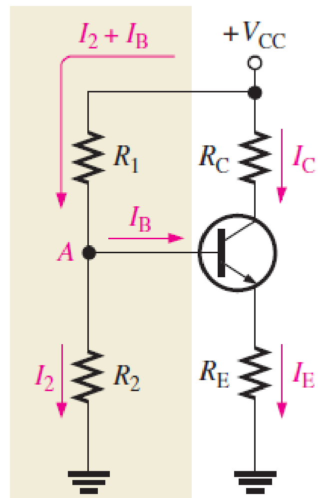
1. Voltage-Divider Bias

A more practical bias method is to use V_{CC} as the single bias source, as shown in Figure. To simplify the schematic, the battery symbol is omitted and replaced by a line termination circle with a voltage indicator (V_{CC}) as shown.

A dc bias voltage at the base of the transistor can be developed by a resistive voltage divider that consists of R1 and R2, as shown in Figure.



VCC is the dc collector supply voltage. <u>**Two current paths**</u> are between point **A** and **ground**: one through **R2** and the other through the **base-emitter junction** of the transistor and RE.

To analyse a voltage-divider circuit in which I_B is small compared to I_2, first calculate the voltage on the base using the unloaded voltage-divider rule:

$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC}$$

Once you know the base voltage, you can find the voltages and currents in the circuit, as follows:

$$V_E = V_B - V_{BE}$$

and

$$I_C \cong I_E = \frac{V_E}{R_E}$$

Then,

$$V_C = V_{CC} - I_C R_C$$

Once you know V_C and V_E, you can determine V_{CE}.

$$V_{CE} = V_C - V_E$$

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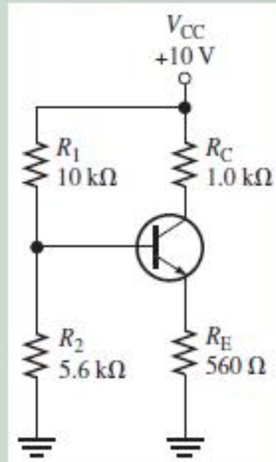
EXAMPLE 5–2 Determine V_{CE} and I_C in the stiff voltage-divider biased transistor circuit of Figure 5–10 if $\beta_{DC} = 100$.

FIGURE 5–10



Solution The base voltage is

$$V_B \cong \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{5.6\text{ k}\Omega}{15.6\text{ k}\Omega}\right)10\text{ V} = 3.59\text{ V}$$

So,

$$V_E = V_B - V_{BE} = 3.59\text{ V} - 0.7\text{ V} = 2.89\text{ V}$$

and

$$I_E = \frac{V_E}{R_E} = \frac{2.89\text{ V}}{560\ \Omega} = 5.16\text{ mA}$$

Therefore,

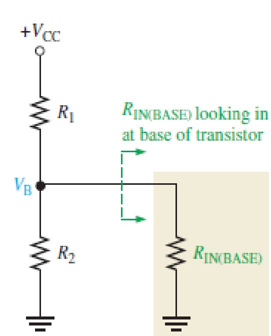
$$I_C \cong I_E = \mathbf{5.16\text{ mA}}$$

and

$$V_C = V_{CC} - I_C R_C = 10\text{ V} - (5.16\text{ mA})(1.0\text{ k}\Omega) = 4.84\text{ V}$$
$$V_{CE} = V_C - V_E = 4.84\text{ V} - 2.89\text{ V} = \mathbf{1.95\text{ V}}$$

Related Problem If the voltage divider in Figure 5–10 was not stiff, how would V_B be affected?

<u>DC Input Resistance at the Transistor Base</u> The dc input resistance of the transistor is proportional to β_{DC}, so it will change for different transistors.



$$R_{IN(BASE)} = \frac{\beta_{DC} V_B}{I_E}$$

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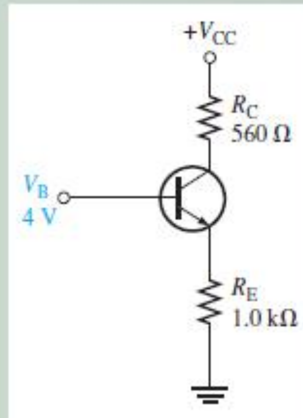
EXAMPLE 5–3 Determine the dc input resistance looking in at the base of the transistor in Figure 5–12. $\beta_{DC} = 125$ and $V_B = 4$ V.

▶ FIGURE 5–12



Solution

$$I_E = \frac{V_B - 0.7\text{ V}}{R_E} = \frac{3.3\text{ V}}{1.0\text{ k}\Omega} = 3.3\text{ mA}$$

$$R_{IN(BASE)} = \frac{\beta_{DC}V_B}{I_E} = \frac{125(4\text{ V})}{3.3\text{ mA}} = \mathbf{152\text{ k}\Omega}$$

Related Problem What is $R_{IN(BASE)}$ in Figure 5–12 if $\beta_{DC} = 60$ and $V_B = 2$ V?

2. Thevenin's Theorem Applied to Voltage-Divider Bias

To analyse a voltage-divider biased transistor circuit for base current loading effects, we will apply Thevenin's theorem to evaluate the circuit.

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC}$$

and the resistance is

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

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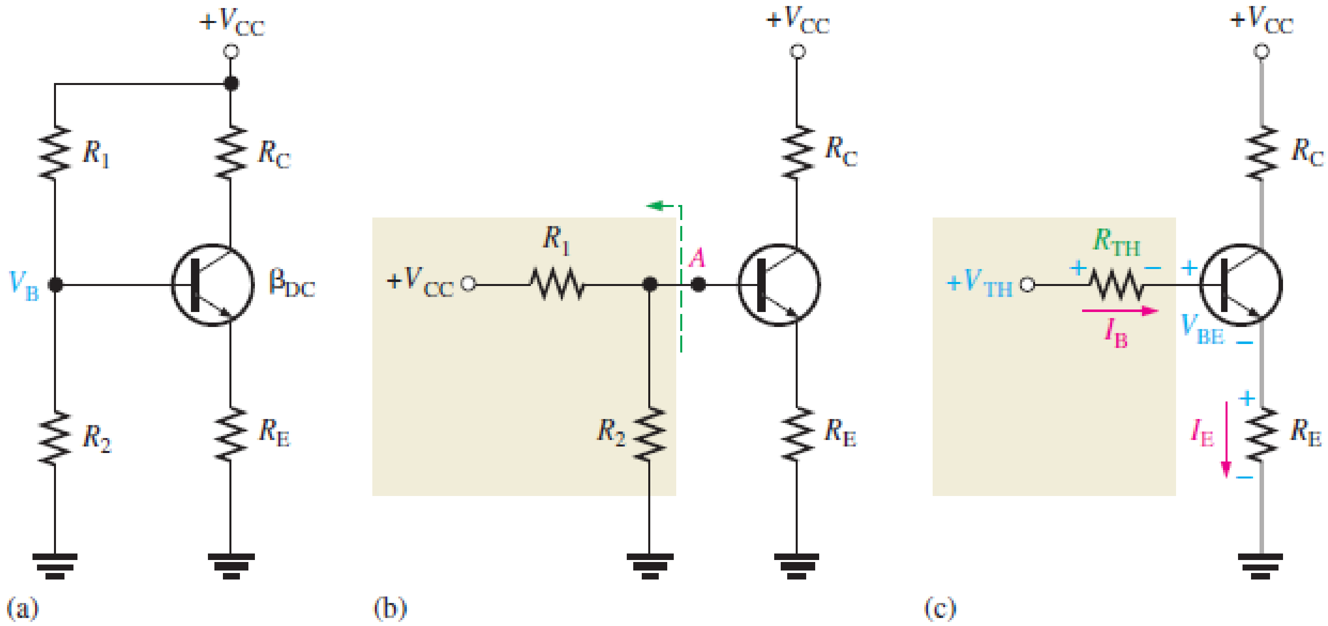


$$V_{TH} - V_{R_{TH}} - V_{BE} - V_{R_E} = 0$$

Substituting, using Ohm's law, and solving for V_{TH},

$$V_{TH} = I_B R_{TH} + V_{BE} + I_E R_E$$

Substituting I_E/β_{DC} for I_B,

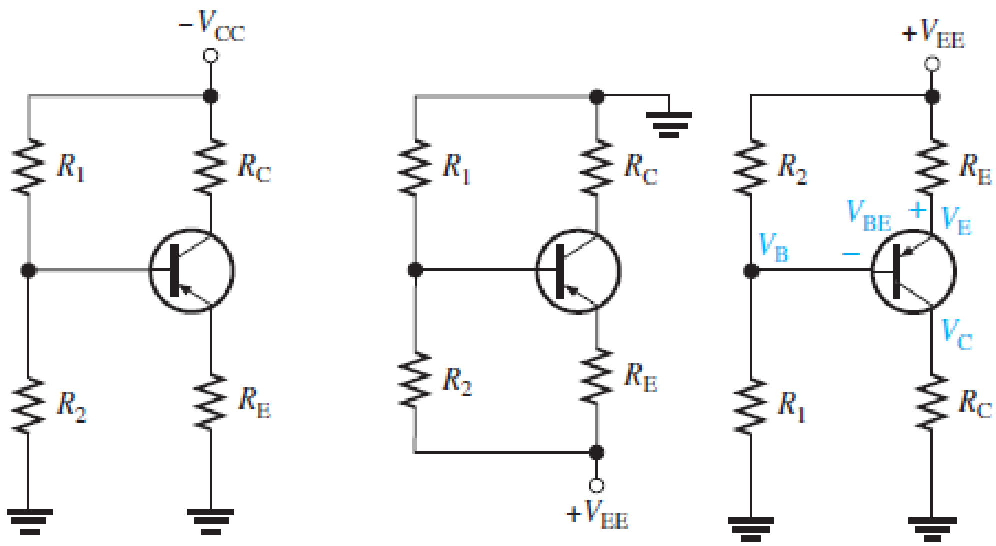
$$V_{TH} = I_E(R_E + R_{TH}/\beta_{DC}) + V_{BE}$$

Then solving for I_E,

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}}$$

3. Voltage-Divider Biased PNP Transistor

pnp transistor requires bias polarities opposite to the npn. This can be accomplished with a negative collector supply voltage, as in Figure (a), or with a positive emitter supply voltage, as in Figure (b).



(a) Negative collector supply voltage, V_{CC} (b) Positive emitter supply voltage, V_{EE} (c) The circuit in (b) redrawn

In a schematic, the *pnp* is often drawn upside down so that the supply voltage is at the top of the schematic and ground at the bottom, as in Figure (c).

$$V_{TH} + I_B R_{TH} - V_{BE} + I_E R_E = 0$$

By Thevenin's theorem,

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC}$$

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

The base current is

$$I_B = \frac{I_E}{\beta_{DC}}$$

The equation for I_E is

$$I_E = \frac{-V_{TH} + V_{BE}}{R_E + R_{TH}/\beta_{DC}}$$

The equation for I_E is

$$I_E = \frac{V_{TH} + V_{BE} - V_{EE}}{R_E + R_{TH}/\beta_{DC}}$$

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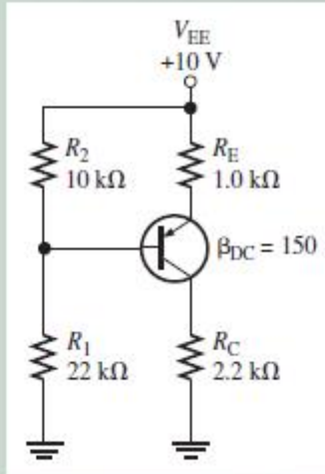
EXAMPLE 5–4

Find I_C and V_{EC} for the *pnp* transistor circuit in Figure 5–15.

▶ FIGURE 5–15



Solution This circuit has the configuration of Figures 5–14(b) and (c). Apply Thevenin's theorem.

$$V_{TH} = \left(\frac{R_1}{R_1 + R_2}\right)V_{EE} = \left(\frac{22\text{ k}\Omega}{22\text{ k}\Omega + 10\text{ k}\Omega}\right)10\text{ V} = (0.688)10\text{ V} = 6.88\text{ V}$$

$$R_{TH} = \frac{R_1R_2}{R_1 + R_2} = \frac{(22\text{ k}\Omega)(10\text{ k}\Omega)}{22\text{ k}\Omega + 10\text{ k}\Omega} = 6.88\text{ k}\Omega$$

Use Equation 5–8 to determine I_E.

$$I_E = \frac{V_{TH} + V_{BE} - V_{EE}}{R_E + R_{TH}/\beta_{DC}} = \frac{6.88\text{ V} + 0.7\text{ V} - 10\text{ V}}{1.0\text{ k}\Omega + 45.9\ \Omega} = \frac{-2.42\text{ V}}{1.0459\text{ k}\Omega} = -2.31\text{ mA}$$

The negative sign on I_E indicates that the assumed current direction in the Kirchhoff's analysis is opposite from the actual current direction. From I_E, you can determine I_C and V_{EC} as follows:

$$I_C = I_E = \mathbf{2.31\text{ mA}}$$

$$V_C = I_CR_C = (2.31\text{ mA})(2.2\text{ k}\Omega) = 5.08\text{ V}$$

$$V_E = V_{EE} - I_ER_E = 10\text{ V} - (2.31\text{ mA})(1.0\text{ k}\Omega) = 7.68\text{ V}$$

$$V_{EC} = V_E - V_C = 7.68\text{ V} - 5.08\text{ V} = \mathbf{2.6\text{ V}}$$

EXAMPLE 5–5

Find I_C and V_{CE} for a *pnp* transistor circuit with these values: $R_1 = 68\ \text{k}\Omega$, $R_2 = 47\ \text{k}\Omega$, $R_C = 1.8\ \text{k}\Omega$, $R_E = 2.2\ \text{k}\Omega$, $V_{CC} = -6\ \text{V}$, and $\beta_{DC} = 75$. Refer to Figure 5–14(a), which shows the schematic with a negative supply voltage.

Solution Apply Thevenin's theorem.

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{47\ \text{k}\Omega}{68\ \text{k}\Omega + 47\ \text{k}\Omega}\right)(-6\ \text{V})$$
$$= (0.409)(-6\ \text{V}) = -2.45\ \text{V}$$

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} = \frac{(68\ \text{k}\Omega)(47\ \text{k}\Omega)}{(68\ \text{k}\Omega + 47\ \text{k}\Omega)} = 27.8\ \text{k}\Omega$$

Use Equation 5–7 to determine I_E.

$$I_E = \frac{-V_{TH} + V_{BE}}{R_E + R_{TH}/\beta_{DC}} = \frac{2.45\ \text{V} + 0.7\ \text{V}}{2.2\ \text{k}\Omega + 371\ \Omega}$$
$$= \frac{3.15\ \text{V}}{2.57\ \text{k}\Omega} = 1.23\ \text{mA}$$

From I_E, you can determine I_C and V_{CE} as follows:

$$I_C \cong I_E = \mathbf{1.23\ mA}$$
$$V_C = -V_{CC} + I_C R_C = -6\ \text{V} + (1.23\ \text{mA})(1.8\ \text{k}\Omega) = -3.79\ \text{V}$$
$$V_E = -I_E R_E = -(1.23\ \text{mA})(2.2\ \text{k}\Omega) = -2.71\ \text{V}$$
$$V_{CE} = V_C - V_E = -3.79\ \text{V} + 2.71\ \text{V} = \mathbf{-1.08\ V}$$