100.1 to 1000.

18. In a *BJT*, largest current flow occurs
(*a*) in the emitter (*b*) in the collector
(*c*) in the base
(*d*) through *CB* junction.

19. In a properly-connected *BJT*, an increase in base current causes increase in
(*a*) I_C only (*b*) I_E only
(*c*) both I_C and I_E (*d*) leakage current.

20. When a *BJT* operates in cut-off
(*a*) $V_{CE} = 0$
(*b*) $V_{CE} = V_{cc}$
(*c*) V_{CE} has negative value
(*d*) I_C is maximum.

21. When a *BJT* is in saturation
(*a*) $I_C = 0$
(*b*) I_B controls I_C
(*c*) $V_{CE} = 0$
(*d*) V_{CE} has positive value.

22. The best approximation for V_C in the circuit shown in Fig. 54.72 will be (assume β to be high)
(*a*) 4 V (*b*) 6.8 V
(*c*) 8.7 V (*d*) 10.7 V

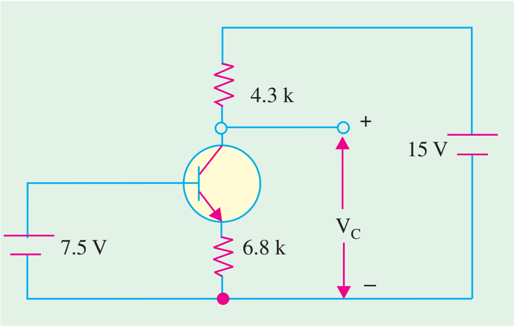

Fig. 57.72

23. Assume = 0.7 V and β = 50 for the transistor in the circuit shown in Fig. 57.73. For = 2V, the value of R_B is

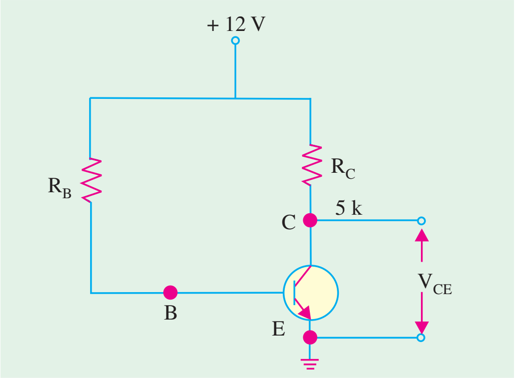

Fig. 57.73

(*a*) 200 Ω (*b*) 242 Ω
(*c*) 283 Ω (*d*) 300 Ω

24. In the circuit shown in Fig. 57.74, if $R_L = R_C =$ KΩ , then the value of V_0 will be

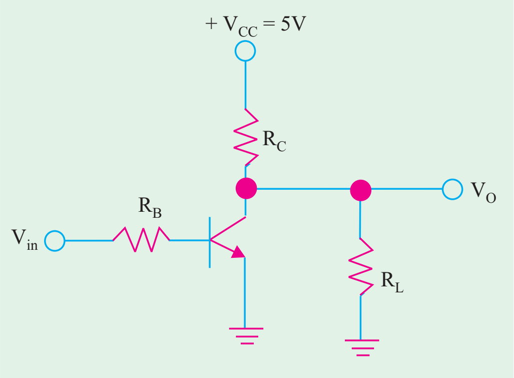

Fig. 57.74

(*a*) 4.55 V (*b*) 2.5 V
(*c*) 1 V (*d*) zero

25. A transistor is operated as a non-saturated switch to eliminate
(*a*) storage time
(*b*) turn-off time
(*c*) turn-on time
(*d*) delay time

26. Early-effect in BJT refers to
(*a*) avalanche break down
(*b*) thermal break down
(*c*) base narrowing
(*d*) zener break-down

(UPSC Engg. Services 2002)

(**Hint.** Early effect also called base-width modulation) is the variation of effective base width by the collector voltage)

27. A bipolar junction transistor (BJT) is used as power control switch by biasing it in the cut-off region (OFF state) or in the saturation region (ON state). In the ON state, for the BJT.
(*a*) both the base-emitter junction and base-collector junctions are reverse biased
(*b*) the base-emitter is reverse biased, and the base-collector junction is forward biased
(*c*) the base-emitter junction is forward biased, and the base-collector junction is reverse biased
(*d*) both the base-emitter and base-collector junctions are forward biased.

ANSWERS

1. (*a*) **2.** (*d*) **3.** (*a*) low, heavily (*b*) lower (*c*) high, lightly **4.** (*c*) **5.** (*b*) **6.** (*b*) **7.** (*d*)
8. (*a*) **9.** (*d*) **10.** (*c*) **11.** (*c*) **12.** (*a*) **13.** (*b*) **14.** (*a*) **15.** (*b*) **16.** (*b*) **17.** (*b*) **18.** (*a*)
19. (*c*) **20.** (*b*) **21.** (*c*) **22.** (*d*) **23.** (*d*) **24.** (*b*) **25.** (*a*) **26.** (*c*) **27.** (*d*)

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