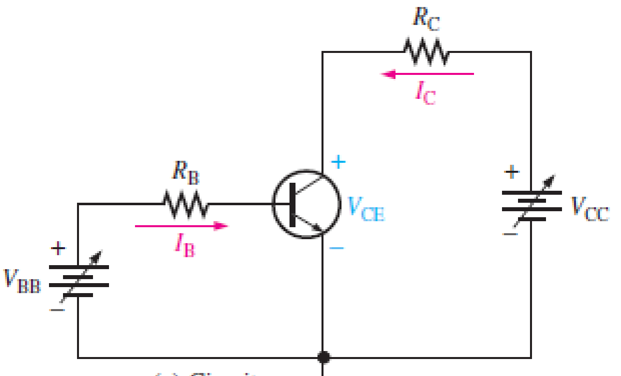
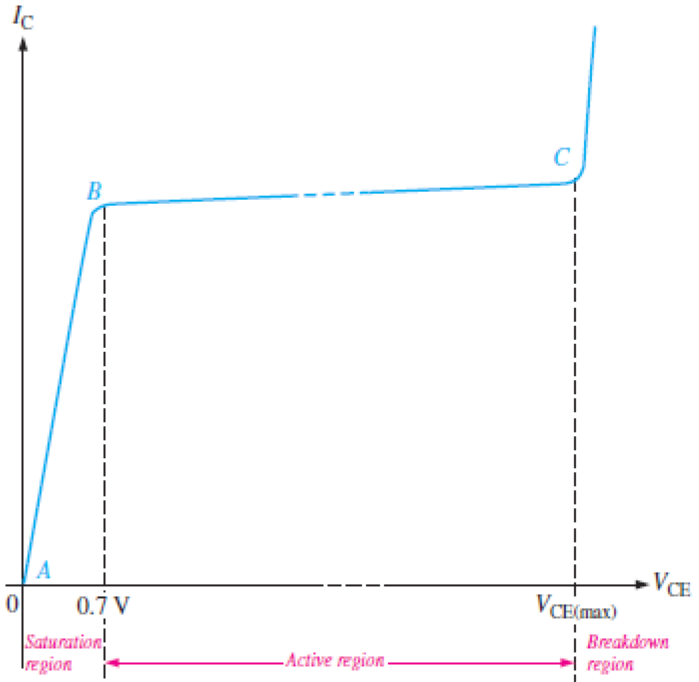
Collector Characteristic Curves



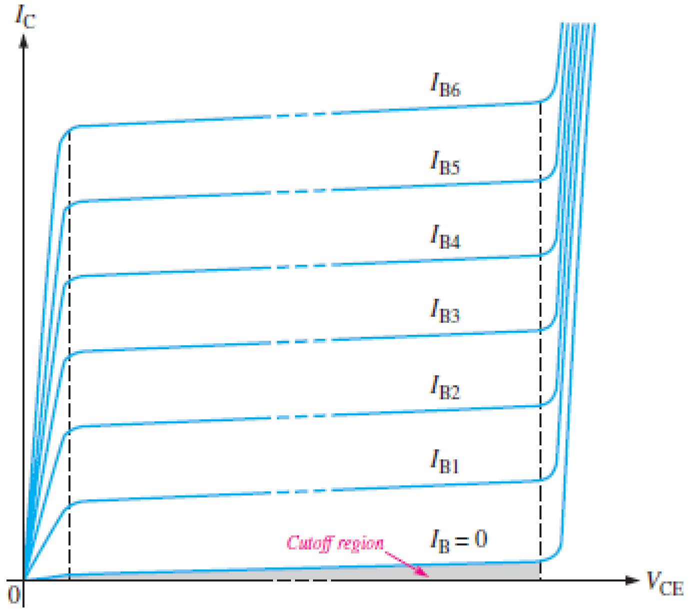
(a) Circuit



(b) I_C versus V_{CE} curve for one value of I_B

Figure (b):

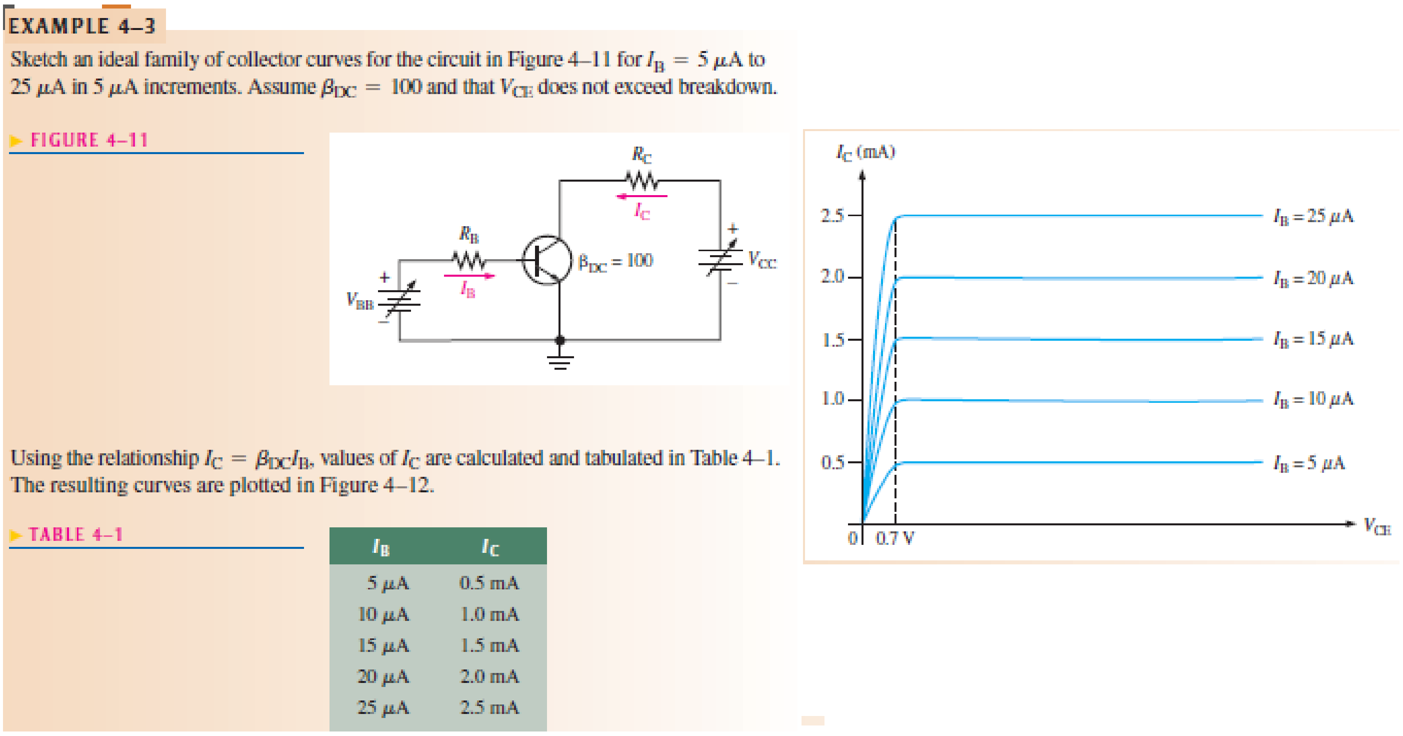
- **If V_{CC} = 0** → BE and BC are forwarded → BJT in **Saturation Region** → I_C independent of I_B.
- **Points A-B**: as V_{CC} increased, V_{CE} increased but still $\mathbf{V_{CE} < 0.7}$ and BC is still forwarded. (I_C still increasing)
- **Points B-C**: $V_{CE} > 0.7$ → BC: reversed, and BJT in the **Linear region** ($\mathbf{I_C = \beta_{DC} I_B}$) and V_{CE} continues to increase
  Note: β_{DC} is dependent on I_C and Temperature so the curve is not flat.
- **Point C**: BJT in **breakdown region**: at high V_{CE}, the reversed-biased BC junction breakdown and I_C increase rapidly.
  Note: *A transistor should never be operated in this breakdown region.*



(c) Family of I_C versus V_{CE} curves for several values of I_B ($I_{B1} < I_{B2} < I_{B3}$, etc.)

Figure (c):

- A family of collector characteristic curves is produced when I_C versus V_{CE} is plotted for several values of I_B, as illustrated.
- When $\mathbf{I_B = 0}$, the transistor is in the **cutoff** region although there is a very small collector leakage current as indicated. The amount of collector leakage current for I_B =0 is exaggerated on the graph for illustration.



EXAMPLE 4–3

Sketch an ideal family of collector curves for the circuit in Figure 4–11 for $I_B = 5\ \mu A$ to $25\ \mu A$ in $5\ \mu A$ increments. Assume $\beta_{DC} = 100$ and that V_{CE} does not exceed breakdown.

FIGURE 4–11

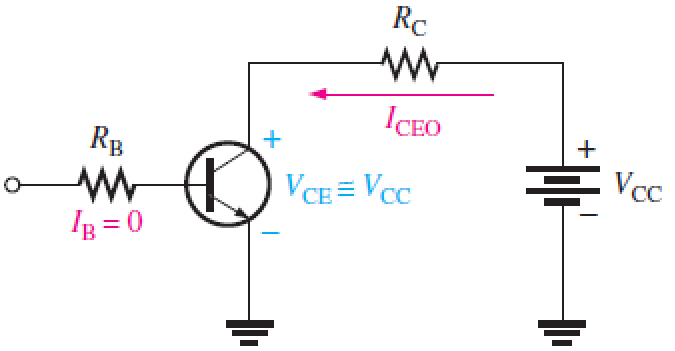
Using the relationship $I_C = \beta_{DC} I_B$, values of I_C are calculated and tabulated in Table 4–1. The resulting curves are plotted in Figure 4–12.

TABLE 4–1

I_B	I_C
5 μA	0.5 mA
10 μA	1.0 mA
15 μA	1.5 mA
20 μA	2.0 mA
25 μA	2.5 mA

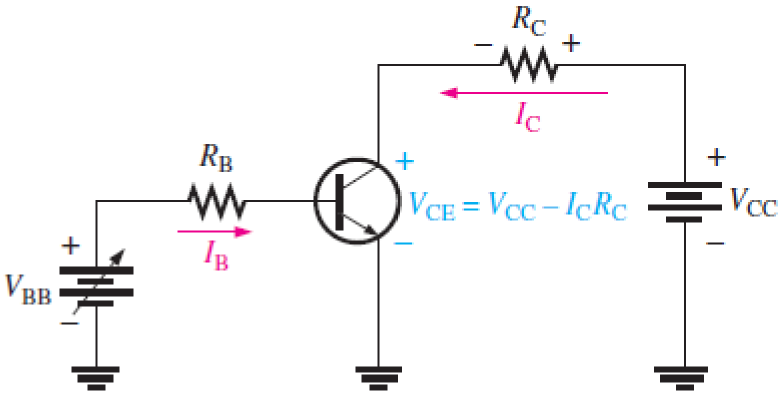
Cutoff

- BE and BC junctions are reversed biased
- Collector Leakage Current I_{CEO} is extremely small and is neglected.



Saturation

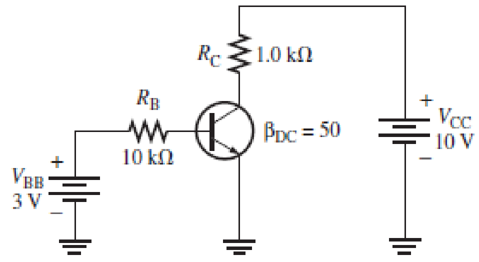
- As I_B increases due to increasing V_{BB}, I_C also increases due to the increased voltage drop across R_C.
- When the transistor reaches saturation, I_C can increase no further regardless of further increase in I_B.
- BE and BC junctions are forward biased.
- $I_C = \beta_{DC} I_B$ is no longer valid.



EXAMPLE 4–4

Determine whether or not the transistor in Figure 4–16 is in saturation. Assume $V_{CE(sat)} = 0.2$ V.

▶ FIGURE 4–16



Solution First, determine $I_{C(sat)}$.

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} = \frac{10\text{ V} - 0.2\text{ V}}{1.0\text{ k}\Omega} = \frac{9.8\text{ V}}{1.0\text{ k}\Omega} = 9.8\text{ mA}$$

Now, see if I_B is large enough to produce $I_{C(sat)}$.

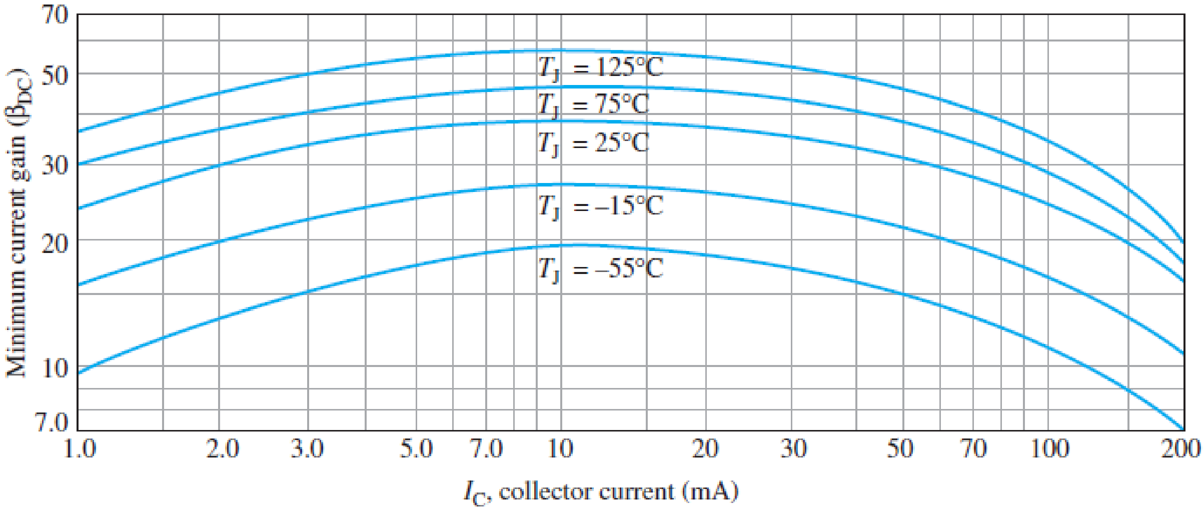
$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{3\text{ V} - 0.7\text{ V}}{10\text{ k}\Omega} = \frac{2.3\text{ V}}{10\text{ k}\Omega} = 0.23\text{ mA}$$

$$I_C = \beta_{DC} I_B = (50)(0.23\text{ mA}) = 11.5\text{ mA}$$

This shows that with the specified β_{DC}, this base current is capable of producing an I_C greater than $I_{C(sat)}$. Therefore, the **transistor is saturated**, and the collector current value of 11.5 mA is never reached. If you further increase I_B, the collector current remains at its saturation value of 9.8 mA.

More about β_{DC}

The β_{DC} is not truly constant but varies with both **collector current** and with **temperature**.



▲ FIGURE 4–17

Variation of β_{DC} with I_C for several temperatures.