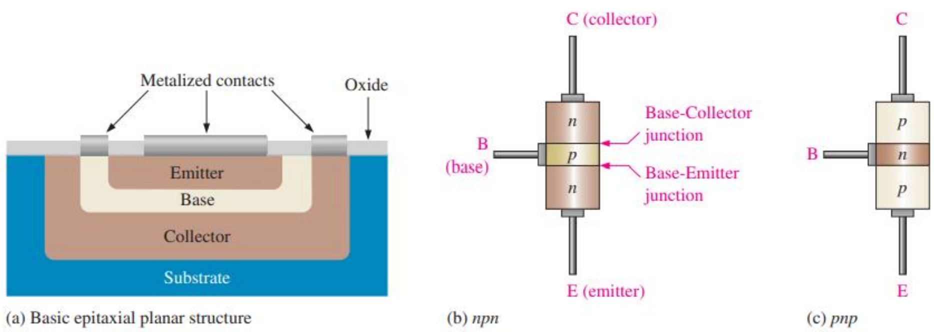
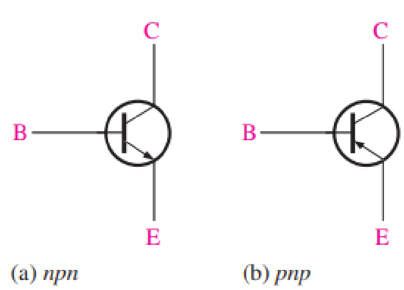
1. Bipolar junction transistor (BJT)

The BJT is constructed with three doped semiconductor regions separated by two pn junctions, as shown in the epitaxial planar structure in Figure 4–1(a). The three regions are called emitter, base, and collector. Physical representations of the two types of BJTs are shown in Figure 4–1(b) and (c).



▲ FIGURE 4–1

The pn junction joining the base region and the emitter region is called the base-emitter junction. The pn junction joining the base region and the collector region is called the base-collector junction, as indicated in Figure 4–1(b)

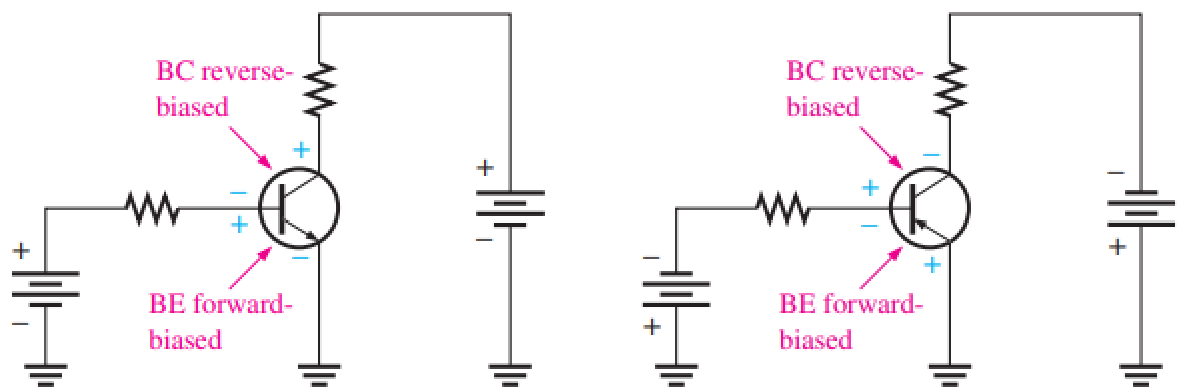


2. Basic BJT Operation

In order for a BJT to operate properly as an amplifier, the two pn junctions must be correctly biased with external dc voltages.

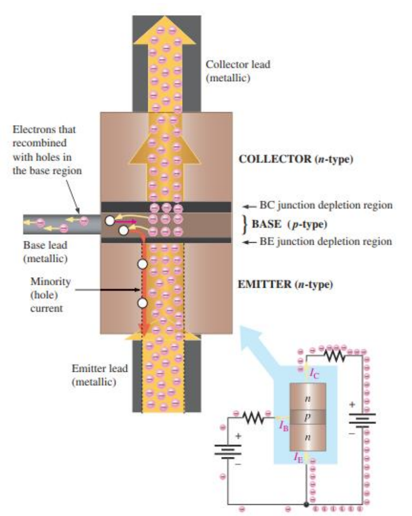
Email: Hasan.muwafaq.gheni@uomus.edu.iq

Figure 4–2 shows a bias arrangement for both npn and pnp BJTs for operation as an amplifier. Notice that in both cases the base-emitter (BE) junction is forward-biased and the base-collector (BC) junction is reverse-biased. This condition is called forward-reverse bias.



(a) *npn* (b) *pnp*

To understand how a transistor operates, let's examine what happens inside the *npn* structure. The heavily doped n-type emitter region has a very high density of conduction-band (free) electrons, as indicate in Figure 4–4



▲ FIGURE 4–4

BJT operation showing electron flow.

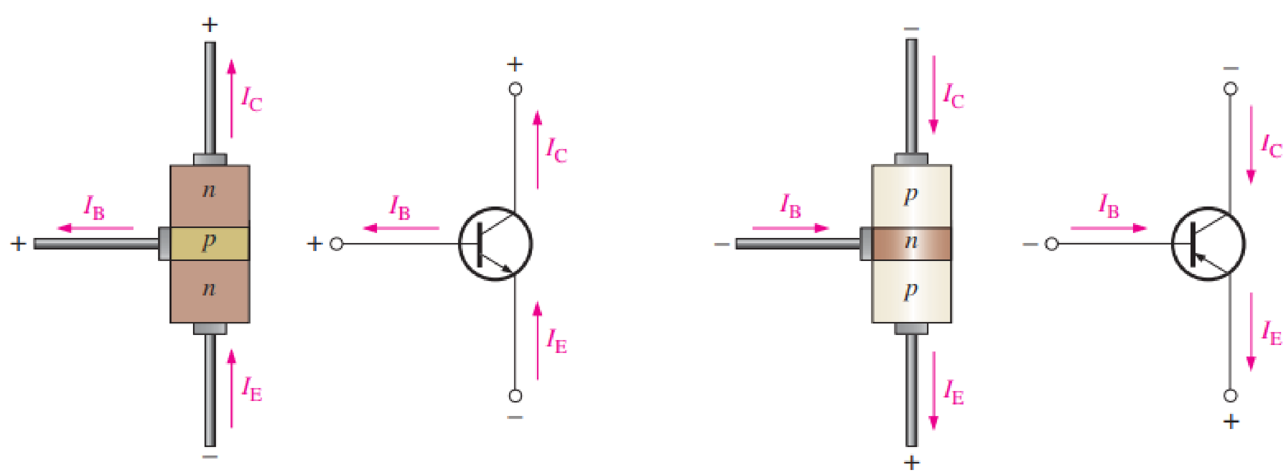
Email: Hasan.muwafaq.gheni@uomus.edu.iq

The directions of the currents in an npn transistor and its schematic symbol are as shown in Figure 4–5(a); those for a pnp transistor are shown in Figure 4–5(b).

Notice that the arrow on the emitter inside the transistor symbols points in the direction of conventional current. These diagrams show that the emitter current (IE) is the sum of the collector current (IC) and the base current (IB), expressed as follows:

$$I_E = I_C + I_B$$

As mentioned before, IB is very small compared to IE or IC. The capital-letter subscripts indicate dc values



(a) *npn* (b) *pnp*

▲ FIGURE 4–5

Transistor currents.

3. BJT Characteristics and Parameters

Two important parameters, $\boldsymbol{\beta DC}$ (dc current gain) and $\boldsymbol{\alpha DC}$ are introduced and used to analyze a BJT circuit. Also, transistor characteristic curves are covered, and you will learn how a BJT's operation can be determined from these curves. Finally, maximum ratings of a BJT are discussed.

The dc current gain of a transistor is the ratio of the dc collector current (I_c) to the dc base current (I_B) and is designated dc beta ($\boldsymbol{\beta DC}$).

$$\boldsymbol{\beta_{DC} = \frac{I_C}{I_B}}$$

Typical values of β_{DC} range from less than 20 to 200 or higher. β_{DC} is usually designated as an equivalent hybrid (h) parameter, h_{FE}, on transistor datasheets. h-parameters are covered in Chapter 6. All you need to know now is that

$$h_{FE} = \beta_{DC}$$

The ratio of the dc collector current (I_C) to the dc emitter current (I_E) is the dc **alpha** (α_{DC}). The alpha is a less-used parameter than beta in transistor circuits.

$$\alpha_{DC} = \frac{I_C}{I_E}$$

Typically, values of α_{DC} range from 0.95 to 0.99 or greater, but α_{DC} is always less than 1. The reason is that I_C is always slightly less than I_E by the amount of I_B. For example, if $I_E = 100$ mA and $I_B = 1$ mA, then $I_C = 99$ mA and $\alpha_{DC} = 0.99$.

EXAMPLE 4–1

Determine the dc current gain β_{DC} and the emitter current I_E for a transistor where $I_B = 50\ \mu A$ and $I_C = 3.65$ mA.

Solution

$$\beta_{DC} = \frac{I_C}{I_B} = \frac{3.65 \text{ mA}}{50\ \mu\text{A}} = \mathbf{73}$$

$$I_E = I_C + I_B = 3.65 \text{ mA} + 50\ \mu\text{A} = \mathbf{3.70\ mA}$$

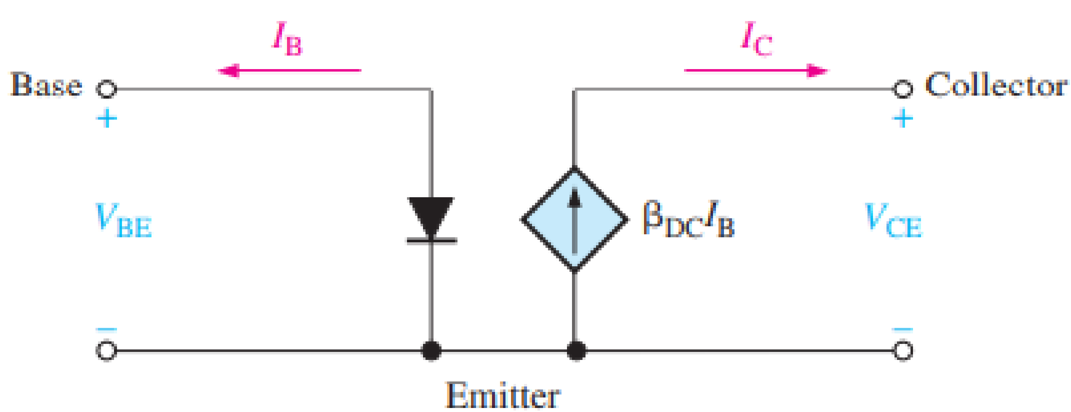
*Related Problem** A certain transistor has a β_{DC} of 200. When the base current is 50 μA, determine the collector current.

*Answers can be found at www.pearsonhighered.com/floyd

4. Transistor DC Model

We can view the unsaturated **BJT** as a device with a current input and a dependent current source in the output circuit, as shown in Figure 4–7 for an *npn.*

The input circuit is a forward-biased diode through which there is base current. The output circuit is a dependent current source (diamond-shaped element) with a value that is dependent on the base current, $\boldsymbol{I_B}$, and equal to $\boldsymbol{\beta_{DC} I_B}$.



Email: Hasan.muwafaq.gheni@uomus.edu.iq

5. BJT Circuit Analysis

Consider the basic transistor bias circuit configuration in Figure 4–8. Three transistor dc currents and three dc voltages can be identified.

I_B: dc base current

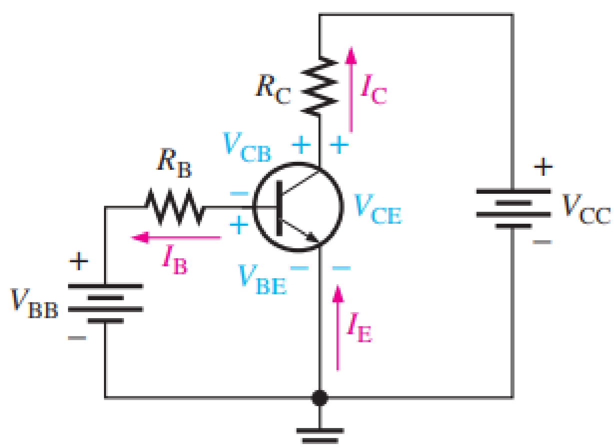
I_E: dc emitter current

I_C: dc collector current

V_{BE}: dc voltage at base with respect to emitter

V_{CB}: dc voltage at collector with respect to base

V_{CE}: dc voltage at collector with respect to emitter



$$V_{BE} \cong 0.7\ \mathrm{V}$$

$$V_{R_B} = V_{BB} - V_{BE}$$

Also, by Ohm's law,

$$V_{R_B} = I_B R_B$$

Email: Hasan.muwafaq.gheni@uomus.edu.iq

Also, by Ohm's law,

$$V_{R_B} = I_B R_B$$

Substituting for V_{R_B} yields

$$I_B R_B = V_{BB} - V_{BE}$$

Solving for I_B,

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

The voltage at the collector with respect to the grounded emitter is

$$V_{CE} = V_{CC} - V_{R_C}$$

Since the drop across R_C is

$$V_{R_C} = I_C R_C$$

the voltage at the collector with respect to the emitter can be written as

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

where $I_C = \beta_{DC} I_B$.

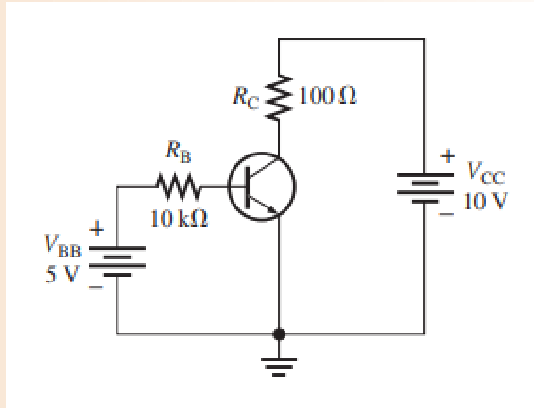
The voltage across the reverse-biased collector-base junction is

$$\mathbf{V_{CB} = V_{CE} - V_{BE}}$$

EXAMPLE 4–2

Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of Figure 4–9. The transistor has a $\beta_{DC} = 150$.

▶ **FIGURE 4–9**



Solution From Equation 4–3, $V_{BE} \cong$ **0.7 V.** Calculate the base, collector, and emitter currents as follows:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega} = \mathbf{430\ \mu A}$$

$$I_C = \beta_{DC} I_B = (150)(430\ \mu\text{A}) = \mathbf{64.5\ mA}$$

$$I_E = I_C + I_B = 64.5\text{ mA} + 430\ \mu\text{A} = \mathbf{64.9\ mA}$$

Solve for V_{CE} and V_{CB}.

$$V_{CE} = V_{CC} - I_C R_C = 10\text{ V} - (64.5\text{ mA})(100\ \Omega) = 10\text{ V} - 6.45\text{ V} = \mathbf{3.55\ V}$$

$$V_{CB} = V_{CE} - V_{BE} = 3.55\text{ V} - 0.7\text{ V} = \mathbf{2.85\ V}$$

Since the collector is at a higher voltage than the base, the collector-base junction is reverse-biased.

Email: Hasan.muwafaq.gheni@uomus.edu.iq