In the base loop, the V_{BB} source forward biases the emitter diode with R_B as a current-limiting resistance. By changing V_{BB} or R_B, we can change the base current. Changing the base current will change the collector current. In other words, *the base current controls the collector current*. This is important. It means that a small current (base) controls a large current (collector).

In the collector loop, a source voltage V_{CC} reverse biases the collector diode through R_C. The supply voltage V_{CC} must reverse bias the collector diode as shown, or else the transistor won't work properly. Stated another way, the collector must be positive in Fig. 6-7*a* to collect most of the free electrons injected into the base.

In Fig. 6-7*a*, the flow of base current in the left loop produces a voltage across the base resistor R_B with the polarity shown. Similarly, the flow of collector current in the right loop produces a voltage across the collector resistor R_C with the polarity shown.

Double Subscripts

Double-subscript notation is used with transistor circuits. When the subscripts are the same, the voltage represents a source (V_{BB} and V_{CC}). When the subscripts are different, the voltage is between the two points (V_{BE} and V_{CE}).

For instance, the subscripts of V_{BB} are the same, which means that V_{BB} is the base voltage source. Similarly, V_{CC} is the collector voltage source. On the other hand, V_{BE} is the voltage between points B and E, between the base and the emitter. Likewise, V_{CE} is the voltage between points C and E, between the collector and the emitter.

Single Subscripts

Single subscripts are used for node voltages, that is, voltages between the subscripted point and ground. For instance, if we redraw Fig. 6-7*a* with grounds, we get Fig. 6-7*b*. Voltage V_B is the voltage between the base and ground, voltage V_C is the voltage between the collector and ground, and voltage V_E is the voltage between the emitter and ground. (In this circuit, V_E is zero.)

You can calculate a double-subscript voltage of different subscripts by subtracting its single-subscript voltages. Here are three examples:

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

$$V_{CB} = V_C - V_B$$

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

This is how you could calculate the double-subscript voltages for any transistor circuit: Since V_E is zero in this CE connection (Fig. 6-7*b*), the voltages simplify to:

$$V_{CE} = V_C$$

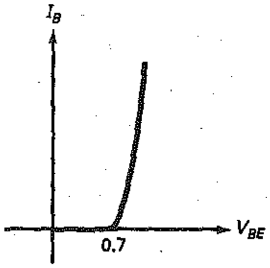
$$V_{CB} = V_C - V_B$$

$$V_{BE} = V_B$$

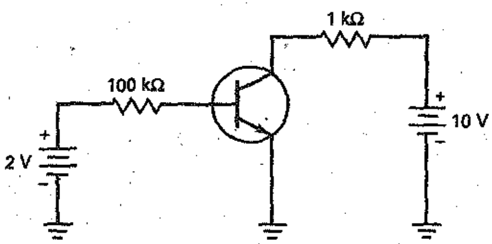
6-5 The Base Curve

What do you think the graph of I_B versus V_{BE} looks like? It looks like the graph of an ordinary diode as shown in Fig. 6-8*a*. And why not? This is a forward-biased emitter diode, so we would expect to see the usual diode graph of current versus voltage. What this means is that we can use any of the diode approximations discussed earlier.

Figure 6-8 (a) Diode curve; (b) example.



(a)



(b)

Applying Ohm's law to the base resistor of Fig. 6-7b gives this derivation:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} \tag{6-6}$$

If you use an ideal diode, $V_{BE} = 0$. With the second approximation, $V_{BE} = 0.7$ V.

Most of the time, you will find the second approximation to be the best compromise between the speed of using the ideal diode and accuracy of higher approximations. All you need to remember for the second approximation is that V_{BE} is 0.7 V, as shown in Fig. 6-8a.

Example 6-4

MultiSim

Use the second approximation to calculate the base current in Fig. 6-8b. What is the voltage across the base resistor? The collector current if $\beta_{dc} = 200$?

SOLUTION The base source voltage of 2 V forward biases the emitter diode through a current-limiting resistance of 100 kΩ. Since the emitter diode has 0.7 V across it, the voltage across the base resistor is:

$$V_{BB} - V_{BE} = 2\text{ V} - 0.7\text{ V} = 1.3\text{ V}$$

The current through the base resistor is:

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{1.3\text{ V}}{100\text{ k}\Omega} = 13\ \mu\text{A}$$

With a current gain of 200, the collector current is:

$$I_C = \beta_{dc} I_B = (200)(13\ \mu A) = 2.6\ mA$$

PRACTICE PROBLEM 6-4 Repeat Example 6-4 using a base source voltage $V_{BB} = 4$ V.

6-6 Collector Curves

In Fig. 6-9*a*, we already know how to calculate the base current. Since V_{BB} forward biases the emitter diode, all we need to do is calculate the current through the base resistor R_B. Now, let us turn our attention to the collector loop.

We can vary V_{BB} and V_{CC} in Fig. 6-9*a* to produce different transistor voltages and currents. By measuring I_C and V_{CE}, we can get data for a graph of I_C versus V_{CE}.

For instance, suppose we change V_{BB} as needed to get $I_B = 10\ \mu A$. With this fixed value of base current, we can now vary V_{CC} and measure I_C and V_{CE}. Plotting the data gives the graph shown in Fig. 6-9*b*. (*Note:* this graph is for a 2N3904, a widely used low-power transistor. With other transistors, the numbers may vary but the shape of the curve will be similar.)

When V_{CE} is zero, the collector diode is not reverse biased. This is why the graph shows a collector current of zero when V_{CE} is zero. When V_{CE} increases from zero, the collector current rises sharply in Fig. 6-9*b*. When V_{CE} is a few tenths of a volt, the collector current becomes *almost constant* and equal to 1 mA.

Figure 6-9 (*a*) Basic transistor circuit; (*b*) collector curve.