Since we are particularly interested in linear amplification, we will have to devise a way to achieve it in the face of the highly nonlinear behavior of the transistor, namely, that the collector current i_C is exponentially related to v_{BE}. We will use the approach described in general terms in Section 1.4. Specifically, we will **bias** the transistor to operate at a dc base–emitter voltage V_{BE} and a corresponding dc collector current I_C. Then we will superimpose the signal to be amplified, v_{be}, on the dc voltage V_{BE}. By keeping the amplitude of the signal v_{be} small, we will be able to constrain the transistor to operate on a short, almost linear segment of the i_C–v_{BE} characteristic; thus, the change in collector current, i_c, will be linearly related to v_{be}. We will study the small-signal operation of the BJT later in this section and in greater detail in Section 5.5. First, however, we will look at the "big picture": We will study the total or large-signal operation of a BJT amplifier. From the transfer characteristic of the circuit, we will be able to see clearly the region over which the circuit can be operated as a linear amplifier. We also will be able to see how the BJT can be employed as a switch.

5.3.1 Large-Signal Operation—The Transfer Characteristic

Figure 5.26(a) shows the basic structure (a skeleton) of the most commonly used BJT amplifier, the **grounded-emitter** or **common-emitter (CE)** circuit. The total input voltage v_I (bias + signal) is applied between base and emitter; that is, $v_{BE} = v_I$. The total output voltage v_O (bias + signal) is taken between collector and ground; that is, $v_O = v_{CE}$. Resistor R_C has two functions: to establish a desired dc bias voltage at the collector, and to convert the collector signal current i_c to an output voltage, v_{ce} or v_o. The supply voltage V_{CC} is needed to bias the BJT as well as to supply the power needed for the operation of the amplifier.

Figure 5.26(b) shows the voltage transfer characteristic of the CE circuit of Fig. 5.26(a). To understand how this characteristic arises, we first express v_O as

$$v_O = v_{CE} = V_{CC} - R_C i_C \tag{5.50}$$

Next, we observe that since $v_{BE} = v_I$, the transistor will be effectively cutoff for $v_I < 0.5$ V or so. Thus, for the range $0 < v_I < 0.5$ V; i_C will be negligibly small, and v_O will be equal to the supply voltage V_{CC} (segment XY of the transfer curve).

As v_I is increased above 0.5 V, the transistor begins to conduct, and i_C increases. From Eq. (5.50), we see that v_O decreases. However, since initially v_O will be large, the BJT will be operating in the active mode, which gives rise to the sharply descending segment YZ of the voltage transfer curve. The equation for this segment can be obtained by substituting in Eq. (5.50) the active-mode expression for i_C, namely,

$$\begin{aligned} i_C &\cong I_S e^{v_{BE}/V_T} \\ &= I_S e^{v_I/V_T} \end{aligned}$$

where we have, for simplicity, neglected the Early effect. Thus we obtain

$$v_O = V_{CC} - R_C I_S e^{v_I/V_T} \tag{5.51}$$

We observe that the exponential term in this equation gives rise to the steep slope of the YZ segment of the transfer curve. Active-mode operation ends when the collector voltage (v_O or v_{CE}) falls by 0.4 V or so below that of the base (v_I or v_{BE}). At this point, the CBJ turns on, and the transistor enters the saturation region. This is indicated by point Z on the transfer curve.

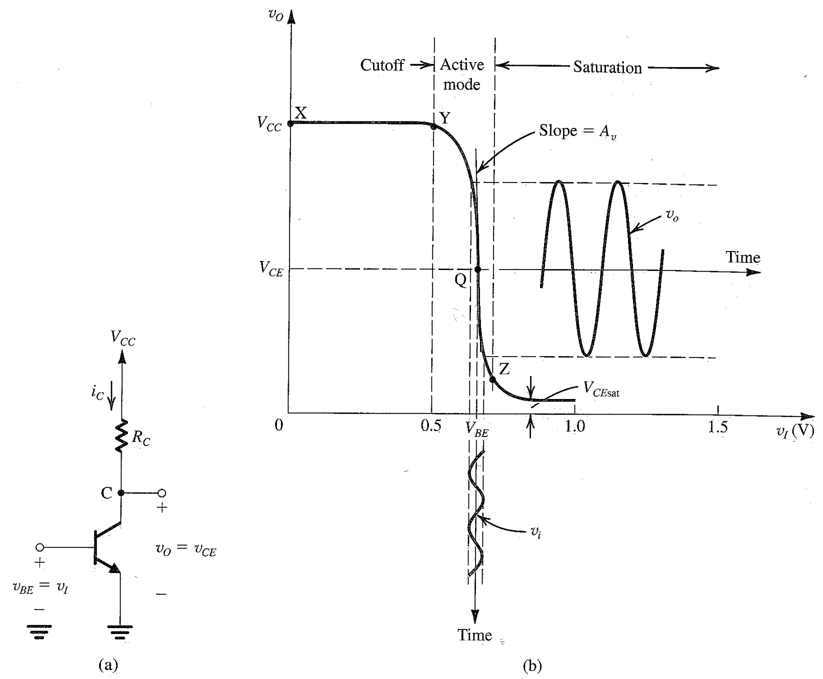

FIGURE 5.26 **(a)** Basic common-emitter amplifier circuit. **(b)** Transfer characteristic of the circuit in (a). The amplifier is biased at a point Q, and a small voltage signal v_i is superimposed on the dc bias voltage V_{BE}. The resulting output signal v_o appears superimposed on the dc collector voltage V_{CE}. The amplitude of v_o is larger than that of v_i by the voltage gain A_v.

Observe that a further increase in v_{BE} causes v_{CE} to decrease only slightly: In the saturation region, $v_{CE} = V_{CE\text{sat}}$, which falls in the narrow range of 0.1 V to 0.2 V. It is the almost-constant $V_{CE\text{sat}}$ that gives this region of BJT operation the name *saturation*. The collector current will also remain nearly constant at the value $I_{C\text{sat}}$,

$$I_{C\text{sat}} = \frac{V_{CC} - V_{CE\text{sat}}}{R_C} \tag{5.52}$$

We recall from our study of the saturation region of operation in the previous section that the saturated BJT exhibits a very small resistance $R_{CE\text{sat}}$ between its collector and emitter. Thus, when saturated, the transistor in Fig. 5.26 provides a low-resistance path between the collector node C and ground and hence can be thought of as a closed switch. On the other hand, when the BJT is cut off, it conducts negligibly small (ideally zero)