# The Bipolar Junction Transistor (BJT)

A complete of a bipolar junction transistor (BJT) is well outside the scope of this class. However, a basic understanding of what happens in a BJT and an example of a simple model are provided below. For more information, several excellent texts exist for beginners, including *Fundamentals of Microelectronics* by Razavi and *The Art of Electronics* by Horowitz and Hill.

The BJT is a three-layer semiconductor structure commonly made of silicon. Other compounds sometimes are used for special-purpose applications (such as for operation at microwave and optical frequencies), but for the present, we will limit our examination to silicon-based transistors and their uses in dc circuits. The three terminals of a BJT are called the emitter, collector, and base. The emitter and collector are made of the same material—either p-type or n-type—and the base is made of the other material. Thus, the BJT can be constructed to have either a pnp configuration or an npn configuration, as shown in the diagrams below.

(a) pnp transistor
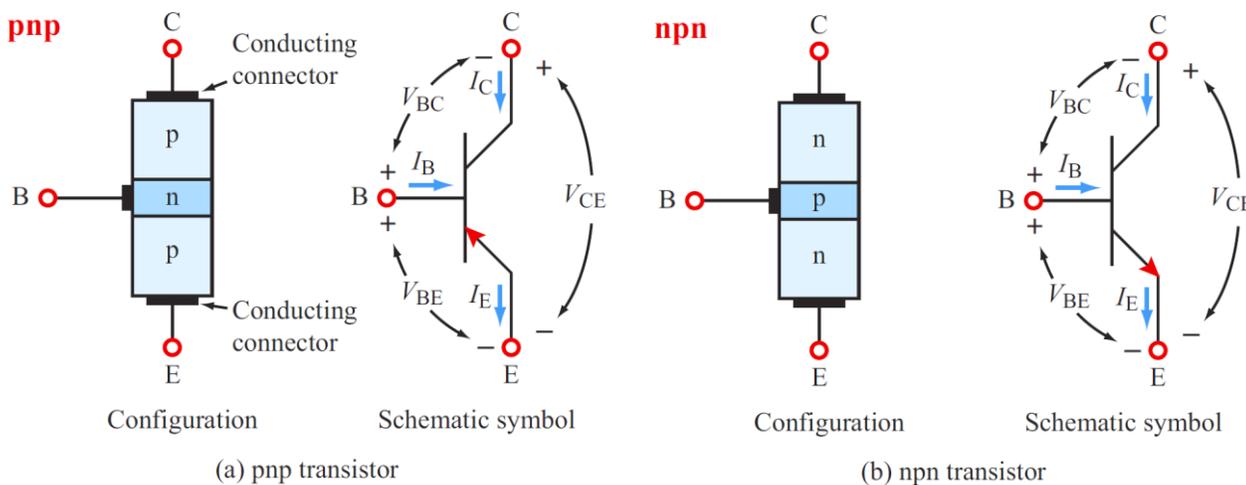
(b) npn transistor

The geometries and fabrication details of real transistors are far more elaborate than the simple diagrams suggest, but the basic idea that the BJT consists of three alternating layers of p- and n-type material is quite sufficient from the standpoint of its external electrical behavior. The figure above also shows schematic symbols used for the pnp and npn transistors. The center terminal is always the base. One of the three leads includes an arrow. The lead containing the arrow identifies the emitter terminal and whether the transistor is a pnp or npn. *The arrow always points towards an n-type material*, so in the pnp transistor, the arrow points towards the base, whereas in an npn transistor, the arrow points away from the base.

A first model of the BJT

The following is a very simple treatment to introduce you to the idea that transistors are associated with equivalent models that are used to develop and analyze circuits. The model discussed below is only valid for large, dc voltages applied to a typical BJT; more complex inputs or conditions require increasingly refined models.

The directions of the terminal currents shown above are defined such that the base and collector currents I_B and I_C, respectively, flow into the transistor, and the emitter current I_E flows out of it. KCL requires that

$$I_E = I_B + I_C$$

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Under normal operating conditions, I_E has the largest magnitude of the three currents, and I_B is much smaller than either I_C or I_E. The transistor can operate under both dc and ac conditions, but we will limit our present discussion to dc circuits. For simplicity, we will consider only the npn common-emitter configuration. Accordingly, we can describe the operation of the npn transistor by the dc equivalent model shown below.
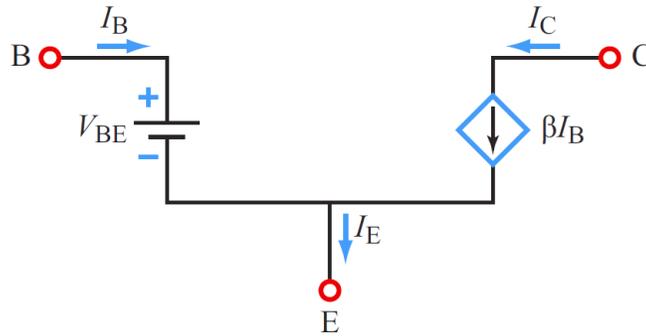

The circuit contains a constant dc voltage source V_{BE} and a dependent current-controlled current source that relates I_C to I_B by

$$I_C = \beta I_B$$

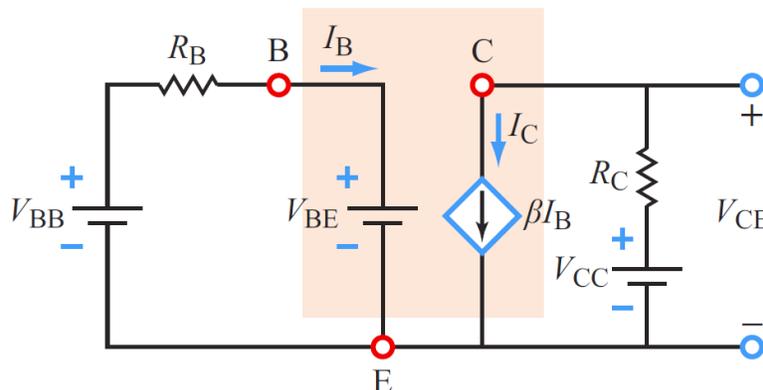where β is a transistor parameter called the common emitter current gain. Under normal operation for silicon transistors, $V_{BE} \sim 0.7$ V, and β may assume values in the range between 30 and 1000, depending on its specific design configuration. Note that to operate in its active mode, the transistor requires that certain dc voltages be applied at its base and collector terminals. We refer to these voltages as V_{BB} and V_{CC}, respectively.

Example
Apply the equivalent-circuit model with $VBE \sim 0.7$ V and $\beta = 200$ to determine I_B, I_C, and V_{CE} in the circuit Below. Assume that $V_{BB} = 2$ V, $V_{CC} = 10$ V, $R_B = 26$ kΩ, and $R_C = 200$ Ω.
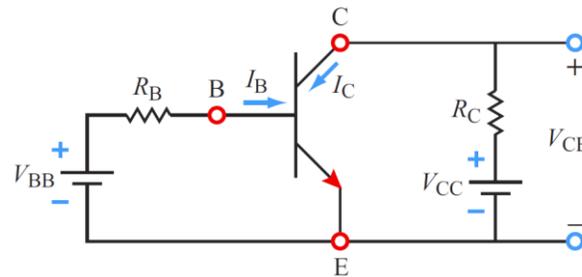
Upon replacing the npn transistor with its equivalent circuit, we end up with the circuit shown below.

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In the left-hand loop, KVL gives

$$-V_{\text{BB}} + R_{\text{B}}I_{\text{B}} + V_{\text{BE}} = 0,$$

Which leads to

$$I_{\text{B}} = \frac{V_{\text{BB}} - V_{\text{BE}}}{R_{\text{B}}}$$

$$= \frac{2 - 0.7}{26 \times 10^3} = 5 \times 10^{-5} \text{ A} = 50 \ \mu\text{A}.$$

Given β = 200,

$$I_{\text{C}} = \beta I_{\text{B}} = 200 \times 50 \times 10^{-6} = 10 \text{ mA}$$

and

$$V_{\text{CE}} = V_{\text{CC}} - I_{\text{C}}R_{\text{C}} = 10 - 10^{-2} \times 200 = 8 \text{ V}$$

Note how the circuit provides an output (V_{CE}) which is an amplified version of the input. Also note that the transistor requires an external source (V_{CC}) to perform its amplification. A transistor does not, by itself, inject any energy into the circuit.