collector-to-emitter current. Conversely, a *pnp* transistor uses a small output base current and negative base voltage (relative its emitter) to control a larger emitter-to-collector current.

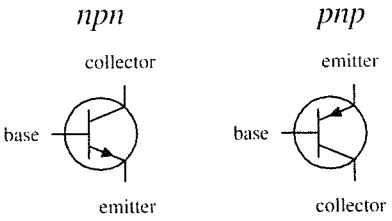
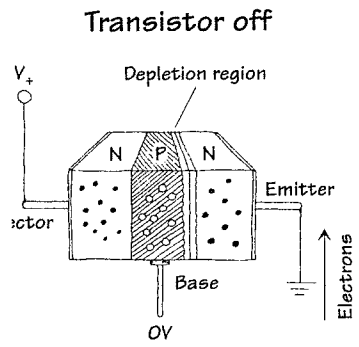


FIGURE 4.45

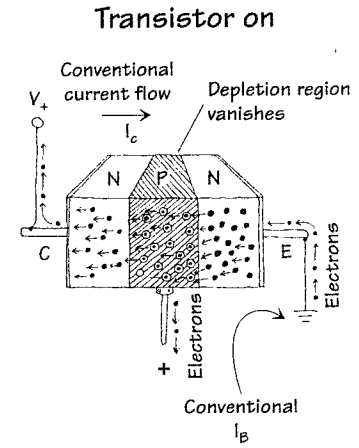
Bipolar transistors are incredibly useful devices. Their ability to control current flow by means of applied control signals makes them essential elements in electrically controlled switching circuits, current-regulator circuits, voltage-regulator circuits, amplifier circuits, oscillator circuits, and memory circuits.

How Bipolar Transistors Work

Here is a simple model of how an *npn* bipolar transistor works. (For a *pnp* bipolar transistor, all ingredients, polarities, and currents are reversed.)



An *npn* bipolar transistor is made by sandwiching a thin slice of *p* semiconductor between two *n*-type semiconductors. When no voltage is applied at the transistor's base, electrons in the emitter are prevented from passing to the collector side because of the *p*-*n* junction. (Remember that for electrons to flow across a *p*-*n* junction, a biasing voltage is needed to give the electrons enough energy to "escape" the atomic forces holding them to the *n* side.) Notice that if a negative voltage is applied to the base, things get even worse—the *p*-*n* junction between the base and emitter becomes reverse-biased. As a result, a depletion region forms and prevents current flow.



If a positive voltage (of at least 0.6 V) is applied to the base of an *npn* transistor, the *pn* junction between the base and emitter is forward-biased. During forward bias, escaping electrons are drawn to the positive base. Some electrons exit through the base, but—this is the trick—because the *p*-type base is so thin, the onslaught of electrons that leave the emitter get close enough to the collector side that they begin jumping into the collector. Increasing the base voltage increases this jumping effect and hence increases the emitter-to-collector electron flow. Remember that conventional currents are moving in the opposite direction to the electron flow. Thus, in terms of conventional currents, a positive voltage and input current applied at the base cause a "positive" current *I* to flow from the collector to the emitter.

FIGURE 4.46