and

$V_{CE(cutoff)} = 15\text{ V}$

Figure 7-5*c* shows the two load lines. Changing the collector resistor with the same collector supply voltage produces load lines of different slopes but the same cutoff values. Also, notice that a smaller collector resistance produces a larger slope (steeper or closer to vertical). This happens because the slope of the load line is equal to the reciprocal of the collector resistance:

$$\text{Slope} = \frac{1}{R_C}$$

PRACTICE PROBLEM 7-4 Using Fig. 7-5*b*, what happens to the circuit's load line if the collector resistor is changed to 5 kΩ?

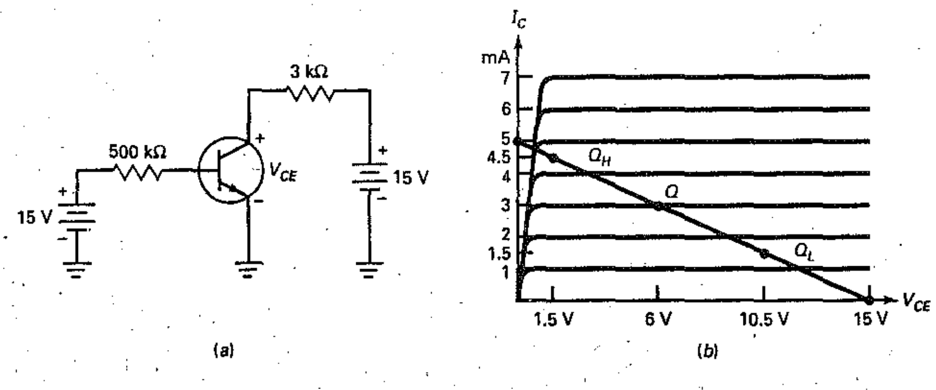
7-3 The Operating Point

Every transistor circuit has a load line. Given any circuit, work out the saturation current and the cutoff voltage. These values are plotted on the vertical and horizontal axes. Then draw a line through these two points to get the load line.

Plotting the *Q* Point

Figure 7-6*a* shows a base-biased circuit with a base resistance of 500 kΩ. We get the saturation current and cutoff voltage by the process given earlier. First, visualize a short across the collector-emitter terminals. Then all the collector supply voltage appears across the collector resistor, which means that the saturation current is 5 mA. Second, visualize the collector-emitter terminals open. Then there is no current, and all the supply voltage appears across the collector-emitter terminals, which means that the cutoff voltage is 15 V. If we plot the saturation current and cutoff voltage, we can draw the load line shown in Fig. 7-6*b*.

Figure 7-6 Calculating the *Q* point. (*a*) Circuit; (*b*) change in current gain changes *Q* point.



Let us keep the discussion simple for now by assuming an ideal transistor. This means that all the base supply voltage will appear across the base resistor. Therefore, the base current is:

$$I_B = \frac{15\text{ V}}{500\text{ k}\Omega} = 30\ \mu\text{A}$$

We cannot proceed until we have a value for the current gain. Suppose the current gain of the transistor is 100. Then the collector current is:

$$I_C = 100(30\ \mu\text{A}) = 3\text{ mA}$$

This current flowing through 3 kΩ produces a voltage of 9 V across the collector resistor. When we subtract this from the collector supply voltage, we get the voltage across the transistor. Here are the calculations:

$$V_{CE} = 15\text{ V} - (3\text{ mA})(3\text{ k}\Omega) = 6\text{ V}$$

By plotting 3 mA and 6 V (the collector current and voltage), we get the operating point shown on the load line of Fig. 7-6*b*. The operating point is labeled Q because this point is often called the **quiescent point.** (*Quiescent* means quiet, still, or resting.)

Why the *Q* Point Varies

We assumed a current gain of 100. What happens if the current gain is 50? If it is 150? To begin, the base current remains the same because the current gain has no effect on the base current. Ideally, the base current is fixed at 30 μA. When the current gain is 50:

$$I_C = 50(30\ \mu\text{A}) = 1.5\text{ mA}$$

and the collector-emitter voltage is:

$$V_{CE} = 15\text{ V} - (1.5\text{ mA})(3\text{ k}\Omega) = 10.5\text{ V}$$

Plotting the values gives the low point Q_L shown in Fig. 7-6*b*.

If the current gain is 150, then:

$$I_C = 150(30\ \mu\text{A}) = 4.5\text{ mA}$$

and the collector-emitter voltage is:

$$V_{CE} = 15\text{ V} - (4.5\text{ mA})(3\text{ k}\Omega) = 1.5\text{ V}$$

Plotting these values gives the high point Q_H point shown in Fig. 7-6*b*.

The three Q points of Fig. 7-6*b* illustrate how sensitive the operating point of a base-biased transistor is to changes in β_{dc}. When the current gain varies from 50 to 150, the collector current changes from 1.5 to 4.5 mA. If the changes in current gain were much greater, the operating point could be driven easily into saturation or cutoff. In this case, an amplifying circuit would become useless because of the loss of current gain outside the active region.

GOOD TO KNOW

Because the values of I_C and V_{CE} are dependent on the values of beta in a base-biased circuit, the circuit is said to be *beta-dependent.*

The Formulas

The formulas for calculating the Q point are as follows:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \qquad (7\text{-}4)$$

$$I_C = \beta_{dc} I_B \qquad (7\text{-}5)$$

$$V_{CE} = V_{CC} - I_C R_C \qquad (7\text{-}6)$$

Example 7-5

IIII MultiSim

Suppose the base resistance of Fig. 7-6*a* is increased to 1 MΩ. What happens to the collector-emitter voltage if β_{dc} is 100?

SOLUTION Ideally, the base current would decrease to 15 μA, the collector current would decrease to 1.5 mA, and the collector-emitter voltage would increase to:

$$V_{CE} = 15 - (1.5 \text{ mA})(3 \text{ k}\Omega) = 10.5 \text{ V}$$

To a second approximation, the base current would decrease to 14.3 μA, and the collector current would decrease to 1.43 mA. The collector-emitter voltage would increase to:

$$V_{CE} = 15 - (1.43 \text{ mA})(3 \text{ k}\Omega) = 10.7 \text{ V}$$

PRACTICE PROBLEM 7-5 If the β_{dc} value of Example 7-5 changed to 150 due to a temperature change, find the new value of V_{CE}.

7-4 Recognizing Saturation

There are two basic kinds of transistor circuits: **amplifying** and **switching.** With amplifying circuits, the *Q* point must remain in the active region under all operating conditions. If it does not, the output signal will be distorted on the peak when saturation or cutoff occurs. With switching circuits, the *Q* point usually switches between saturation and cutoff. How switching circuits work, what they do, and why they are used will be discussed later.

Impossible Answers

Assume that the transistor of Fig. 7-7*a* has a breakdown voltage greater than 20 V. Then, we know that it is not operating in the breakdown region. Furthermore, we can tell at a glance that the transistor is not operating in the cutoff region because of the biasing voltages. What is not immediately clear, however, is whether the transistor is operating in the active region or the saturation region. It must be operating in one of these regions. But which?

Figure 7-7 (*a*) Base-biased circuit; (*b*) load line.